SKM

Sydney WATER

Metropolitan Water Plan

Western Sydney Recycled Water Initiative

Environmental Assessment for Replacement Flows Project

Main Document, Appendices A, B, C, D, E, E, F & G

November 2006





Environmental Assessment prepared by

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In respect of:	Western Sydney Recycled Water Initiative - Replacement Flows Project	

Certification

I certify that I have prepared the contents of this Environmental Assessment and to the best of my knowledge the information contained in the Assessment is neither false nor misleading.

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Summary of the environmental assessment

Introduction

The Replacement Flows Project (the Project) is part of the Western Sydney Recycled Water Initiative that is a component of the *2006 Metropolitan Water Plan.* The *2006 Metropolitan Water Plan* sets out how the NSW Government will achieve its objectives for securing Sydney's water needs over the next 25 years.

The Project involves the construction and operation of an Advanced Water Treatment Plant (AWTP) and associated works. It will include treating existing tertiary effluent from St Marys, Penrith and Quakers Hill sewage treatment plants (STPs) in north western Sydney at an AWTP located at St Marys, producing up to 50 million litres per day (ML/day) of highly treated recycled water. The recycled water would be substituted, as replacement flows, for water that is currently released from Warragamba Dam for extraction and river health purposes. The volume of tertiary treated effluent discharged directly from Penrith STP would be minimised, and sufficient volume of tertiary treated effluent discharged from St Marys and Quakers Hill STPs would be maintained for the downstream water users in South Creek.

The recycled water would be substituted, as replacement flows, for water that is currently released from Warragamba Dam for extraction and river health purposes.

The general study area for the Project is shown in **Figure 1**.

Need for the project

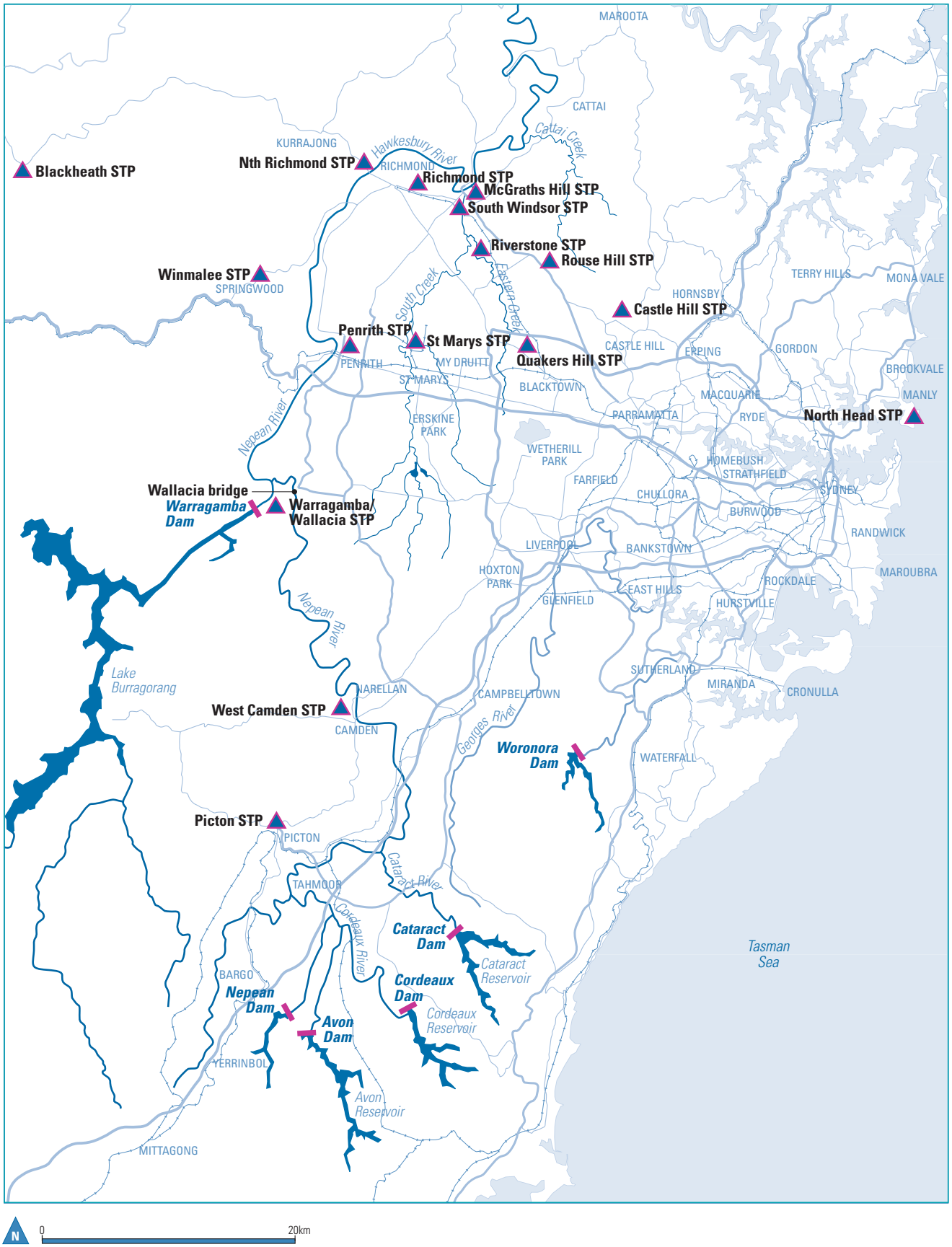
The *2006 Metropolitan Water Plan* objectives are to:

- provide a secure supply of water that can meet the long term needs of Sydney
- ensure that water supplies are adequate during drought
- minimise costs to the community and the environment.

The Replacement Flows Project objectives are to:

- save up to 18 billion litres per year of current Warragamba Dam discharges by providing high quality recycled water to the Nepean River as a replacement for existing Warragamba Dam releases
- reduce the discharge of nutrients from Penrith, Quakers Hill and St Marys STPs into the Hawkesbury-Nepean River and South Creek

Figure 1 General study area



- maintain appropriate flows for irrigation
- ensure environmental values are maintained – including aquatic ecosystems, primary industries, recreation and aesthetics and drinking water.

The Project, in combination with other planned river management changes, would ensure that the substitution of Warragamba Dam releases would deliver an equivalent or higher level of environmental benefit to the river and maintain water for irrigation/agriculture, recreational needs and for aquatic life.

Purpose of the Environmental Assessment

This Environmental Assessment has been prepared under Part 3A of the *Environmental Planning and Assessment Act 1979* to obtain project approval for the Replacement Flows Project.

This Environmental Assessment has been prepared under Part 3A of the *Environmental Planning and Assessment Act 1979* to obtain project approval for the Replacement Flows Project. It assesses the key environmental issues associated with the Project and proposes mitigation measures to address any potential impacts. It also includes a draft 'Statement of Commitments' that outlines Sydney Water's commitments for the management of environmental effects that could occur from the construction, commissioning, operation and maintenance of the project.

Strategic framework

2006 Metropolitan Water Plan

The *2006 Metropolitan Water Plan* outlines strategies to balance demand for water with a sustainable supply in the long-term. The plan is based on an adaptive management approach, with a diverse suite of options to meet Sydney's long term water needs during drought and non-drought times, while minimising the costs to the community and the environment. The key elements of the plan that are or will be put in place to achieve water savings, recycling and additional supply targets are summarised in **Figure 2**.

The *2006 Metropolitan Water Plan* reiterates the commitment of the *2004 Metropolitan Water Plan* to increase the environmental flow releases from the Upper Nepean Storages (Avon, Cordeaux, Cataract, Nepean) and to reconfigure weirs to allow those flows to contribute to the maintenance of the river water quality upstream and downstream of Penrith Weir. These releases will be a portion of all flows entering these storages. Current estimates are that the first 68 ML/day of flow into the catchments of these dams will be released from the dams and through the upstream weirs in the Nepean River (refer to **Table 1**). The Sydney Catchment Authority is proceeding with the works to enable these discharges to occur by 2009.

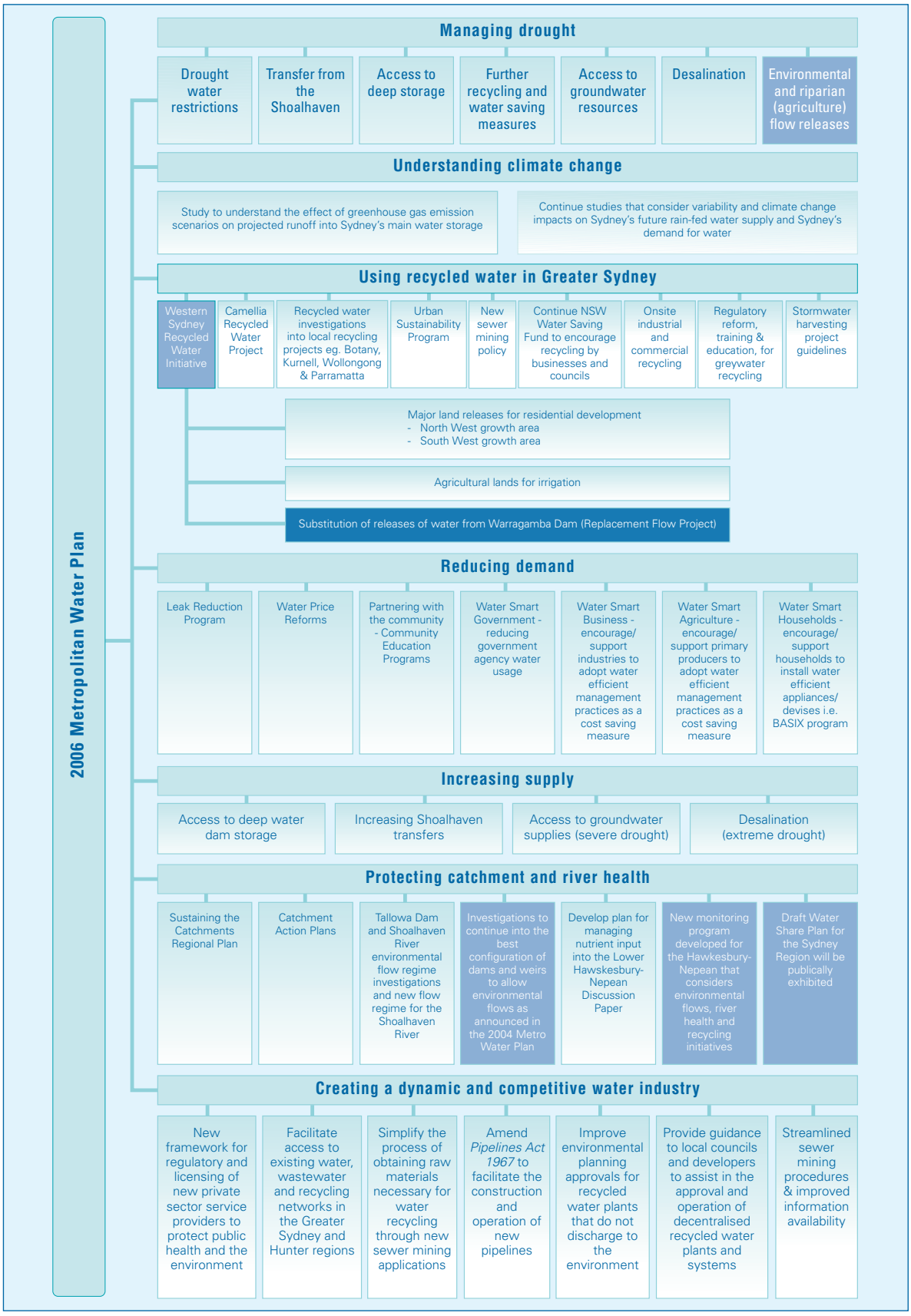
Table 1 Environmental Flows in the Hawkesbury-Nepean River system

Site	Current Flows (ML/day)	2010 Flows (ML/day)
Warragamba Dam	43.3[1]	(43.3)[1]
Cataract Dam	1.3	Up to 16.5[2]
Cordeaux Dam	1.9	Up to12.6[2]
Avon Dam	0	Up to 10.4[2]
Nepean Dam	4.4	Up to 28.5[2]

1 This is the flow released during non-drought conditions. The current drought conditions discharge from Warragamba Dam is about 22 ML/day. The discharge from Warragamba Dam would cease if the Replacement Flows Project were implemented

2 Flows from the Upper Nepean Dams would provide a base level of 68 ML/day. Flows up to this volume will be allowed to pass. For flows above this volume the total flow released will be 20% of the flow as long as the 20% is above the base value shown.

Figure 2 2006 Metropolitan Water Plan



Replacement Flows Project

Parts of the Metropolitan Water Plan linked to the Replacement Flows Project

The current releases from Warragamba Dam would effectively cease by 2009, in line with the replacement flows discharge at Penrith Weir and the increased flows from the Upper Nepean Dams.

The current releases from Warragamba Dam would effectively cease by 2009, in line with the replacement flows discharge at Penrith Weir and the increased flows from the Upper Nepean Dams. A final regime for environmental flow releases from Warragamba Dam will be formally set by 2015. Increases to interim environmental flows would, however, be considered from 2009, provided sufficient water is available. The Project would offset an equivalent portion of any future determination regarding environmental and riparian discharges from Warragamba Dam.

Outcomes of the Replacement Flows Project in the context of the Metropolitan Water Plan

The Replacement Flows Project, Upper Nepean dam releases and reuse projects are all initiatives under the *2006 Metropolitan Water Plan*. The outcomes for the Project and the Upper Nepean dam releases are forecast to be:

- in normal (non-drought) conditions, the same or greater flows in all stretches of the Hawkesbury-Nepean River upstream of its junction with South Creek
- in normal (non-drought) conditions, an increase in the proportion of catchment derived flows throughout the Hawkesbury-Nepean River system
- significant reduction in nutrient loads discharged to the Nepean River at Penrith due to the AWTP
- significant reductions in the nutrient loads discharged into South Creek, due primarily to the reduced loads discharged from St Marys and Quakers Hill STPs.

Description of the Project

The project consists of:

- an Advanced Water Treatment Plant (AWTP) at the St Marys STP site for the treatment of tertiary treated effluent from Quakers Hill, Penrith and St Marys STPs. The AWTP would produce about 50 ML/day of highly treated recycled water for discharge to the Hawkesbury-Nepean River downstream of Penrith Weir, and approximately 8 ML/day of concentrate to be discharged to the Northern Suburbs Ocean Outfall Sewer (NSOOS)
- a pipeline for the transfer of tertiary treated effluent from Penrith STP to the AWTP site at St Marys STP
- a pipeline for the transfer of tertiary treated effluent from Quakers Hill STP to the AWTP at St Marys STP
- a pipeline for the transfer of recycled water produced by the AWTP at St Marys STP to Penrith STP
- a pipeline for the transfer of the concentrate from the AWTP to Quakers Hill STP
- a storage pond at Quakers Hill STP for the temporary storage of the concentrate, when the NSOOS may not be available for discharge (during periods of extended wet weather)
- transfer of the concentrate to the NSOOS via an existing pipeline from Quakers Hill STP to Seven Hills and a new pipeline between Seven Hills and Vineyard Creek at Dundas
- balance storages and pumping stations at Penrith, Quakers Hill and St Marys STPs.

A new pumping station may also be required at Seven Hills where the existing pipeline joins the new pipeline to Vineyard Creek. Some upgrade works may also be required to the existing pipeline.

The project is shown schematically in **Figure 3**.

The estimated nutrient concentrations in the highly treated recycled water to be used as replacement flows is presented in **Table 2**. For comparison and to show the performance expected of the AWTP, typical tertiary treated effluent concentrations are also shown.

Table 2 Likely water quality of highly treated recycled water

Stage	Water quality (Concentration in mg/L)				
	Ammonia (NH_4)	Oxides of nitrogen (N0x)	Total nitrogen (TN)	Total phosphorus (TP)	Total dissolved solids (TDS)
Tertiary treated effluent	0.10	2.96	4.5	0.05	400-600
Replacement Flow (Highly Treated Recycled Water)	0.00	0.44	0.79	0.01	25-35

Total nitrogen (TN) and oxidised nitrogen (NO_x) (comprising the two nitrogen species of nitrite (NO_2) and nitrate (NO_3)) can stimulate algal production. Excess nitrogen concentration can lead to algal blooms. Similarly, ammonia is readily taken up by aquatic plants and can stimulate their growth. In addition, phosphorus in high concentrations is associated with excessive plant and algal growth.

The average volume of concentrate generated by the AWTP process is expected to be about 8 ML/day. The concentrate would contain between 3000 and 4000 milligrams per litre (mg/L) of total dissolved solids (TDS), approximately 7 times greater than the concentrations in the tertiary treated effluent from the STPs and approximately one tenth as salty as seawater (35,000 mg/L). The concentrate would also contain sulphate (500 to 1000 mg/L), chloride (1000 to 1500 mg/L), calcium (130 to 200 mg/L) and alkalinity (480 to 850 mg/L as $CaCO_3$). It would have a pH of 7.5 to 8.0 and contain the majority of nutrients originally in the effluent from the sewage treatment plants.

Alternatives

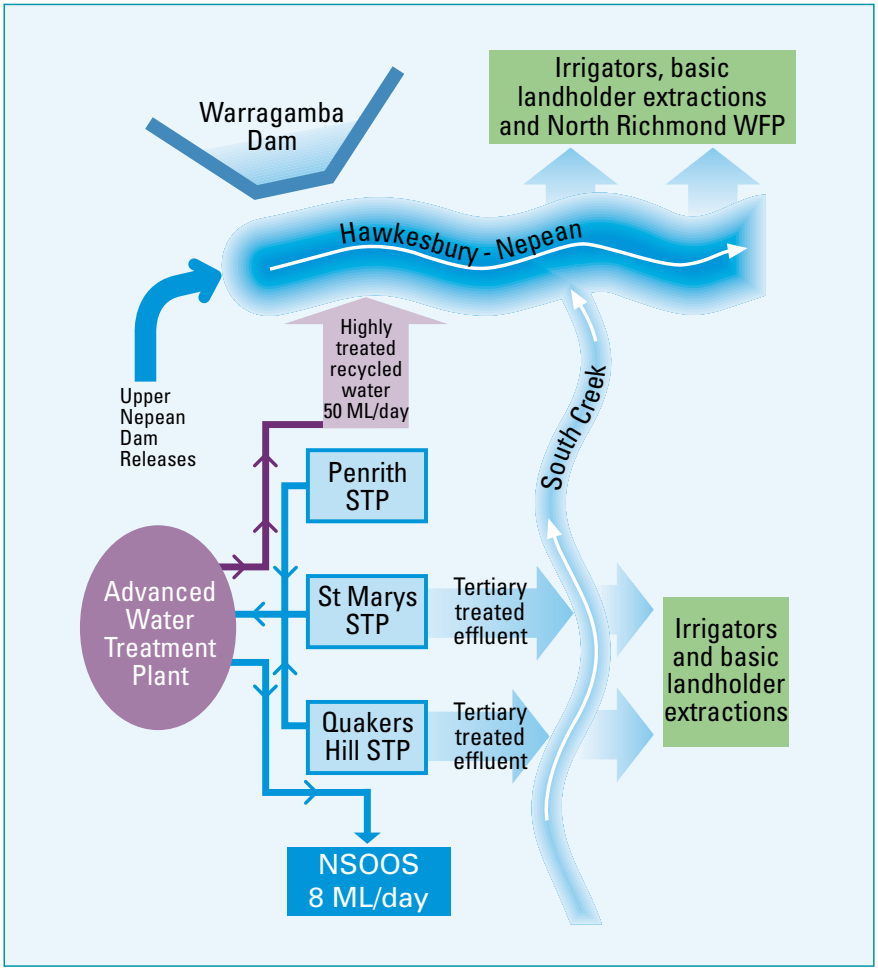
Options were considered for the major components of the scheme including:

- the AWTP location and configuration
- treatment options for the AWTP
- pipeline routes
- replacement flow discharge locations
- concentrate removal and disposal.

St Marys was selected as the preferred AWTP location due to its central location, land availability and the technical and operational advantages of the site.

St Marys was selected as the preferred AWTP location due to its central location, land availability and the technical and operational advantages of the site. Reverse osmosis was selected as the preferred main treatment technology due to its ability to achieve the goals of removing nutrients from the tertiary treated effluent, in particular the bioavailable forms of phosphorus and nitrogen.

Figure 3 Replacement flows project during normal operations



The pipeline routes were selected to minimise impacts on the local community, road users and the natural environment. This includes using areas that are void of significant vegetation (such as asset protection zones or fire-breaks), distant from sensitive receivers (residential areas) and away from significant infrastructure (main roads and rail).

Discharge of replacement flow downstream of Penrith Weir was selected as the preferred option as it provided better water quality outcomes during low flow conditions and did not have the additional costs, environmental and social issues associated with construction at the alternative location (Wallacia Bridge).

Disposal of the concentrate to the NSOOS was determined to be the preferred option after considering environmental and operational implications.

Environmental Impact and Mitigation

Key issues of river health and water users

The project would be constructed and operated within the Hawkesbury-Nepean River system. The area affected by the project includes residential, industrial, rural and natural areas. The operation of the project would have the potential to impact on the waterways in the project area and this is reflected in the assessment of key issues.

The environmental assessment of key issues is divided into reaches of the Hawkesbury-Nepean River and tributaries, addressing them in order from upstream to downstream. The water quantity and quality changes as a result of the project are summarised in **Figures 4, 5** and **6.** The assessment of the impacts of the Replacement Flows project is based on the assumption that the 2009 river management changes will occur. The impacts of these changes on other aspects of the waterways such as aquatic flora and fauna, recreation and agriculture are discussed below. Impacts on threatened aquatic species, fisheries and human health are considered for the Hawkesbury-Nepean River system as a whole.

Figure 4 Comparison of existing non drought flows with predicted 2009 flows (with Replacement Flows Project)

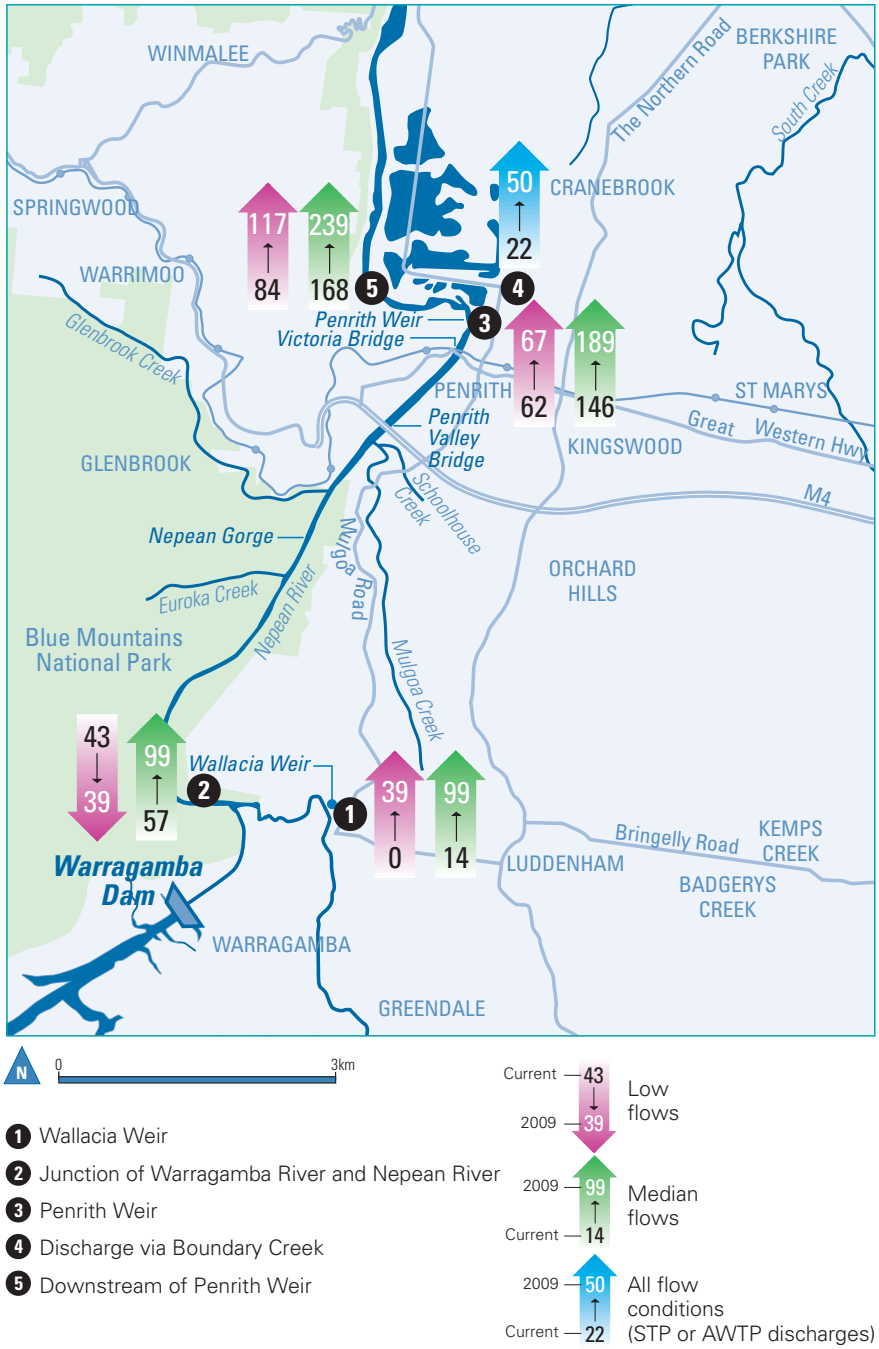
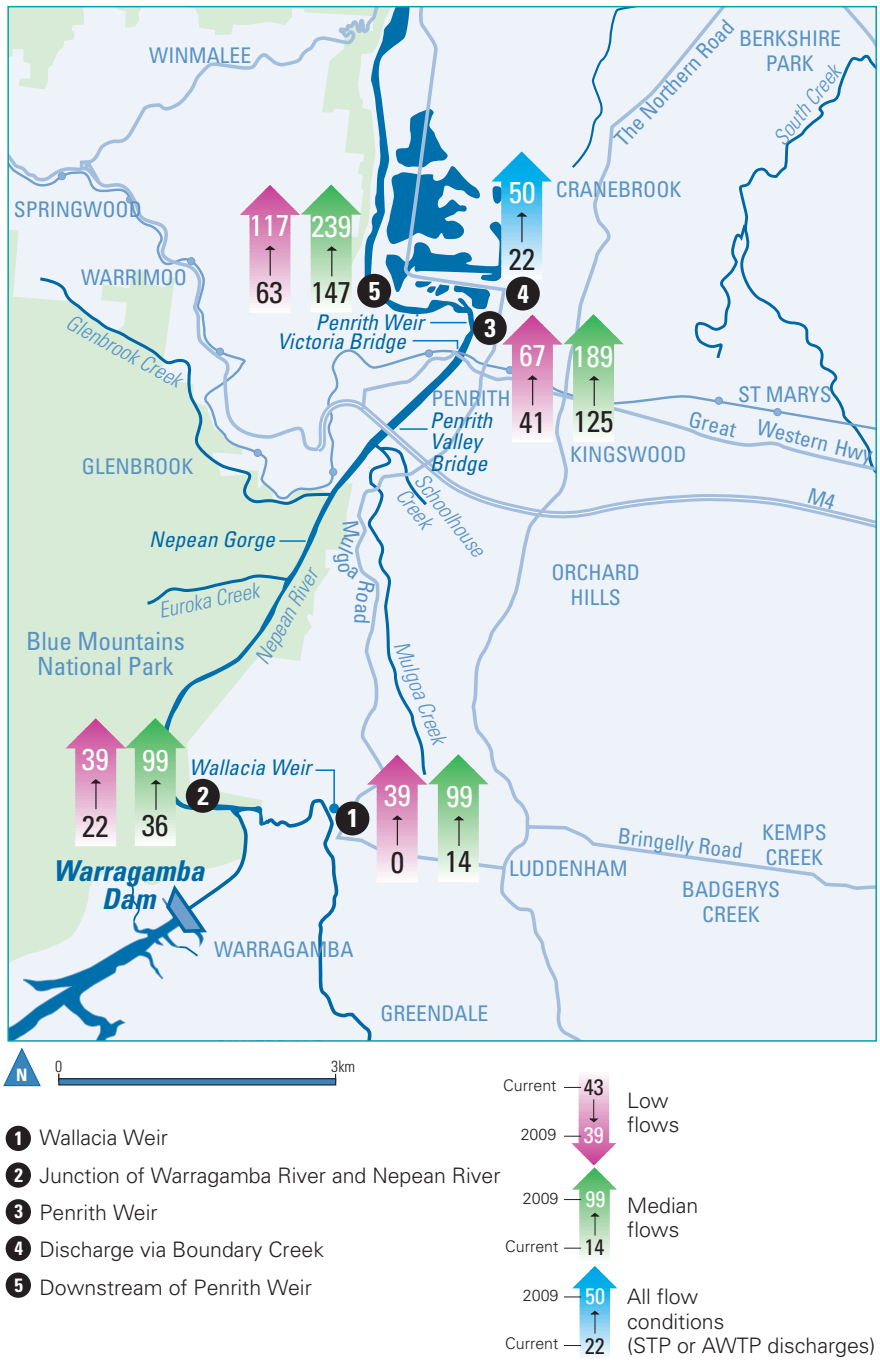


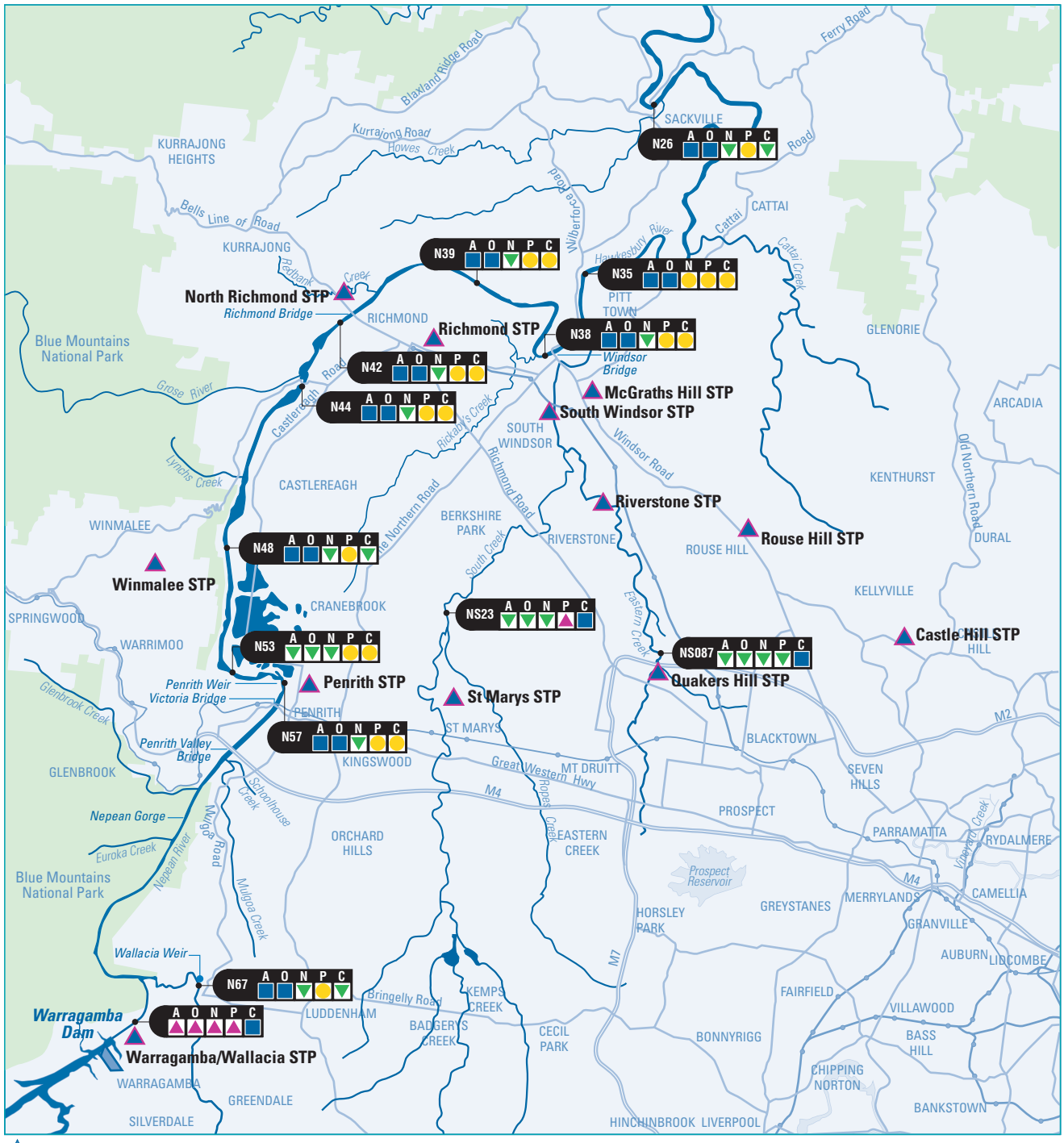
Figure 5 Comparison of existing drought flows with predicted 2009 flows (with Replacement Flows Project)



Warragamba River

Operation of the project would result in a reduction of flow volumes in the Warragamba River that would allow effluent from the new Wallacia STP to dominate water quality conditions in the river and potentially create favourable conditions for growth of exotic macrophytes. These conditions could also affect the health of native aquatic species. To mitigate this impact Sydney Water would develop an effluent management strategy to reduce the impact of the discharge from Wallacia STP to an acceptable level. The project would not have any additional impact on fish or other aquatic values with the implementation of this strategy.

Figure 6 Predicted changes in concentrations of key water quality indicators



Warragamba River
Wallacia to Penrith Weir
N67 - Nepean River at Wallacia
N57 - Nepean River at Penrith Weir
Penrith to Yarramundi
N53 - Nepean River downstream of Penrith STP
N48 - Nepean River at Smith Road
N44 - Nepean River at Yarramundi Bridge
Yarramundi to South Creek
N42 - Hawkesbury River at North Richmond
N39 - Hawkesbury River at Freemans Reach
N38 - Hawkesbury River at Windsor Bridge
South Creek to Sackville
N35 - Hawkesbury River at Wilberforce
N26 - Hawkesbury River at Sackville Ferry
South Creek
NS087 - Downstream of Quakers Hill STP
NS23 - Downstream of St Marys STP

The Warragamba River is not a popular or accessible area for recreation. The recreational amenity of the area may decrease due to decreased flows but overall this would have a minor impact on recreational values of the Hawkesbury-Nepean River system.

Nepean River – Wallacia Weir to Penrith Weir

Although there would be increased flows and improved water quality into this reach, the Penrith weir pool would still largely control the water levels and quality. The operation of the project would therefore have a neutral effect on the aquatic ecology of this reach, although there may be some positive effects on native fish diversity, abundance and growth. Native aquatic flora may also benefit and there may be positive effects on fish migration.

This reach of the river supports a number of recreational activities and the recreational amenity of this reach of the river would remain relatively unchanged as a result of the project.

The project would not have an adverse impact on agricultural users, with flow in this section increasing marginally.

Nepean River – Penrith Weir to Yarramundi

The Project (in conjunction with the 2009 river management changes) may have a beneficial effect on the aquatic ecology within this reach of the Nepean River, with the increase in flow continuing to support flowing water macroinvertebrate communities. The combination of increased flow and improved water quality may be beneficial to native fish species, while the improvement in water quality and flows within the main river channel would most likely favour native macrophytes over exotic macrophytes. The potential for excessive growth of other aquatic weeds should also decline with a reduction in nutrient loads.

A study would be undertaken, in consultation with Department of Primary Industries (Fisheries), to determine whether the discharge of the Project would result in changes to the natural fish migration over Penrith Weir.

The discharge of replacement flows via Boundary Creek has the potential to attract migrating fish away from the fishway at Penrith Weir. Although fish may be able to reproduce and survive in Boundary Creek, the attraction of the replacement flows could result in a reduction in fish migrating further up the Nepean River.

The major potential impact of the Project would be on fish species that migrate upstream during low flows. Those species that are stimulated to migrate by high flows would not be affected, as the discharge via Boundary Creek would only contribute a small percentage of the total river flow.

Under present conditions, the low flow (95th percentile) passing over Penrith Weir (including the fishway) is 62 ML/day, compared with over 22 ML/day from Boundary Creek. Despite its lower flow volume, Boundary Creek may attract some fish in these conditions, but the attraction would depend on water quality, particularly water temperature. The replacement flows discharge via Boundary Creek would be of a greater volume (up to 50 ML/day), the quality of the discharge would be improved and therefore there is potential to impact on fish migration. A study would be undertaken, in consultation with Department of Primary Industries (Fisheries), to determine whether the discharge of the Project would result in changes to the natural fish migration over Penrith Weir. Based on outcomes of this study appropriate design and other mitigation measures would be developed.

Hawkesbury River – Yarramundi to South Creek

The operation of the project would have a neutral effect on aquatic ecology and recreational amenity within this reach, as it is effectively a freshwater tidal pool and flow and water levels would be relatively unchanged. Improved water quality could, however, lead to a reduction in growth of exotic macrophytes.

Agricultural water users in this reach would not be adversely affected by the Project, as flows into the freshwater tidal pool downstream of Yarramundi would increase.

Hawkesbury River - South Creek to Sackville

This reach is within the freshwater tidal pool and changes in flows or water levels are not expected. The operation of the project would therefore have a neutral effect on aquatic ecology within this reach of the river. Improved water quality could, however, lead to a reduction in the growth of exotic macrophytes and the occurrence of algal blooms.

The reduction in algae and aquatic weeds would be expected to increase the appeal and suitability of the river for recreational purposes and increased clarity would enhance the scenic qualities of the water resource. Due to the possible increased numbers of fish, recreational fishers may also benefit from the improvements to river health.

Similar to the Yarramundi to South Creek reach, agricultural water users in this reach would not be adversely affected by the project as flows into the freshwater tidal pool downstream of Yarramundi would increase.

South Creek

There will be a major reduction in flow and nutrient load in South Creek downstream of the STPs. Although concentrations of phosphorus would increase slightly and nitrogen concentrations would decrease, overall water quality would be relatively unchanged. The South Creek system would remain a relatively degraded environment and the Project would have a neutral effect on riparian, native fish, macroinvertebrate and macrophyte species within South and Eastern Creeks.

The waters of South Creek are not used extensively for recreational purposes and as such the changes to water quality and waterway health would have little effect on the recreational value of the creek.

The water requirements of downstream extractors were accounted for when determining the volumes of tertiary treated effluent that would continue to be discharged to South and Eastern Creeks. Consequently, there would be no adverse impacts on agricultural water users downstream of the STPs on South and Eastern Creeks.

Threatened aquatic species

The assessments concluded that the project would not have a significant impact on the threatened species known to occur within the Hawkesbury-Nepean River in the area of the Project.

Three threatened aquatic species were identified as having potential habitats within the project area. Macquarie Perch, Australian Grayling and Sydney Hawk Dragonfly are listed under the NSW *Fisheries Management Act 1994*, while the Macquarie Perch and Australian Grayling are also listed under the Commonwealth *Environmental Protection and Biodiversity Act 1999*. An assessment of significance was prepared for each of the species likely to occur in the study area. The assessments concluded that the project would not have a significant impact on the threatened species known to occur within the Hawkesbury-Nepean River in the area of the Project.

Fisheries

The major commercial fisheries in the Hawkesbury-Nepean River System are located in the saline estuarine and marine areas downstream of Wisemans Ferry. The effects of the project on the freshwater reaches have been assessed to be neutral or beneficial and therefore there would be no adverse indirect impacts on downstream commercial fisheries.

Human health

A number of exposure pathways were assessed to examine the potential impact on human health of releasing highly treated recycled water (replacement flows) into Hawkesbury-Nepean River. These included undertaking water-based recreational activities and the unlikely scenario that someone would drink untreated river water downstream of the replacement flows discharge.

During effective operation of the AWTP (specifically the microfiltration and reverse osmosis processes), no additional risk from pathogens or chemicals was identified for the exposure pathways examined.

During effective operation of the AWTP (specifically the microfiltration and reverse osmosis processes), no additional risk from pathogens or chemicals was identified for the exposure pathways examined. Notably, the consumption of shellfish and irrigated vegetables, and in particular the consumption of treated drinking water produced by the North Richmond Water Filtration Plant, presented risks well below World Health Organisation benchmark values.

No unsafe concentrations of non-cancer risk chemicals were identified. Under conditions where the operation of the AWTP is significantly compromised, three carcinogenic chemicals were identified to be equal to or slightly above benchmark values where the predominant exposure pathway was by contact (through the skin) with river sediment closest to Penrith Weir. This risk, however, is likely to be over-estimated as the concentrations of these chemicals are below the detection limit of current analytical methods.

Other important issues

Terrestrial flora and fauna

Potential terrestrial flora and fauna impacts could occur during construction. At the AWTP site, impacts would be limited to the loss of isolated trees or small stands or regrowth within predominantly cleared areas. The proposed infrastructure and pipeline routes have been located to minimise impacts on remnant vegetation, in particular the endangered ecological communities of Cumberland Plain Woodland and River-flat Eucalypt Forest and threatened species such as the Cumberland Land Snail, Green and Golden Bell Frog and Juniper-leaved Grevillea, all listed under the NSW *Threatened Species Conservation Act 1995.*

The Cumberland Plain Woodland community is also listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. Standard construction environmental management practices would be implemented and techniques such as underground boring would be used to avoid areas of significant vegetation.

Waste Management

Spoil and other waste materials are likely to be generated during construction. Appropriate waste management strategies would be implemented, in accordance with the requirements of the NSW *Waste Avoidance and Resource Recovery Act 2001*. This would include investigation of opportunities for reuse of potential wastes such as spoil or disused construction materials.

Operational waste will include about 8 ML/day of concentrate from the AWTP that would be discharged to the NSOOS. No significant impacts would result from the addition of the concentrate stream to the NSOOS.

Noise and vibration

The main components of the project that would generate noise during operation would be the AWTP and the various pumping stations. An assessment of operational noise impacts was made according to the requirements of the Department of Environment and Conservation's *Industrial Noise Policy*. Due to the location of the works and the distances to sensitive receivers, the operational noise generated from the AWTP site and the pumping stations could be able to be managed to meet the requirements of the policy.

Noise management measures would be implemented to minimise construction noise impacts.

Construction activities, particularly related to the pipelines, would impact on the acoustic environment of the area and would present a short-term nuisance to adjoining residents and users of public reserves. Noise management measures would be implemented to minimise construction noise impacts. Construction activities would be undertaken in accordance with Australian Standard AS 2436-1981 *Guide to Noise Control on Construction* and noise goals would be adopted for construction as detailed in the Department of Environment and Conservation (DEC) noise control guidelines *Construction Site Noise*.

There is the potential for vibration impacts on properties under which boring would take place. General construction activities would be managed in accordance with appropriate standards for managing vibration.

Stakeholder Engagement and Consultation

During the planning process for the Environmental Assessment, the following activities were carried out to inform the community and stakeholders of the project and to receive and address issues and concerns raised.

Planning Focus Meeting

A Planning Focus Meeting was held in July 2006 and was attended by representatives from key Government agencies and Councils.

Meetings with local Councils

Meetings were held with all the local Councils affected by the project. These meetings established awareness of the project in the context of the *2006 Metropolitan Water Plan*. In some cases, specific details of infrastructure in the affected Council area were discussed.

Presentations

Sydney Water offered a detailed presentation on the project to a number of stakeholders. The majority of stakeholders accepted the offer and the presentations included general information on the project and specific issues of interest for each of the agencies.

Issue specific consultation

A pre-referral briefing was held with Commonwealth Department of Environment and Heritage (DEH) regarding potential impacts on matters of National Environmental Significance.

Local Aboriginal stakeholders were consulted in accordance with Department of Environment and Conservation guidelines.

Community information

The community has been informed about the project through the *2006 Metropolitan Water Plan* communication activities. In addition Sydney Water has established an information page for the project on the Sydney Water website. The website includes a range of fact sheets that are available for information and can be downloaded.

A free-call number (1800 685 833) is also available for general inquiries.

Justification for the Project

The Environmental Assessment has confirmed that the Replacement Flows Project, in combination with other planned river management changes, would ensure that the substitution of Warragamba Dam releases with highly treated recycled water released from below Penrith Weir would deliver an equivalent or higher level of environmental benefit to the Hawkesbury-Nepean River system.

The Replacement Flows Project has a long reaching beneficial affect on water quality, particularly with respect to nitrogen, with improvements in water quality persisting downstream of South Creek and continuing to Sackville.

The project would have greatest effect on reaches of the Hawkesbury-Nepean River downstream of the Warragamba River junction. It would reduce the concentrations and loads of nitrogen species in the Hawkesbury-Nepean River and reduce the nutrient loads entering South and Eastern Creeks. The Replacement Flows Project has a long reaching beneficial effect on water quality, particularly with respect to nitrogen, with improvements in water quality persisting downstream of South Creek and continuing to Sackville. Phosphorus concentrations would be largely unaffected by the Project in the majority of river reaches.

The Project, in conjunction with the Upper Nepean Dam releases, would also generally increase the variability of flows in the river system. The improvements in water quality and quantity may also to provide an improved habitat for fish, macroinvertebrates and native aquatic flora.

Improved water quality could lead to a reduction in water weed growth and algal blooms in the Hawkesbury-Nepean River from Penrith to Yarramundi and from the South Creek confluence to Sackville. This would, in turn, improve opportunities for people to use the river for recreation.

The implementation of the Project, in conjunction with the other strategies outlined in the *2006 Metropolitan Water Plan*, would further alleviate current demand pressures placed on Sydney's domestic water supply.



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Glossary

Acid sulphate soils	Naturally acid clays, mud and other sediments usually found in swamps and estuaries. They may become extremely acidic when drained and exposed to oxygen and may produce acidic leachate run-off that can pollute waters and liberate toxins.
Ambient	The background level at a specified location, being a composite of all sources. Examples of the use of this term include 'ambient noise' or 'ambient air pollutants
Amenity	Something that contributes to physical or material comfort.
Anti-scalent	The name of the chemicals added to water to prevent mineral/scaling deposits from forming. These chemicals (eg sodium hexametaphosphate, organophosphate or polyacrylates) suspend the minerals (eg calcium and silicate) in the water while it is passed through the membranes preventing the deposition and hardening of these minerals within the reverse osmosis membranes.
Aquaculture	The process of raising and harvesting fresh and saltwater plants and animals.
Aquifer	Rock or soil formation containing water in recoverable quantities.
Aquifer recharge	The infiltration or injection of natural waters or recycled waters into an aquifer, providing replenishment of the ground water resource.
Artefact	An object, normally portable, made or modified by human hands.
Asset management	A process that enables a utility to determine how to minimise the total cost of owning and operating infrastructure assets while continuously delivering appropriate service levels to customers.
Average dry weather flow	The flow of sewage produced on a typical day in dry weather.

Average recurrence interval	The average recurrence interval (ARI) (measured in years) is a term used to describe the frequency or probability of floods occurring. Large floods occur rarely, whereas small floods occur more frequently. For example, a 100 year ARI flood is a flood that occurs (or is exceeded) on average once every 100 years.
Background noise	The underlying level of noise present in the ambient noise, excluding the noise source under investigation, when extraneous noise is removed. This is described using the L_{A90} descriptor.
Bacteria	Single celled microorganisms that exist either as free-living organisms or as parasites and have a broad range of biochemical, and often pathogenic, properties. Bacteria can be grouped by form into five general categories - cocci (spherical), bacilli (rod-shaped), vibrio (curved rod-shaped), spirilla (spiral), and filamentous (thread-like).
Benthic	The bed of a body of water, including the silt or mud that lies there.
Bioavailable	The extent to which a nutrient can be used by a living organism.
Biocide	A chemical agent that is capable of destroying living organisms.
Biological diversity	The variety of all life forms, comprising genetic diversity (within species), species diversity and ecosystem diversity.
Boring	Activity that involves drilling a small diameter pilot hole along a predetermined alignment by means of a drill head and drill rods thrust from a drilling rig. The pilot hole is enlarged through a reaming process to construct a borehole of sufficient size to accommodate the pipe.
Breakpoint chlorination	A process that involves the addition of hypochlorite solution to the recycled water. It is applied to remove chloramines and ammonia that pass through the reverse osmosis membranes.
Bund	A bund is an embankment or wall of brick, stone, concrete or other impervious material, which may form part or all of the perimeter of a compound and provides a barrier to retain liquid.
Carbon dioxide stripping	A post-treatment process undertaken to reduce the corrosiveness of the recycled water by increasing the pH from about 5 to 7.
Chloramines	The addition of chlorine to water that contains ammonia generates chloramines, for example monochloramine (NH_2Cl) and dichloramine ($NHCl_2$), both of which are disinfectants. Chloramines are disinfectants used to control biological fouling of the reverse osmosis membranes.

Chlorophyll a	A plant pigment whose concentration in water is used to estimate the amount of phytoplankton or algae. Increases in chlorophyll a in the water indicate that plants, algae or cyanobacteria are actually growing.
Clean in place	Addition of cleaning chemicals through the reverse osmosis membranes during operation which eliminates the need to dismantle the reverse osmosis process equipment.
Concentrate	Highly treated recycled water which did not pass through the reverse osmosis membrane on the first stage is passed through a second reverse osmosis process (stage 2) in order to improve the recovery rate and further concentrate the waste stream.
Concentrate stream	Refers to the water that contains elements removed from the tertiary treated effluent by the reverse osmosis membranes. This waste stream would be delivered to the NSOOS via the waste pipeline.
Confluence	A flowing together of two or more streams or rivers.
Contaminated	A condition or state which represents or potentially represents an adverse health or environmental impact because of the presence of potentially hazardous substances.
Contaminants	Unwanted and potentially detrimental organic, inorganic and biological substances.
Cyanobacteria	Also known as blue-green algae. They are a naturally occurring component of most aquatic ecosystems and occur in freshwater, estuarine and marine environments. Excess numbers of algal cells or 'blooms' may occur in waterways that have elevated nutrients, warm water temperatures, adequate sunlight and long residence times. Many species have the potential to produce toxins (toxic cyanobacteria) that present a hazard to human health.
dB(A)	Unit used to measure 'A-weighted' sound pressure levels. A-weighting is an adjustment made to sound-level measurement to approximate the response of the human ear.
Dechlorination	Treatment of recycled water with metabisulphate to remove any residual chlorine.

Disability adjusted life year	The Disability Adjusted Life Year (DALY) is a health gap measure that extends the concept of potential years of life lost due to premature death (PYLL) to include equivalent years of 'healthy' life lost by virtue of being in states of poor health or disability. The DALY combines in one measure the time lived with disability and the time lost due to premature mortality. One DALY can be thought of as one lost year of 'healthy' life. It also represents the burden of disease as a measurement of the gap between current health status and an ideal situation where everyone lives into old age free of disease and disability. One µDALY is one Disability Adjusted Life Year per million people, which is used by the World Health Organisation (WHO) as a measure of safe pathogen health burden.
Disinfection by-products	Chemical compounds (e.g. chloroform and other trihalomethanes) produced during disinfection of water, that have been shown to be detrimental to health in laboratory animal studies.
Dissipate	To disperse or dispel.
Dissolved oxygen	Measured as per cent (%) saturation and mg/L. This is a measure of the amount of oxygen dissolved in water. Dissolved oxygen is vital for many riverine and estuarine biota, including native fish and is also vital for the functioning of healthy aquatic ecosystems.
Dual reticulation	The simultaneous supply of water from two separate sources, requiring two sets of pipes: one to provide potable water (for drinking, cooking and bathing purposes); the other to provide recycled water for non-potable (eg gardening, toilet flushing) purposes.
Earthworks	The process of extracting, moving and depositing earth during construction.
Ecologically sustainable development	Using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased.
Ecosystem	A functional unit of energy transfer and nutrient cycling in a given place such as a forest or estuary; it includes all the relationships within the biotic community and between the biotic components of the system.
Effluent	The liquid product of sewage treatment that is discharged into the environment or reused. The quality of effluent provided by the treatment plant depends on the treatment process used.
Electrical conductivity	A measure of the amount of dissolved salts in the water. It is important as some plants and animals are salt sensitive while others require higher salt concentrations.

Endocrine	A hormone secreted by the endocrine gland.
Endocrine disrupting chemical (EDC)	A substance or mixture of substances which occur outside an organism that alters function(s) of the endocrine system and consequently causes adverse health effects in the organism, or its offspring, or (sub)populations.
Environmental flow	Water which is used to better maintain the ecological health of the waterway.
Environment protection licence	A licence that allows pollution to the environment but under controlled conditions regulated by the Department of Environment and Conservation (Environment Protection Authority).
Erodability	The erosion potential of soils.
Erosion	The natural process where wind or water detaches a soil particle and provides energy to move the particle.
Eutrophication	Eutrophication is a process in which a water body becomes rich in dissolved nutrients, often leading to algal blooms, low dissolved oxygen, and changes in the composition of plants and animals in the water body. This occurs naturally, but can be exacerbated by human activity that increases nutrient inputs to the water body.
Extraction limit	Maximum quantity that can be removed from a watercourse by irrigators.
Faecal coliform	A group of coliforms that colonise the intestinal tract of animals. These bacteria are relatively harmless, and help the body digest food. Faecal coliforms found in the water are an indicator that there are upstream inputs of animal waste. Because they live in the digestive system, they are an indicator of other, more harmful viruses and bacteria.
Fish assemblages	A fish assemblage refers to the distribution and abundance of fish species within a particular area of a water body. The composition may include both native, translocated (introduced) and exotic species. Native fish species are particularly vulnerable to changes in flow regulation and habitat disturbance and to a degree by poor water quality. Their composition is used as an indicator of ecosystem health, as alien fish species generally have a higher tolerance of habitat disturbance and associated changes in water quality and flow rates, than native species (Gehrke, 1996).
Floodplain	Large flat area of alluvium adjacent to a watercourse, characterised by frequent erosion and aggravated by channelled and overbank stream flow.
Fluvial	Produced by the action of a river or stream

Genus/Genera (plural)	A taxonomic category ranking below a family and above a species and generally consisting of a group of species exhibiting similar characteristics. In taxonomic nomenclature, the genus name is used either alone or followed by a Latin adjective or epithet to form the name of a species.
Greenhouse gases	A gas in Earth's atmoshere that traps heat and can contribute to global warming. Although greenhouse gases are a natural part of the atmosphere, human activity is increasing them mostly through the production and release of carbon dioxide, methane and nitrous oxide.
Greywater	A combination of wastewater from the laundry, bathroom and kitchen but excluding toilets.
Groundwater	Subsurface water.
Habitat	The place where an organism lives; habitats are measurable and can be described by their flora and physical components.
Helminths	Parasitic worms including roundworms, tapeworms, hookworms and pinworms.
Hoarding	A temporary fence enclosing a construction site.
Horticulture	The cultivation of a garden, orchard, or nursery; the cultivation of flowers, fruits, vegetables, or ornamental plants.
Hydrology	The scientific study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.
Hydrophobicity	Repelling, tending not to combine with, or incapable of dissolving in water.
Impaired sites	Sites that are no longer in a pristine condition or are degraded in some way.
Interim environmental flows	This relates to the flows released in accordance with SCA's Water Management Licence. Clause S4.1 of the licence identifies the requirement to release 33.3ML/d of water from Warragamba Dam for environmental purposes until such time as flow provisions are further assessed and revised in accordance with Clause S4.2.
Intrusive noise	Refers to noise that intrudes above the background level by more than 5 dB(A).
Irrigation	The watering of crops, pasture, golf courses, parks, gardens and open spaces.
$LA_{(XX)}$	The $L_{A(XX)}$ refers to statistical indicators that represent the percentage of time that a noise level is exceeded. These levels are commonly the L_{A1}, L_{A10}, and the L_{A90}, and are graphed to show how these levels change over the course of a 24 hour period.

L_{A90}	An important statistical indicator that represents the A-weighted sound pressure level that is exceeded for 90% of the time over which the noise is measured. This is often termed the background noise.
L_{Aeq}	Although the L_{Aeq} is not a statistical indicator, it is probably one of the most important of the noise descriptors. It represents the equivalent continuous A-weighted noise level for the measurement period. This is the level of noise energy averaged over the measurement period.
L_{Amax} Maximum noise level	The highest noise level during a specified time period or during a specified number of events expressed as the absolute maximum value of the root-mean-square (r.m.s.) sound pressure level using time weighting 'F'.
L_{Amin} Minimum noise level	The lowest noise level during a specified time period or during a specified number of events, expressed as the absolute minimum value of the root-mean-square (r.m.s.) sound pressure level using time weighting 'F'.
Lentic	Pertaining to or living in still water.
Macroin-vertebrate	Macroinvertebrate refers to aquatic invertebrates including insects, crustaceans, molluscs and worms which inhabit a river channel, pond, lake, wetland or ocean. They are used as environmental indicators to assess the health of aquatic ecosystems.
Macrophytes	Macrophytes encompass the instream flowering plants that may be found attached or floating within a waterway. They include submergent (underwater) and emergent species (such as reeds that emerge out of the water) that inhabit both estuarine and freshwater reaches of a river. Macrophytes are important biological indicators in this study as their distribution depends upon water quality and flow conditions.
Mass balance	A mass balance (also called a material balance) is an accounting of material entering and leaving a system.
Microfiltration	This involves the pumping of a stream of water through a membrane to separate impurities from the water. Microfiltration removes particles above the range of 0.1 to 1.0 microns; dissolved salts (eg nitrate) pass through these membranes.
Micron	A millionth part of a metre.
Mitigation measure	Any action or activity that can be used to prevent or eliminate a hazard or reduce it to an acceptable level.

ML	A million litres. 1 million litres = 1 megalitre
Monochloramine	Monochloramine is the most common disinfectant. See chloramines above.
Monovalent	Able to form only one covalent or ionic bond. Divalent is two, trivalent, three.
Muffler	Any of various devices for deadening sound, such as the sound produced by gases from an internal-combustion engine.
Nanogram	The billionth part of a gram. (10^{-9})
Nanometre	The billionth part of a metre. (10^{-9})
Non-point source	Pollution that enters receiving waters from dispersed sources (such as surface runoff) rather than through point sources, such as pipes.
Non-potable water	Water used for purposes other than drinking, cooking, bathing and laundry: for example, irrigation of gardens, lawns and toilet flushing.
Nutrients	Nitrogen (N) and Phosphorus (P) are essential nutrients to ecosystem biota at certain concentrations. However, excess nutrients stimulate excessive growth of aquatic plants such as phytoplankton, cyanobacteria, macrophytes, sea grasses and algae. Measures of N and P indicate how eutrophic a waterbody is and how susceptible it will be to nuisance plant growth.
Overflow	Untreated or partially treated discharge or leakage of sewage (under wet and dry weather) from a sewerage system. They can occur at either designed overflow structures or other points in the system.
Oxidation	Process where a substance is converted to another form by combination with oxygen. Organic matter decomposed by bacteria is subject to oxidation.
Particulates	Dust and other fine particles.
Passive recreation	This refers to recreational pursuits that are non-consumptive such as picnicking, wildlife observations, walking, biking or canoeing.
Pathogen	A micro-organism capable of causing diseases in humans, animals or plants. They may be bacteria, virus or parasites found in sewage.
Peak Flow	The maximum flow of sewage produced due to diurnal variations in flow on a typical day.
Perennial	Refers to plants that have a life cycle lasting more than two years.
Peri urban	Peri-urban areas are outside formal urban boundaries and urban jurisdictions which are in a process of urbanisation and which therefore progressively assume many of the characteristics of urban areas.

pH	A measure of how acidic or alkaline a solution is. The pH scale is 0-14 with a score of 7 representing a neutral value. Values less than 7 indicate an acid solution, greater than 7 an alkaline solution. Most freshwater and estuarine biota have a tolerance range of between approximately 6.5 and 8.
Physico-chemical	Relating to both physical and chemical properties.
Potable water	Water of a quality suitable for drinking, cooking and personal bathing.
Potential archaeological deposit	A potential archaeological deposit, or PAD, is defined as any location where the potential for subsurface archaeological material is considered to be moderate or high, relative to the surrounding study area landscape. The potential for subsurface material to be present is assessed using criteria developed from the results of previous surveys and excavations relevant to the region.
Primary contact	Direct contact with water, including swimming, diving, water skiing and surfing.
Proponent	The person or body proposing to carry out a development or activity.
Rainwater tanks	Tanks used to collect and store rainfall from roofs for reuse.
Ramsar wetland	A wetland listed under the Convention on Wetlands of International Importance (Ramsar Convention 1971).
Raw water	Water that forms the source supply for potable water, before it has been treated.
Receiving water	A body of water such as a stream, river, lake, or ocean, which receives stormwater and wastewater.
Recharge zone	A recharge zone is where water flows into the ground to become groundwater through the recharge system.
Recycled water	The recycled water referred to in this project is the tertiary treated effluent which has been further treated by passing through the AWTP. This water would form the replacement flows when it is released into the Hawkesbury- Nepean River.
Rehabilitation	The restoration of a landscape and especially the vegetation following its disturbance.
Relic	The NSW *Heritage Act 1977* defines a 'relic' as any deposit, object or material evidence: which relates to settlement of that area that comprises NSW, not being an aboriginal settlement; and which is 50 or more years old.
Remnant Vegetation	Native vegetation remaining after widespread clearing has taken place.
Replacement flows	The defined end use for the highly treated recycled water once it is discharged into the Hawkesbury-Nepean River below Penrith Weir.

Reverse osmosis	Used to purify water and remove dissolved salts and other impurities. The process involves forcing water through a membrane to allow the removal of particles as small as ions.
Riffle	A rocky shoal or sandbar lying just below the surface of a waterway.
Riparian	Relating to the banks of a natural water way.
Riparian vegetation	In the context of this study riparian vegetation encompasses the woody and non-woody vegetation that inhabits the riverine riparian zone of the Hawkesbury-Nepean River and its tributaries. The riparian zone may be defined as "the stream channel between the high and low water mark towards the uplands where vegetation may be influences by elevated water tables and flooding and by the ability of soils to hold water ".
Schedule 10 chemicals	Describes a group of 114 substances that are listed under Schedule 10 of the *Sydney Water Act 1994*. It includes a range of polyaromatic compounds, monocyclic aromatic compounds, metals, organochlorine pesticides, halogenated aliphatic compounds, organophosphate pesticides, herbicides and other organic and inorganic toxicants. At certain concentrations, these chemicals may affect the survival, growth or reproduction of aquatic species or have effects on human health. The Department of Environment and Conservation (EPA) also set requirements for source control, education and ongoing monitoring programs. These apply to sewage treatment plants discharging to the ocean and the Hawkesbury-Nepean River.
Secondary contact	Activities where contact with water may occur, but is not necessary. Examples include boating and fishing.
Sediment	Material of varying sizes that has been or is being moved from its site of origin by the action of wind, water or gravity.
Sewage	The used water of community or industry, conveyed through sewers to be treated at a sewage treatment plant.
Sewerage	The sewage transfer and treatment system that comprises the pipes, pumps and sewage treatment plant.
Sewer mining	The extraction of water from sewers or wastewater systems that is treated and reused with the return of solids to the sewerage system.
Shroud	Something that covers or conceals.
Site compound	Area enclosing construction machinery, stockpiles and site offices.
Spoil	Soil or materials arising from excavation activities.
Stakeholder	An individual or group that has an interest in the project.

Stockpile	Temporarily stored materials, eg soil, sand, gravel, spoil/waste.
Stormwater	All surface water runoff from rainfall, predominantly in urban catchments; such areas may include rural residential zones.
Taxonomic	The science dealing with the description, identification, naming, and classification of organisms.
Tertiary treatment	Third stage in the treatment of sewage. This process consists largely of removal of nutrients and any remaining suspended solids and may include disinfection of the effluent.
Tertiary treated effluent	Term given to tertiary treated wastewater from Penrith, St Marys and Quakers Hill sewage treatment plants.
Trace chemicals	Chemicals found in very small amounts in a given substance.
Translucent	Refers to releases whereby a percentage of inflows to a dam must be released. This involves passing a fixed percentage of the actual inflow to (beyond) the dam and aims to mimic natural conditions.
Transparent	Refers to flows passed through storage and released from a dam that equal all inflows to the storage.
Turbidity	A measure of the "muddiness" of water because of stirred-up sediment or the like - important because it determines how much light can penetrate for important biochemical processes such as photosynthesis.
Ultrafiltration	This is a membrane process involving the forcing of a feed stream of water onto a membrane surface to separate impurities from the main product. Ultrafiltration removes particles above the range of 0.002 to 0.1 microns. It does not remove dissolved salts.
Wastewater	The used water of community, industry and agriculture.
Water quality	The chemical, physical and biological condition of water.
Water resource	The sources of supply of ground and surface water in a given area.
Wet-weather overflows	Overflow that occurs during or as a result of excess stormwater inflow and infiltration to the sewerage system.



Acronyms and abbreviations

$	Australian dollars
ADI	Australian Defence Industries
ADWF	Average dry weather flow
AGL	Australian Gas Light Company
AMU	Archaeological Management Unit
ANIC	Australian National Insect Collection
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AS	Australian Standard
AWTP	Advanced Water Treatment Plant
BASIX	Building and Sustainability Index
CIP	Clean-in-place
$CaCO_3$	Calcium carbonate
CAP	Catchment Action Plan
Chlor-N	Chloramine nitrogen
CO_2	Carbon dioxide
DA	Development Application
DALY	Disability Adjusted Life Year
$dB(A)_{period}$	Unit used to measure 'A-weighted' sound pressure levels
DEC	Department of Environment and Conservation
DEH	Department of Environment and Heritage
DoP	Department of Planning
DPI	Department of Primary Industries
EA	Environmental Assessment
EDCs	Endocrine disrupting compounds
EIS	Environmental Impact Statement
EMS	Environmental Management System

ENCM	Environmental Noise Control Manual
EP&A Act	Environmental Planning & Assessment Act, 1979
EPBC Act	Environment Protection and Biodiversity Conservation Act, 1999
FM Act	Fisheries Management Act, 1994
G	Giga (10^9)
GL	Gigalitre (1 billion litres)
GW	Giga watt
gWh	Giga watt hours
ha	Hectare
INP	Industrial Noise Policy
IPART	Independent Pricing and Regulatory Tribunal
kg	Kilogram
km	Kilometre
kWhr	Kilo watt hours
LA_{Eq}	Equivalent continuous 'A-weighted' noise level for the measurement period
LALC	Local Aboriginal Land Council
LEP	Local Environment Plan
m	Metre
M	Mega (10^6)
m/s	Metres per second
m^2	Square metre
m^3	Cubic metre
mg/L	Milligrams per litre
ML	Megalitre (1 million litres)
ML/day	Megalitres per day
NGRS	North Georges River Submain
NH_3	Ammonia
NH_4	Ammonium
NH_4-N	Ammonium as nitrogen
NOx	Oxidised nitrogen
NOx-N	Oxidised nitrogen as nitrogen
NP&W Act	National Parks & Wildlife Act, 1974
NSOOS	Northern Suburbs Ocean Outfall Sewer
NSST	North Side Storage Tunnel
NSW	New South Wales
Org-N	Organic nitrogen
pa	Per annum
PAD	Potential Archaeological Deposit
PEA	Preliminary Environmental Assessment
PFM	Planning Focus Meeting
ppt	Parts per thousand

PDWF	Peak dry weather flow
REP	Regional Environmental Plan
RFP	Replacement Flows Project
RTA	Roads and Traffic Authority
RO	Reverse osmosis
ROTAP	Rare or Threatened Australian Plants
SEPP	State Environmental Planning Policy
SREP	Sydney Regional Environment Plan
STP	Sewage treatment plant
SWSOOS	South Western Suburbs Ocean Outfall Sewer
t	Metric tonne
TDS	Total dissolved solids
TN	Total nitrogen
TP	Total phosphorus
TSC Act	Threatened Species Conservation Act, 1995
TSS	Total suspended solids
ug/L	Micrograms per litre
WELS	Water Efficiency Labelling Scheme



1 Introduction

This chapter introduces the Replacement Flows Project (the Project). It provides an outline of the Project, its purpose and the structure of the Environmental Assessment report.

1.1 The Project

The *2006 Metropolitan Water Plan* sets out how the New South Wales (NSW) Government will achieve its objectives for securing Sydney's water needs over the next 25 years. It aims to recycle up to 70 billion litres per year by 2015 through the implementation of specific recycling projects. The Western Sydney Recycled Water Initiative is a key component of the *2006 Metropolitan Water Plan* and will provide savings of up to 27 billion litres per year. The Replacement Flows Project is an important part of the initiative, contributing up to 18 billion litres per year of those savings.

The Replacement Flows Project involves treating existing tertiary treated effluent from three sewage treatment plants (STPs) in north western Sydney, at a new Advanced Water Treatment Plant (AWTP), to produce high quality recycled water. The recycled water would be substituted, as replacement flows, for water that is currently released from Warragamba Dam.

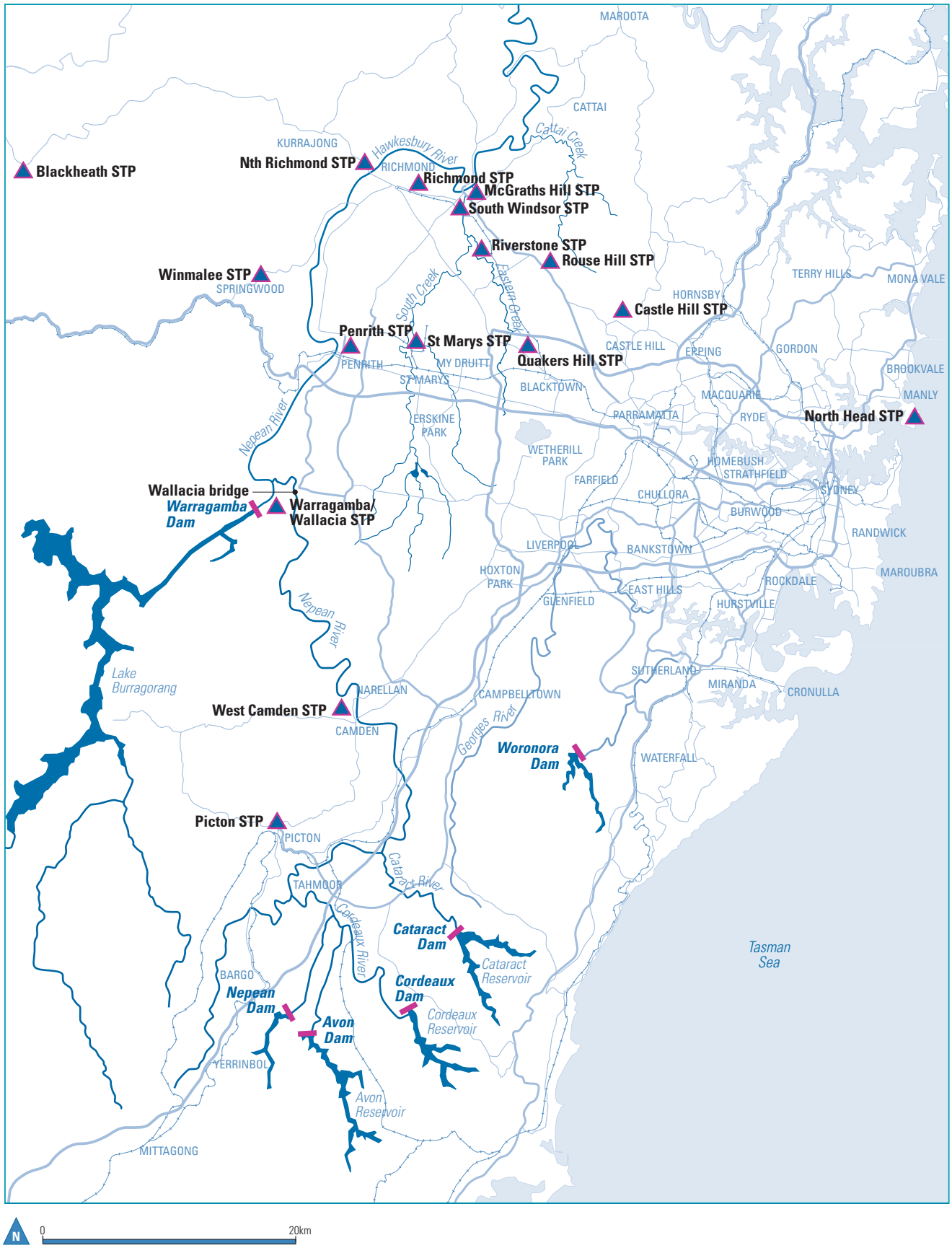
This Environmental Assessment report was prepared under Part 3A of the *Environmental Planning and Assessment Act 1979* in order to obtain project approval for the Project. It assesses the key environmental issues associated with the Project and proposes mitigation measures to address any potential impacts. It also includes a draft Statement of Commitments that outlines the proposed measures for the mitigation of environmental effects that could occur from the construction, commissioning, operation and maintenance of the Project.

1.2 Proponent and description of the Project

The proponent for the Project is Sydney Water Corporation (Sydney Water). Sydney Water is seeking approval for the Western Sydney Recycled Water Initiative - Replacement Flows Project (the Project).

The Project is the construction and operation of an AWTP and associated works. The general study area for this assessment is shown in **Figure 1.1**.

Figure 1.1 The general study area



The Project comprises:

- an AWTP at the St Marys STP site
- pipelines which would transfer tertiary treated effluent from Quakers Hill, Penrith and St Marys STPs to the AWTP
- pipelines for the transfer of the concentrate from the AWTP, via Quakers Hill STP, to the Northern Suburbs Ocean Outfall Sewer (NSOOS) at Vineyard Creek, Dundas
- a storage pond for concentrate at Quakers Hill STP and balance storage tanks and pumping stations at Penrith, Quakers Hill and St Marys STPs
- a pipeline for the transfer of recycled water from the AWTP to the existing outlet at Penrith STP into Boundary Creek, which discharges into the Hawkesbury-Nepean River below Penrith Weir.

This assessment analyses the effects of the Project, with a particular focus on key issues identified by the Director-General of Planning. It has been prepared in accordance with the requirements of Part 3A of the *NSW Environmental Planning and Assessment Act 1979* (EP&A Act) to assist the Minister for Planning in assessing the Project.

1.3 Need for the Project

The 2006 Metropolitan Water Plan sets out how the NSW Government will achieve its objectives for securing Sydney's water needs over the next 25 years.

The *2006 Metropolitan Water Plan* sets out how the NSW Government will achieve its objectives for securing Sydney's water needs over the next 25 years. The objectives will be achieved by:

- providing a secure supply of water that can meet the long term needs of Sydney
- ensuring that water supplies are adequate during drought
- minimising costs to the community and the environment.

The Western Sydney Recycled Water Initiative is one component of the *2006 Metropolitan Water Plan*, and the implementation of this initiative will contribute to maximising the beneficial use of recycled water for residential, industrial, agricultural and environmental purposes.

The relationship between the *2006 Metropolitan Water Plan*, the Western Sydney Recycled Water Initiative - Replacement Flows Project and other Government initiatives is described in detail in **Chapter 2**.

The beneficial use of recycled water for environmental purposes includes using it to maintain flows and for river health purposes. Currently, water suitable for drinking is released from Warragamba Dam to maintain river health and to provide for extraction by irrigators. In non-drought conditions, approximately 33 million litres of water per day (ML/day) is released as base flow and another 10 ML/day is released for agricultural or irrigation purposes. Under current drought conditions the total release is 22 ML/day. If required, additional releases must be made to ensure a minimum flow of 50 ML/day is maintained over Penrith Weir.

The Replacement Flows Project, in combination with other planned river management changes, would ensure that the substitution of Warragamba Dam releases would deliver an equivalent or higher level of environmental benefit to the river and maintain water for irrigation/ agriculture, recreational needs and for aquatic life.

The Project will use recycled water to replace these releases from Warragamba Dam and by 2015 would save up to 18 billion litres of drinking water each year (NSW Government 2006).

The Replacement Flows Project, in combination with other planned river management changes, would ensure that the substitution of Warragamba Dam releases would deliver an equivalent or higher level of environmental benefit to the river and maintain water for irrigation/agriculture, recreational needs and for aquatic life.

The objectives of the Project are to:

- save up to 18 billion litres per year of current Warragamba Dam discharges by providing high quality recycled water to the Nepean River as a replacement for existing Warragamba Dam releases
- reduce the discharge of nutrients from Penrith, Quakers Hill and St Marys STPs into the Hawkesbury-Nepean River and South Creek
- maintain appropriate flows for irrigation
- ensure environmental values are maintained – including aquatic ecosystems, primary industries, recreation and aesthetics and drinking water.

1.4 Structure of the Environmental Assessment Report

This Assessment has been prepared in accordance with the NSW Department of Planning guidelines and the Director-General's Environmental Assessment requirements. A summary of the information contained within each part and chapter of this report is provided below.

The document is in two volumes. Volume 1 contains the main text and Appendices A and B which assist in understanding the document. Volume 2 comprises working papers which provide the technical support for Volume 1. The working papers are presented as Appendices C-G.

Part A provides an introduction and sets a context for the project through the following chapters:

- **Chapter 1** introduces the project and provides background information on its broad strategic context and an overview of the environmental assessment process.
- **Chapter 2** describes how the project relates to the NSW Government's strategic framework for securing Sydney's future water supply.

Part B contains all the project details within the following chapters:

- **Chapter 3** provides a detailed description of the project.
- **Chapter 4** describes the alternative schemes and options within the scheme that were considered. This chapter also details why the project, as described in **Chapter 3**, was preferred.
- **Chapter 5** provides an overview of the Part 3A process and describes how key issues were established for the project. This chapter also describes where the Environmental Assessment requirements are addressed within the document.
- **Chapter 6** provides an analysis of all the Commonwealth, NSW and local regulatory requirements and guidelines for the Project and summarises any licences and approvals required.

Part C contains all the environmental assessment information for the project within the following chapters:

- **Chapter 7** discusses the key issues and the potential impacts of those issues and proposes measures to mitigate those impacts.
- **Chapter 8** provides consideration of other issues and summarises the management of these issues.
- **Chapter 9** provides a description of stakeholder engagement and community consultation.

- **Chapter 10** provides justification for the Project in the context of the 2006 Metropolitan Water Plan and the *Environmental Planning and Assessment Act 1979*. It also provides an overall conclusion.
- **Chapter 11** provides the draft Statement of Commitments for the project.
- **Chapter 12** lists the reference used during the study

A glossary of terms and a list of abbreviations is provided.

Appendices to this document also provide information relevant to the Environmental Assessment, including the key issues that must be considered as part of the overall Environmental Assessment of the Project. Appendices included in this report are as follows:

Appendix A – Land Tenure and Zoning

Appendix B – Project Declaration and Environmental Assessment Requirements

Appendix C – Assessment of the water cycle, water quality and aquatic ecology

Appendix D – Human health risk assessment

Appendix E – Terrestrial ecology assessment

Appendix F – Noise and vibration assessment

Appendix G – Environmental risk assessment



2 Strategic framework

This chapter describes how the Replacement Flows Project (the Project) relates to the NSW Government's strategic framework for securing Sydney's future water supply. The roles of other NSW Government and Sydney Water plans and strategies are also discussed.

2.1 2006 Metropolitan Water Plan

2.1.1 Outline

When fit-for-purpose recycled water is used for non-potable uses, it reduces the demand on the drinking water system, thus boosting total water availability.

The *2006 Metropolitan Water Plan* outlines strategies to balance demand for water with a sustainable supply. It is based on an adaptive management approach, with a diverse suite of options to meet Sydney's long term water needs during drought and non-drought times, while minimising the costs to the community and the environment.

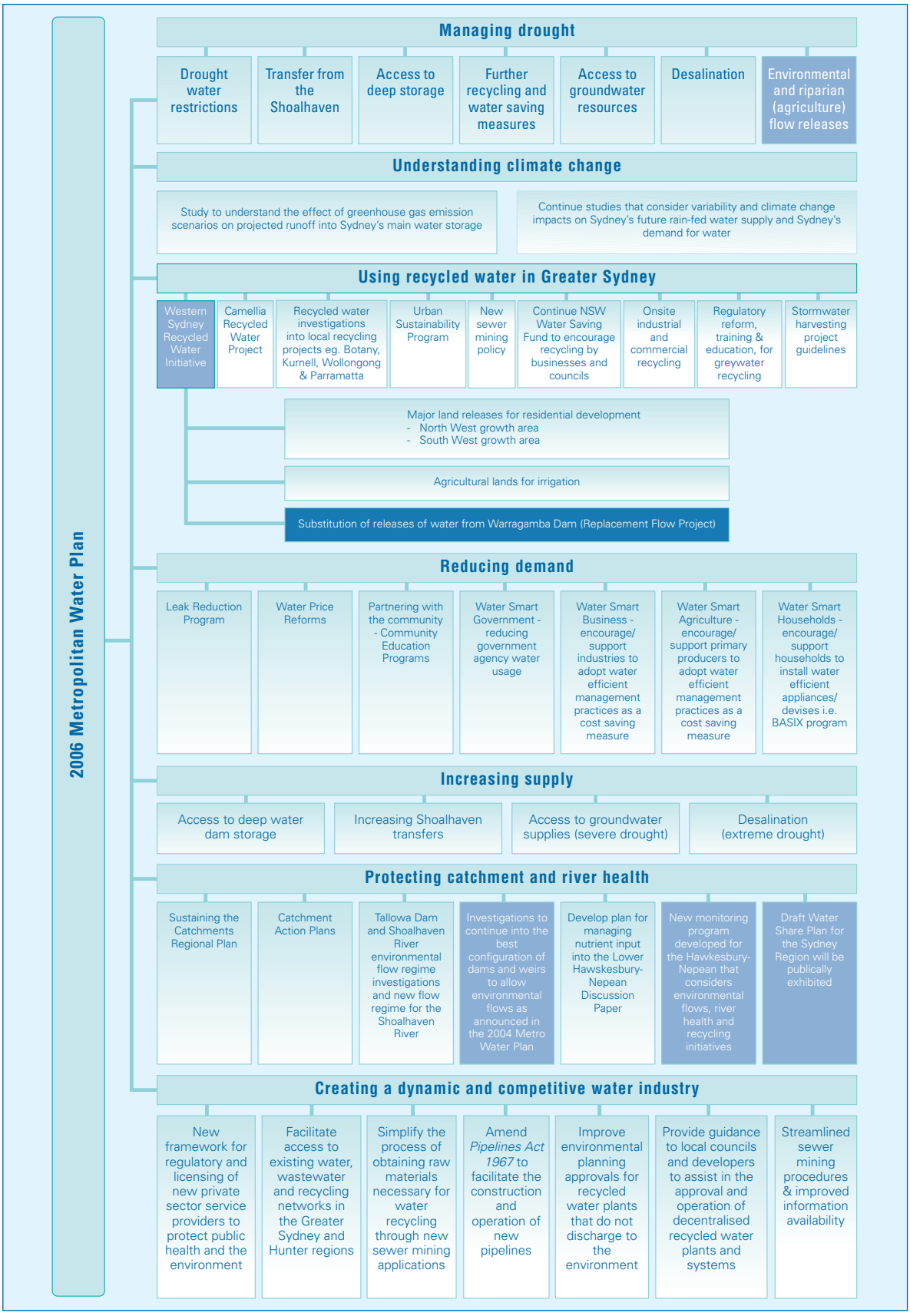
The overall elements of the plan are summarised in **Figure 2.1**. The key elements of the plan that are or will be put in place to quantify water savings, recycling and additional supply targets are shown in **Figure 2.2**. These are explained in **Table 2.1**, while **Table 2.2** lists other important actions that will take place as part of the *2006 Metropolitan Water Plan*.

2.1.2 Using recycled water in Sydney

Recycled water is a focus of the *2006 Metropolitan Water Plan*. The measures to deliver potential savings of up to 70 billion litres per year by 2015 by using recycled water are captured in 'Using recycled water in greater Sydney'. This includes a number of programs, including the Western Sydney Recycled Water Initiative.

When fit-for-purpose recycled water is used for non-potable uses, it reduces the demand on the drinking water system, thus boosting total water availability. Recycling can also deliver substantial river health benefits by reducing the load of nutrients discharged by sewage treatment plants (STPs). Recycled water is a non-rainfall-dependent supply option, so it can reduce the impact of future droughts by reducing demand pressures on rain-fed storages.

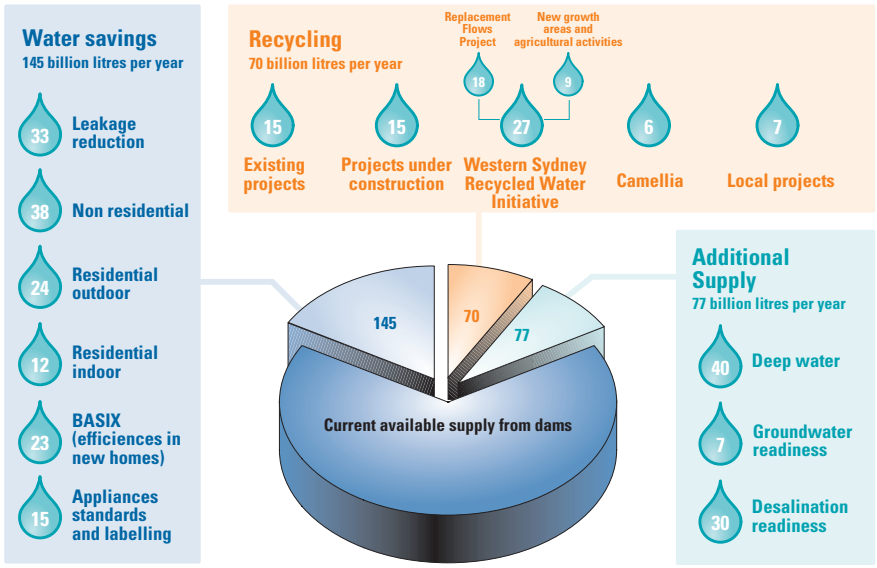
Figure 2.1 2006 Sydney Metropolitan Water Plan



Replacement Flows Project

Parts of the Metropolitan Water Plan linked to the Replacement Flows Project

Figure 2.2 Metropolitan Water Plan - water savings



The Western Sydney Recycled Water Initiative should make available an extra 27 billion litres of water a year by 2015

The objective of the Western Sydney Recycled Water Initiative is to maximise the beneficial use of recycled water for residential, industrial, agricultural and environmental purposes. The Initiative should make available an extra 27 billion litres of water a year by 2015. Large-scale water recycling will result in significant benefits if used in the new, large growth areas of western Sydney because:

- there are or will be significant markets for recycled water in Western Sydney including:
  - major land releases for residential development
  - agricultural lands for irrigation
  - substitution of releases of water from Warragamba Dam (the Replacement Flows Project)
- there are several large existing STP's that already produce high quality tertiary treated effluent. These would require limited additional treatment to be suitable for use as recycled water
- transportation costs and disruption are minimised
- effluent from western Sydney STPs needs to be recycled over the next 25 years, in order to reduce the discharges from the plants and to protect the Hawkesbury-Nepean River system.

The Western Sydney Recycled Water Initiative comprises two schemes that correspond to the main growth centres – the North West Growth Centre and the South West Growth Centre (refer to **Figure 2.3**).

The North West Growth Centre is the first area to receive recycled water as there are already several STPs in the region (shown in **Figure 2.3**) that produce tertiary treated effluent suitable for reuse. Future development plans for the South West Growth Centre are still being finalised and a south west recycling scheme is intended for implementation as development proceeds. The Replacement Flows Project, as it relates to the North West Growth Centre scheme, is the subject of this Environmental Assessment shown conceptually in **Figure 2.3**, and the detail of the Project is shown schematically in **Figure 3.2** in **Chapter 3**.

Table 2.1 Measures to meet Sydney's growth needs to 2015

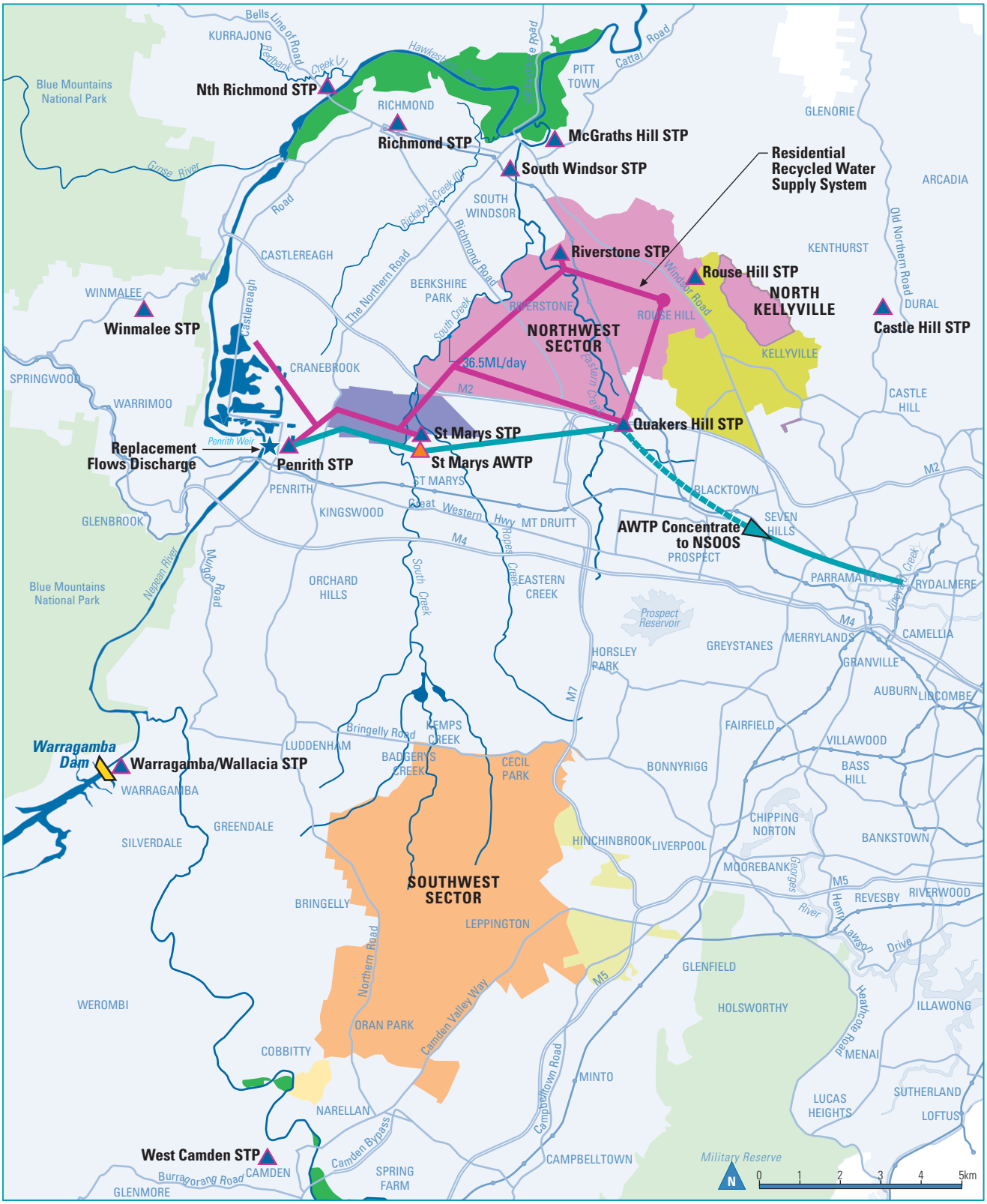
Action area	Additional water available (billion litres per year	Measure
Recycling	15	There are 14 existing recycled water schemes in greater Sydney that will continue to recycle 15 billion litres of wastewater a year
	15	There will be new schemes constructed and brought on line in the next few years that will double the current volume of recycled water
	27	**The Western Sydney Recycled Water Initiative (which includes the Replacement Flows Project) will recycle water for homes, agriculture and replace releases from Warragamba Dam saving up to 27 billion litres a year**
	16	The Camellia recycled water project will provide recycled water to industrial and open space users at Camellia (near Parramatta) saving up to 6 billion litres of water a year
	7	Local recycled water projects at Botany, Kurnell, Wollongong, Penrith and Quakers Hill will save up to 7 billion litres of water a year
Water savings	33	The continuation of Sydney Water's leakage reduction program will save 33 billion litres of water a year by 2015
	38	Combination of regulatory (Water Savings Action Plans), funding (Water Savings Fund) and cooperative partnerships (Every Drop Counts Business Program) and other smaller programs to work with organisations to reduce water use by 38 billion litres a year
	24	The residential outdoor programs (rainwater tank rebates, residential landscape assessment program) will achieve savings of 24 billion litres a year by 2015
	12	The residential indoor programs (waterfix, washing machine rebates) will achieve savings of 12 billion litres a year by 2015
	23	BASIX (the building sustainability index) will continue to generate savings from new houses and BASIX for alterations and additions will produce additional savings of 23 billion litres a year
	15	The Water Efficiency Labelling Scheme (WELS) and Smart Approved Water Mark Scheme will continue to generate savings in new appliances
Additional supply	40	Warragamba and Nepean Dams have been re-engineered to allow an extra 40 billion litres of drinking water to be taken from the existing storage every year
	7	Extracting groundwater from Kangaloon (near Upper Nepean) will boost average water availability by 7 billion litres per year. Any supplies from the Leonay borefield will be additional to this
	30	The capacity to deploy desalination boosts average water availability by between 30 and 70 billion litres a year

Table 2.2 Other key elements of the 2006 Metropolitan Water Plan

Key element	Actions required
Managing drought	Investigate groundwater resources and develop a new drought restrictions regime for when the current drought is over
Understanding climate change	Undertake studies to consider climate variability and climate change impacts on Sydney's future rain-fed water supply and Sydney's demand for water
Using recycled Water in greater Sydney	Provision of grants to councils for stormwater harvesting and other measures designed to save water and protect the environment Development of a Sewer Mining Policy Third party access to Sydney Water's wastewater network for recycled water projects Reform regulations for domestic greywater use
Reducing demand for water (Water savings)	Continue the Water Savings Fund Complete Water Savings Action Plans and implement them over the next four years Release the NABERS HOME Water rating tool Release new guidelines for reasonable use of river and groundwater by households Pilot leakage reduction in schools and implement further measures to improve government water efficiency Implement a program to increase awareness of the need for continued water saving efforts
Increasing supply (additional supply)	Publish investigations on all seven groundwater sites and consult communities about groundwater use and borefield construction Complete investigations and consult with the community about potential new Shoalhaven operating rules to increase transfers using existing infrastructure Purchase the design blueprint for a possible future desalination plant
Protecting catchment and river health	Implement the Sustaining the Catchments Regional Plan Implement catchment action plans through partnerships between Catchment Management Authorities, landholders, community groups and local and state government Continue investigations and consultation to determine a new regime of environmental flow releases from Tallowa Dam on the Shoalhaven River and decide on a new flow regime for the lower Shoalhaven River **Continue investigations into dam and weir configurations to allow the implementation of environmental flows announced in the 2004 Metropolitan Water Plan** Develop a new plan for managing nutrient inputs to the lower Hawkesbury-Nepean (specifically targeting wastewater, stormwater and agricultural run-off) **Finalise a monitoring program to assess the effectiveness of new environmental releases from Sydney Catchment Authority's dams** **Devise a new integrated monitoring program for the Hawkesbury-Nepean River system considering river health, environmental flows and recycling** **Complete the draft water sharing plan for Sydney**
Creating a dynamic and competitive water industry	Establish regulatory framework for increased competition and innovative service delivery in the water industry Introduce legislation to Parliament (following consultation) to establish a framework for the regulation and licensing of new private sector service providers and an access regime Amend environmental planning and assessment system to make approval of small recycling plants easier Implement new procedures for streamlined sewer mining applications.

Actions shown in bold text are important requirements for the Replacement Flows project

Figure 2.3 Western Sydney Recycled Water Initiative



Residential Recycling
- Former ADI Development
- Camden Greenfield Development
- Hoxton Park Development
- Northwest growth Sector
- Southwest growth Sector
- Rouse Hill Project Area
- Replacement Flows Discharge Point
- Residential Recycled Water Supply System
- Replacement Flows Project

Agricultural Recycling
- Agricultural land
- Sewage Treatment Plant (STP)
- Advanced Water Treatment Plant (AWTP)

General Features
- Major Roads
- Railway lines
- Rivers
- Lakes/Dams
- National Park or Reserve

2.1.3 Protecting catchment and river health

The Sydney Catchment Authority (SCA) is responsible, under the terms of its Water Management Licence, for releasing flows from dams into the rivers downstream. These (interim) flows are for environmental purposes and water extraction to meet basic landholder rights. There is also a requirement for the maintenance of diversion and compensation weirs in the middle Nepean and to ensure that a minimum flow of 50 ML/day is maintained over the Penrith Weir.

Schedule 4 of the Water Management Licence specifies the environmental releases to be made from each of the SCA's water management works (current releases are summarised in **Table 2.3**). Other water releases for riparian purposes are specified under schedule 5 of the Water Management Licence (currently 10ML/day for Warragamba).

In accordance with the licence, a temporary variation to the terms of the licence for a specified time period may be approved, upon application by the SCA. The SCA has utilised this provision during the current drought to negotiate reductions and suspensions of release requirements as a drought management measure to preserve water in the storages for the supply of drinking water. The current Warragamba Dam release has been reduced from 43.3 ML/day to 22 ML/day in response to current drought conditions.

The *2006 Metropolitan Water Plan* reiterates the commitment of the 2004 plan to increase the environmental flow releases from the Upper Nepean Storages (Avon, Cordeaux, Cataract, Nepean) and to reconfigure weirs to allow those flows to contribute to the maintenance of the river health upstream and downstream of Penrith Weir. These releases will be a portion of all flows entering these storages. Current estimates are that the first 68 ML/day of flow into the catchments will be released from the dams and through the upstream weirs in the Nepean River (refer to **Table 2.3**). The SCA is proceeding with the works to enable these discharges to occur by 2009.

The current releases from Warragamba Dam would effectively cease by 2009, in line with the replacement flows discharge at Penrith Weir and the increased flows from the Upper Nepean Dams. A final regime for environmental flow releases from Warragamba Dam will be formally set by 2015. Increases to interim environmental flows would, however, be considered from 2009, provided sufficient water is available. The 50 ML/day Replacement Flows Project will offset an equivalent portion of any future determination regarding environmental and riparian discharges from Warragamba Dam.

Table 2.3 Interim flow releases from the Hawkesbury-Nepean River dams

Site	Current Flows (ML/day)	2009 Flows (ML/day)
Warragamba Dam	43.3[1]	(43.3)[1]
Cataract Dam	1.3	Up to 16.5[2]
Cordeaux Dam	1.9	Up to12.6[2]
Avon Dam	0	Up to 10.4[2]
Nepean Dam	4.4	Up to 28.5[2]

1 This is the flow release during non-drought conditions. The current drought conditions discharge from Warragamba Dam is about 22 ML/day. The discharge from Warragamba Dam would cease if the Replacement Flows Project were implemented

2 Flows from the Upper Nepean Dams are subject to rainfall but should provide a base level of 68 ML/day. Flows up to this volume (transparent flows) will be allowed to pass. For flows above this volume (translucent flows) the total flow released would be 20% of the flow as long as the 20% is above the base value shown.

2.1.4 Outcomes of the Replacement Flows Project in the context of the Metropolitan Water Plan

The outcomes for the Project and Upper Nepean dam releases are forecast to be:

- in normal (non drought) conditions, same or greater flows in all stretches of the Hawkesbury-Nepean River upstream of the South Creek confluence
- in normal (non drought) conditions, an increase in the proportion of catchment derived flows throughout the Hawkesbury-Nepean river system
- significant reductions in nutrient loads discharged to the Nepean River at Penrith due to the AWTP
- significant reductions in the nutrient loads discharged into South Creek due to reduced flows into the creek from St Marys and Quakers Hill STPs.

The Project, in combination with other planned river management changes, would ensure that the substitution of Warragamba Dam releases would deliver an equivalent or higher level of environmental benefit to the river, while maintaining water for drinking (North Richmond Water Filtration Plant), agricultural and recreational purposes and for aquatic life. It is an essential component of the NSW Government's plan for securing Sydney's water needs over the next 25 years.

2.1.5 Sydney Water's water management projects under the Metropolitan Water Plan

The *2006 Metropolitan Water Plan* encapsulates existing Sydney Water projects as well as identifying new initiatives such as the Replacement Flows Project. Sydney Water is currently planning for a number of recycling projects including Appin STP and recycled water proposal, Camellia recycled water scheme and the local recycled water projects for areas such as Penrith, Quakers Hill, Botany and Wollongong.

There are also schemes under construction such as the West Camden STP upgrade, amplification and reuse scheme (refer to **Section 2.2.2** for more details), Hoxton Park recycled water scheme and Ropes Crossing (former ADI site) recycled water scheme. The *2006 Metropolitan Water Plan* identifies 14 recycled water schemes across Sydney that currently reuse 15 billion litres of water. Of these schemes, Sydney Water has implemented the following:

- Rouse Hill recycled water area
- North Head STP recycled water plant
- Aorangi Farm, which takes effluent from the Gerringong STP
- Carlton Farm at Picton STP
- On-site reuse at all STPs
- Reuse of effluent for irrigation at Dunheved, Castle Hill, Liverpool, Richmond, Kiama and Ashlar golf courses.

In addition, Sydney Water has implemented supply to BlueScope Steel from the Wollongong Recycled Water Plant.

Broader plans such as the draft Water Sharing Plan for the Sydney Region can have important implications for projects like the Replacement Flows Project.

Demand management is also a significant component of Sydney Water's activities and there are many initiatives currently in place. These include the Every Drop Counts Business Program, WaterFix for residential installation of water saving devices and leak checks, washing machine and rainwater tank rebates.

In terms of water supply, the active leak reduction program is Sydney Water's major campaign to reduce water loss from leaking pipes. This program aims to detect and repair hidden leaks along Sydney Water's 21,000 kilometres of water pipelines and the equally vast network of pipes from water main to meter pipes (owned by customers).

2.2 Other Hawkesbury-Nepean water management plans and strategies[1]

1 Any Sydney Water projects or strategies that are referred to in this section, such as the South Creek Servicing Strategy, are not part of this Environmental Assessment. They are, however, important components in the implementation of the Replacement Flows Project. Where relevant, they are subject to separate environmental impact assessment.

Sydney Water actively plans for sustainable water resource management and in doing so undertakes projects to implement key NSW Government and Sydney Water corporate strategies and plans.

Specific strategies such as those recommended by the *Healthy Rivers Commission Inquiry into the Hawkesbury-Nepean River 1998* provide Sydney Water with direction on water management priorities. They also ensure that Sydney Water's initiatives are supported by a consistent catchment wide approach to water management.

Broader plans such as the draft Water Sharing Plan for the Sydney Region can have important implications for projects like the Replacement Flows Project. The actions in these plans can assist, amend and amplify the outcomes of Sydney Water strategies and plans, so careful consideration of these effects is essential.

The strategies and plans that provide direction and closely interact with the Replacement Flows Project are discussed below.

2.2.1 Healthy Rivers Commission and Statement of Joint Intent

The Healthy Rivers Commission was established in 1995 by the NSW Government, with the express purpose of making recommendations to Government on:

- suitable objectives for water quality, flows and other goals central to achieving ecologically sustainable development in a realistic time frame
- the known or likely views of stakeholder groups on the recommended objectives
- the economic and environmental consequences of the recommended objectives
- strategies, instruments and changes in management practices needed to implement the recommended objectives.

The Hawkesbury-Nepean River system was one of six catchments that were the subject of the Commission's inquiry. The outcome of the inquiry was a set of recommendations for future river health management in each catchment (Healthy Rivers Commission, 1998).

The NSW Government endorsed and modified some of the recommendations. These endorsed and modified recommendations for the Hawkesbury-Nepean River were captured in the Statement of Joint Intent for the Hawkesbury-Nepean River system. Sydney Water is one of

the 12 NSW Government agencies and 26 Local Government authorities bound by the Statement of Joint Intent to implement the endorsed recommendations.

The Statement of Joint Intent included specific recommendations regarding the use of highly treated effluent, such as that produced by Sydney Water's STPs in north western Sydney, for river flows. The recommendations included evaluating the use of this tertiary treated effluent to "offset the potential impact of requiring additional releases from Warragamba Dam for environmental flow purposes". An integrated approach to the management of water quality and river flows was also recommended, including provision to use effluent "in the make-up of environmental flows, subject to satisfying water quality safeguards and discharging the effluent in a variable pattern at an appropriate location."

The implementation of the Replacement Flows Project, although not providing for variable flows, would satisfy the recommendations about highly treated effluent use for environmental flows in the Statement of Joint Intent. The Project is also consistent with the other strategies and objectives identified in the Statement of Joint Intent for the improved management of the Hawkesbury-Nepean River system.

2.2.2 Sydney Water's Hawkesbury-Nepean Wastewater Strategy

The Hawkesbury-Nepean Wastewater Strategy identifies options for reducing the impact of wastewater discharges on river quality, while at the same time providing wastewater services to an increasing population in the catchment

The Hawkesbury-Nepean Wastewater Strategy identifies options for reducing the impact of wastewater discharges on river quality, while at the same time providing wastewater services to an increasing population in the catchment. The strategy will also meet the water needs of the Hawkesbury-Nepean River by integrating wastewater management into the total water balance for the system.

Over the last 10 years the Hawkesbury-Nepean Wastewater Strategy has resulted in upgrades to nutrient removal processes at the Sydney Water STPs that discharge into the Hawkesbury-Nepean system. These upgrades have resulted in significant reductions in the total phosphorus and nitrogen being discharged, with Sydney Water's STPs upstream from Sackville having reduced these loads by 93 per cent and 54 per cent respectively (SWC 2005).

Currently, improvements associated with the strategy are occurring at West Camden STP to cater for growth and reduce the nutrient loads discharged to the Nepean River. Tertiary treated effluent from the West Camden STP will be diverted to irrigate agricultural and recreational areas, while the remainder will maintain a base flow in the Hawkesbury-Nepean River system.

Although it is not specifically included in the Hawkesbury-Nepean Wastewater Strategy the Replacement Flows Project is consistent with the aims of the strategy. It would further reduce the nutrient loads contributed to the river by Sydney Water's STPs and provide water for downstream water users in drought periods.

2.2.3 Other Sydney Water wastewater initiatives in the Hawkesbury Nepean Catchment

The provision of wastewater services to unsewered areas in the Hawkesbury-Nepean catchment helps to reduce nutrient load contributions to the river. The Mulgoa, Wallacia and Silverdale Sewerage Scheme was approved in September 2004, and commenced operation in August 2006.

The scheme involves the provision of a reticulated sewerage system to over 1000 unsewered properties in the three townships. It also involved the construction of a new STP plant at Wallacia and the decommissioning of the plant located at Warragamba. The new STP will significantly improve the quality of effluent discharged to Warragamba River.

The collection and transfer of wastewater from Mulgoa, Wallacia and Silverdale to the new Wallacia STP will protect the environment and reduce associated health problems from untreated sewage entering the waterways from the on-site systems and improve the quality of life for residents in these areas.

2.2.4 Sydney Metropolitan Strategy and Sydney Water's South Creek Servicing Strategy

The recycled water for the growth centres would be supplied from the same STPs that would be connected by pipelines as part of the Project (St Marys, Quakers Hill and Penrith)

The NSW Government's Metropolitan Strategy *City of Cities: A Plan for Sydney's Future* includes the development of infrastructure in the proposed growth centres of north western and south western Sydney. The north west areas include Riverstone (including Vineyard), Riverstone East, Schofields /Nirimba (including Alex Avenue), Marsden Park, Box Hill, and North Kellyville.

State Environmental Planning Policy (SEPP) (Sydney Region Growth Centres) 2006, reflects the intention of the *2006 Metropolitan Water Strategy* and requires all new developments to be provided with water for non-drinking uses from a water recycling plant in areas that are serviced or will be serviced by a recycled water plant. This requirement will assist in meeting water quality objectives for South Creek and reducing the demand for drinking water.

The North West Growth Centre will be supplied with recycled water from the existing Sydney Water STPs in the area. The recycled water from these STPs needs to be shared amongst the markets identified in the Western Sydney Recycled Water Initiative – residential development, substitution for Warragamba releases and for agricultural irrigation. The proposed residential development in the North West Growth Centre will provide a significant proportion of the demand for recycled water.

The recycled water for the growth centres would be supplied from the same STPs that would be connected by pipelines as part of the Project (St Marys, Quakers Hill and Penrith). In addition, Riverstone STP will be upgraded and amplified to receive and treat sewage from the North West Growth Centre and will also supply recycled water to the growth centre (shown in **Figure 2-3**). Rouse Hill STP will continue to supply recycled water to its current catchment and will also supply recycled water to the North Kellyville growth area.

In response to the Sydney Region Growth Centres SEPP, Sydney Water is developing the South Creek Servicing Strategy to provide drinking water, recycled water and wastewater services to growth areas. The purpose of the strategy is to service growth in a cost effective and sustainable way in the South Creek catchment (which encompasses both the North West and South West Growth Centres) and to:

- ensure that water is available for existing and future demands and users
- protect the South Creek and Hawkesbury-Nepean River
- identify and manage key risks to the services provided, infrastructure and the environment
- be acceptable to key stakeholders.

The provision of recycled water for non-drinking uses via dual reticulation to residential areas in the growth centres has been adopted as a mandatory requirement for the servicing strategy (in response to the SEPP and *2006 Metropolitan Water Plan)*.

Residential recycled water use in the growth centres and existing users are considered to be the first priority for allocation of recycled water. Based on current population projections for the North West Growth Centre, there is and will continue to be sufficient treated effluent produced at St Marys, Quakers Hill and Penrith STPs to satisfy all current and future recycled water demands, including the Replacement Flows Project.

Supplying recycled water to residential growth centres through the South Creek Servicing Strategy, in conjunction with the Project, will contribute significantly to attaining the objectives of the Western Sydney Recycled Water Initiative.

2.2.5 Water Sharing Plan for the Sydney region

The *2006 Metropolitan Water Plan* commits to the completion of the draft Water Sharing Plan for the Sydney region.

Under the *Water Management Act 2000*, the Department of Natural Resources is preparing water management plans covering aspects such as water sharing, water use, drainage management and floodplain management. The current focus has been on developing water sharing plans in order to protect water for the environment, while also securing the rights of water users, such as towns, farmers, industry and irrigators. The plans are prepared for water management areas declared by the Minister for Natural Resources.

The current focus has been on developing water sharing plans in order to protect water for the environment, while also securing the rights of water users, such as towns, farmers, industry and irrigators.

The Water Sharing Plan for the Sydney region is currently in draft and will be released for public comment in mid 2007. The objectives of the plan include providing for the principal water supply for the people of Sydney, the Illawarra, the Shoalhaven, Southern Highlands, Blue Mountains and Central Coast and contributing to the sustainable and integrated management of the water cycle across the greater metropolitan region.

The Water Sharing Plan for the Sydney region is likely to include requirements with the potential to affect the Replacement Flows Project. Those requirements would:

- define the releases of environmental water from dams and weirs
- define maximum extraction limits for individual licences in one year, averaged over several years
- define an overall long-term extraction limit for each river (including the Hawkesbury-Nepean River)
- define a very low flow level below which irrigation extraction would not be allowed ('cease-to-pump' rules)
- define daily flow sharing which would limit the amount of water each licensee could extract on a given day (to protect local stream environments that could be compromised by a spike in extractions)
- establish reasonable use guidelines for river water and groundwater use
- allow licensees to nominate that water allowed for extraction under their licences be reserved as environmental water for river health benefit from time to time or for long periods of time
- ensure a regulatory regime to allow replacement flows to be recognised and discharged as a replacement for the current Warragamba Dam releases.

The requirements that may be outlined in the Water Sharing Plan for the Sydney region would affect the volume of water that would be present in different reaches of the Hawkesbury-Nepean River at any one time. The Water Sharing Plan for the Sydney region would have an effect on the Replacement Flows Project through the release of water from the Upper Nepean Dams, leading to additional flows to the upper sections of the river and the areas above Penrith Weir.

The Project would add flows below Penrith Weir and in this way, with the Water Sharing Plan, would coordinate in providing flows to maintain the health of the river system. In addition, the limitations on extractions would ensure that a suitable proportion of the flows contributed by releases from the dams and the Project are retained as environmental water.

The Project would therefore operate in conjunction with the Water Sharing Plan for the Sydney region. The predicted outcomes of these together are:

- greater flows (on average) in the Hawkesbury-Nepean River upstream of the junction with South Creek
- a significant reduction in nutrient loads discharged into the Nepean River at Penrith
- a significant reduction in nutrient loads discharged into South and Eastern Creeks
- up to 18 billion litres of drinking water conserved each year.

The Replacement Flows Project would be consistent with the objectives of the Water Sharing Plan for the Sydney region, particularly in providing water supplies and integrated water cycle management. The implications of the Water Sharing Plan for the Sydney region have been incorporated into the Replacement Flows Project by adopting its likely requirements as underlying assumptions in the Project.



3 Description of the project

This chapter describes the Replacement Flows Project (the Project) for which Project Approval is being sought. The description provides an outline of the Advanced Water Treatment Plant (AWTP) at St Marys Sewage Treatment Plant (STP), the alignment of the pipelines connecting Quakers Hill STP, St Marys STP and Penrith STP and the concentrate pipeline connecting to the Northern Suburbs Ocean Outfall Sewer (NSOOS). Infrastructure required at each site is also described, along with construction and operational procedures for the Project.

3.1 Overview

The Replacement Flows Project is part of a water management system that would increase the amount of drinking water available from Warragamba Dam.

The Replacement Flows Project is part of a water management system that would increase the amount of drinking water available from Warragamba Dam. The Project would include treating tertiary effluent from the St Marys, Penrith and Quakers Hill STPs in north western Sydney at an AWTP located at the St Marys STP. The AWTP would produce up to 50 million litres a day (ML/day) of highly treated recycled water for discharge downstream of Penrith Weir. This would be substituted, as replacement flows, for water that is currently released from Warragamba Dam for extraction and river health purposes. The volume of tertiary treated effluent discharged directly from Penrith STP would be minimised, and the volume of tertiary treated effluent discharged from St Marys and Quakers Hill STPs would be sufficient to provide for the downstream water users in South Creek.

3.2 Development area

The Project lies within Penrith, Blacktown, Baulkham Hills and Parramatta local government areas.

3.2.1 Land use

The existing land uses in the area around the Sydney Water STP sites associated with the Project are shown in **Figure 3.1**. Predominant land uses in these areas include residential, industrial, recreational open space and public infrastructure.

Figure 3.1 Land use adjacent to STPs



Quakers Hill STP has residential development to the north and south, community open space to the east and a drainage easement to the west.

St Marys STP is located within an industrial area. The former Australian Defence Industry (ADI) site is located to the north and west of the STP.

The Penrith STP site is located within a general industrial area. A public recreation area and low density residential development is located to the east, commercial development is located to the south, open space recreation and low density residential development to the north and rural land to the west.

The proposed pipeline routes are discussed in detail in **Section 3.5**. Generally, the land use between Quakers Hill STP and St Marys STP includes the Westlink M7 Motorway, the Castlereagh Freeway reserve and existing residential development to the south of the proposed pipelines. The pipelines also pass through parkland and along local road easements.

Between St Marys STP and Penrith STP the proposed pipelines extend along the southern property boundary of the former ADI site (including proposed regional parkland and residential zones), immediately north of existing residential development and along road easements adjacent to residential development.

The concentrate pipeline east of Quakers Hill STP is located in parklands, adjacent to and under railway lands, and in road reserves through suburban areas.

An assessment of potential land use impacts is provided in **Chapter 8**.

3.2.2 Tenure

Land ownership details are provided in **Appendix A** for all land potentially affected by the proposed development. Most of the potentially affected land is owned by:

- Sydney Water
- Blacktown City Council
- Penrith City Council
- Parramatta City Council
- Baulkham Hills Shire Council
- the Minister administering the *Environmental Planning and Assessment Act 1979* (currently Minister for Planning)
- the Roads and Traffic Authority
- the Housing Commission of NSW (Department of Housing)
- St Marys Land Limited.

Easements for the pipelines across these lands would be acquired, as necessary.

3.3 Elements of the Project

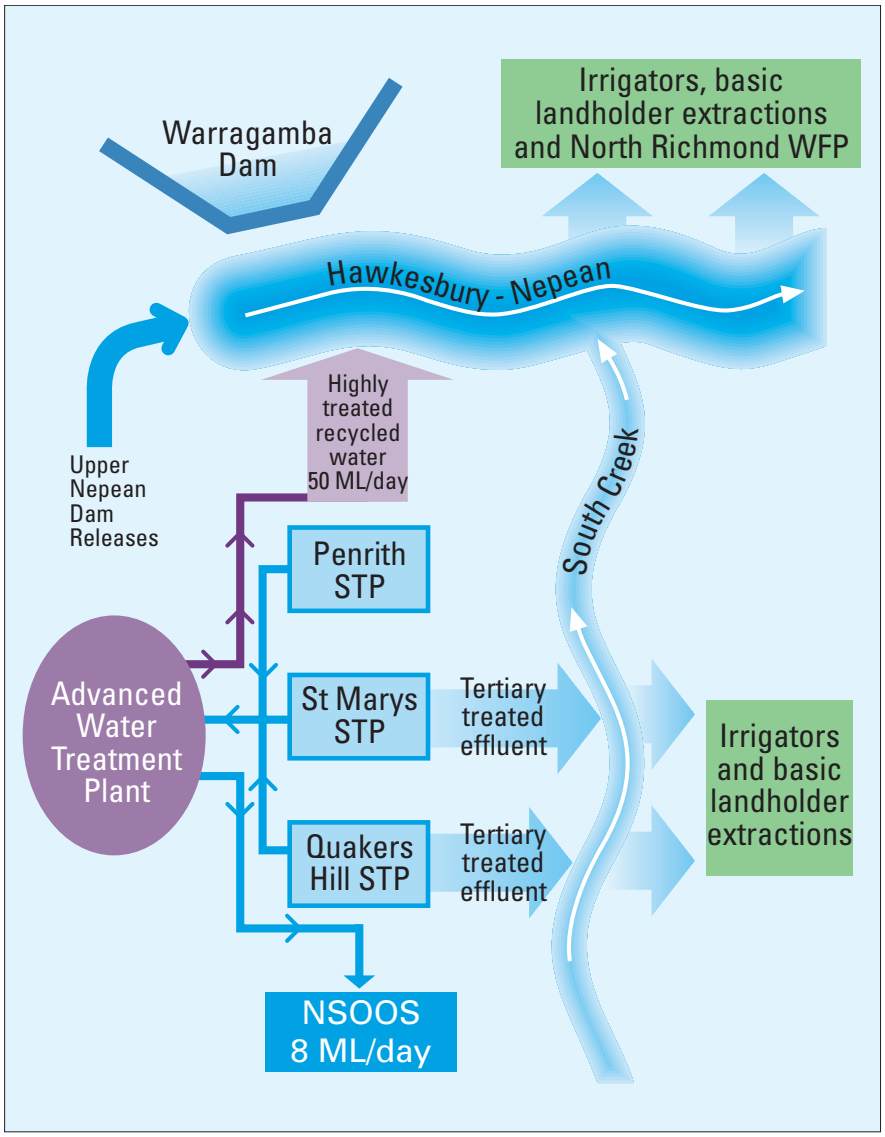
The Project consists of:

- an AWTP at the St Marys STP site for the treatment of the tertiary treated effluent from Quakers Hill STP, Penrith STP and St Marys STP. The AWTP would produce up to 50 ML/day of highly treated recycled water for discharge to the Hawkesbury-Nepean River downstream of Penrith Weir, and about 8 ML/day of a concentrate for discharge to the Northern Suburbs Ocean Outfall Sewer (NSOOS)
- a pipeline for the transfer of tertiary treated effluent from Penrith STP to the AWTP at the St Marys STP site
- a pipeline for the transfer of tertiary treated effluent from Quakers Hill STP to the AWTP at the St Marys STP site
- a pipeline for the transfer of recycled water produced by the AWTP at St Marys STP to the Penrith STP
- discharge of the replacement flows to the Hawkesbury-Nepean River, via the Penrith STP discharge to Boundary Creek, immediately downstream of Penrith Weir
- a pipeline for the transfer of the concentrate from the AWTP to Quakers Hill STP
- a storage pond at Quakers Hill STP for the temporary storage of the concentrate, when the NSOOS may not be available for discharge (during periods of extended wet weather)
- transfer of the concentrate to the NSOOS via an existing pipeline from Quakers Hill STP to Seven Hills and a new pipeline between Seven Hills and Vineyard Creek at Dundas
- balance storages and pumping stations at Penrith, Quakers Hill and St Marys STPs.

A new pumping station may also be required at International Peace Park at Seven Hills where the existing pipeline would join the new pipeline. Some upgrade works may also be required to the existing pipeline.

The Project is shown schematically in **Figure 3.2**, and described in detail in **Section 3.4**.

Figure 3.2 Replacement flows project during normal operations



3.4 Advanced Water Treatment Plant

The AWTP would produce about 50 ML/day of highly treated recycled water.

The AWTP would produce about 50 ML/day of highly treated recycled water. To produce 50 ML/day, about 65 ML/day of tertiary treated effluent would be required from the three STPs. This would also result in the production of about 8 ML/day of concentrate and 7 ML/day of backwash water from the pre-treatment works. The AWTP would require an area of approximately four hectares within the perimeter of St Marys STP, as generally shown on **Figure 3.3a,b,c,d**.

The recycled water treatment process is shown in **Figure 3.4** and is likely to comprise:

- Pre-treatment
  - mechanical strainer
  - ultrafiltration or microfiltration
  - chemical dosing systems
- Main treatment
  - single pass, two stage reverse osmosis process for product water
  - single stage reverse osmosis process for concentrate volume reduction
- Post Treatment
  - pH adjustment
  - breakpoint chlorination
  - dechlorination
- Ancillary facilities
  - chemical dosing system
  - membrane cleaning modules
  - power supply, laboratory, administration buildings and other site developments.

Figure 3.3a St Marys AWTP site

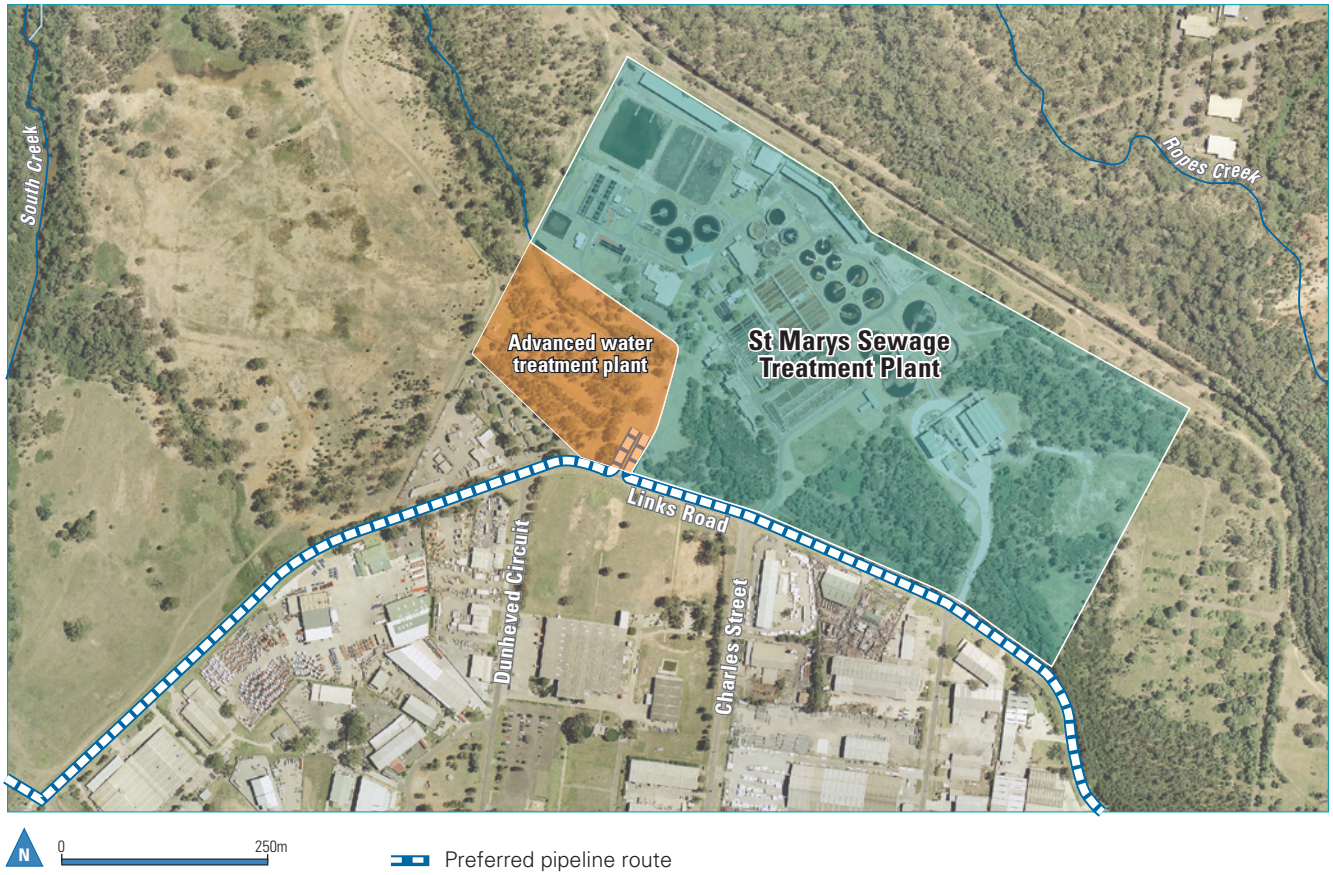


Figure 3.3b Layout of St Marys AWTP site



Figure 3.3c Artists impression of AWTP

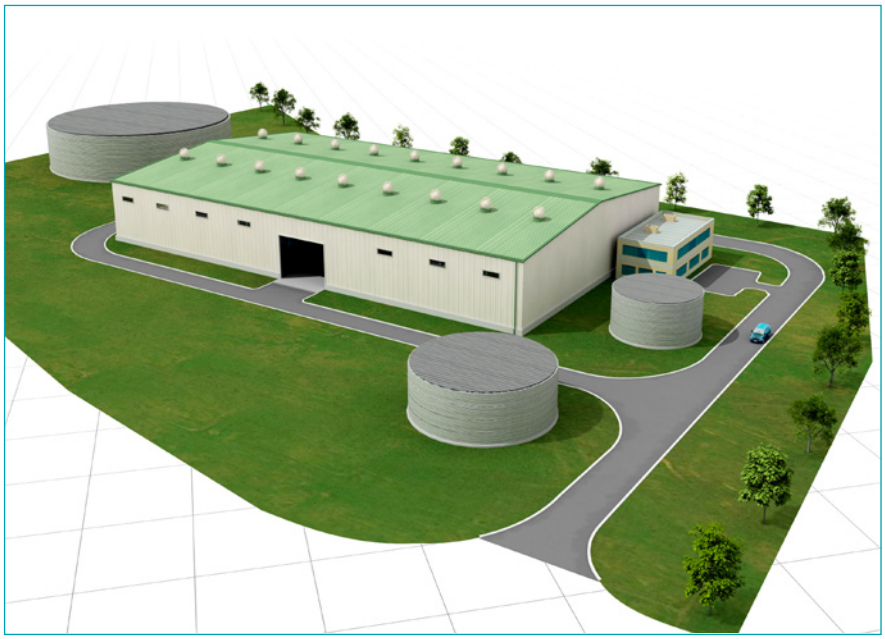


Figure 3.3d Artists impression of AWTP showing internal layout

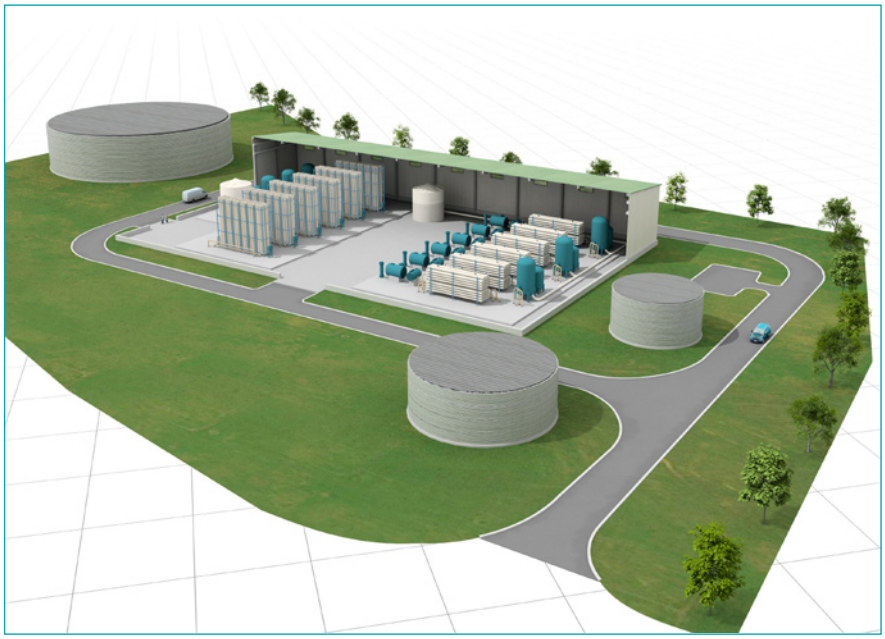
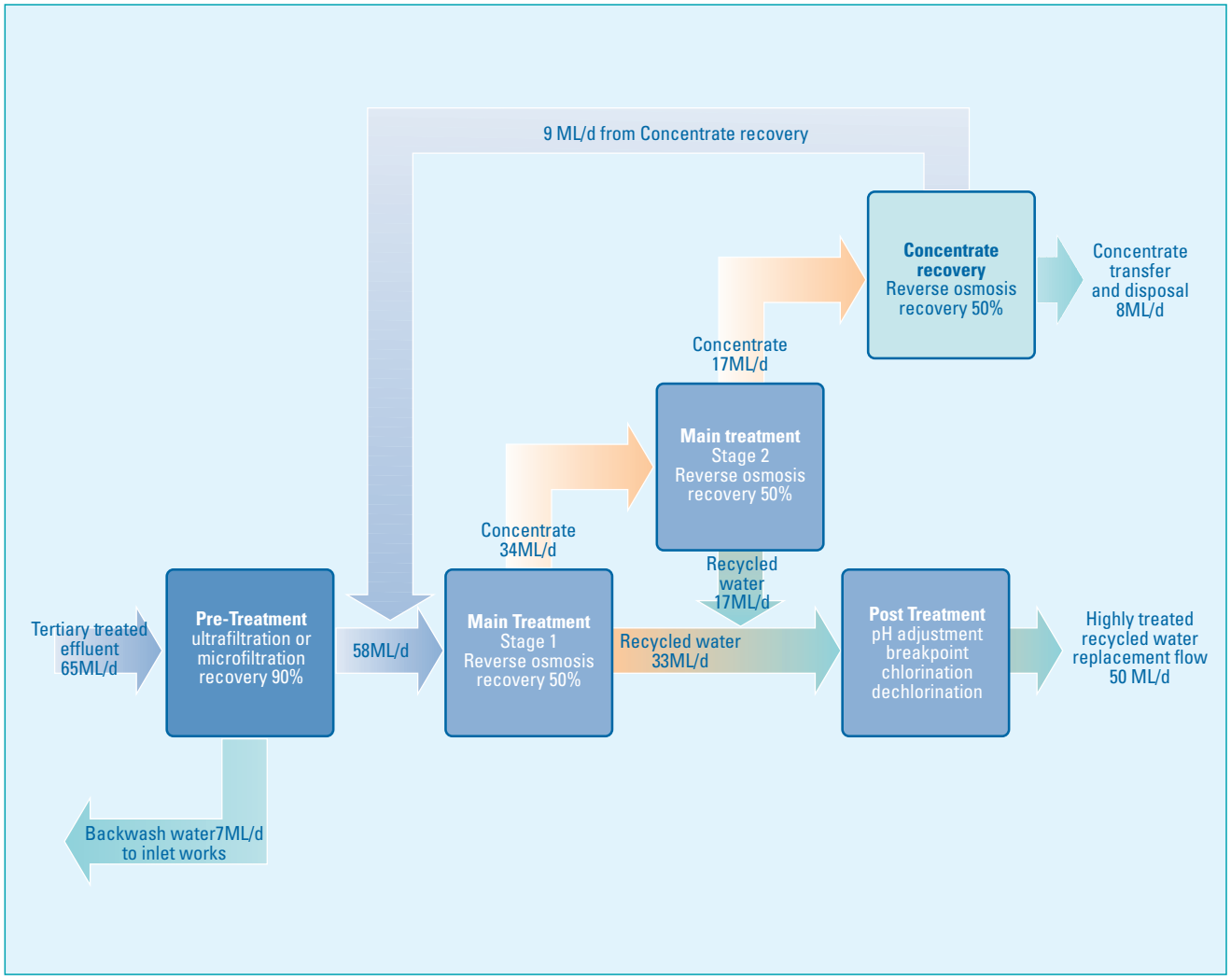


Figure 3.4 Water treatment process and flow balance



3.4.1 Pre-treatment process

Pre-treatment of the tertiary treated effluent (or feed water) is required to remove suspended solids and to condition the water to prevent fouling of the membranes. The tertiary treated effluent would pass through a mechanical strainer, followed by ultrafiltration or microfiltration. Microfiltration can remove suspended solids as small as 0.05 micromillimetres (microns), while ultrafiltration can remove suspended solids as small as 0.01 microns.

Once suspended solids have been removed from the feed water, the water would be dosed with chemicals. Sodium hypochlorite and ammonia would be added to the feed water to form chloramine, which controls biological growth and prevents membrane fouling. Anti-scalents (e.g. sodium hexametaphosphate, organophosphonate or polyacrylates) and/or mineral acids would also be added to prevent mineral deposits (or scaling) of the reverse osmosis membranes. Anti-scalents suspend the minerals (e.g. calcium and silicate) in the water while it is passed through the membranes, preventing the deposition and hardening of these minerals within the membranes.

Approximately 65 ML of tertiary treated effluent from Penrith, St Marys and Quakers Hill STPs would pass through the pre-treatment process each day. Of the 65 ML, about 7 ML containing suspended solids concentrated by the pre-treatment process would be generated and returned to the inlet of St Marys STP for further treatment (refer to **Figure 3.4**). The remaining 58 ML would continue to the main treatment process.

3.4.2 Main treatment process

Osmosis is the diffusion or movement of water from an area of high water concentration to an area of low water concentration, across a semi-permeable membrane

Reverse osmosis has been identified as the preferred technology to achieve the project objectives identified in Chapter 1. Alternative technologies considered are discussed in **Chapter 4**.

Osmosis is the diffusion or movement of water from an area of high water concentration to an area of low water concentration, across a semi-permeable membrane, in order for the system to reach equilibrium (that is for the concentration on both sides of the membrane to be the same).

In reverse osmosis the natural osmotic forces are overcome or reversed by applying an external pressure to the concentrated solution, thus the flow of water is reversed.

The proposed reverse osmosis system would consist of a single pass, two-stage recovery process for recycled water and a one stage recovery process for the concentrate stream. In a single pass system the water fed into the process passes through the reverse osmosis process once, prior to post treatment and discharge (stage 1). The remaining water which does not pass through the reverse osmosis membrane is then passed through a second reverse osmosis process (stage 2) to improve the recovery rate and further concentrate the waste stream. This process is then repeated to further reduce the volume of the concentrate prior to its disposal. The proposed treatment process is shown conceptually in **Figure 3.4**.

In reverse osmosis the natural osmotic forces are overcome or reversed by applying an external pressure to the concentrated solution, thus the flow of water is reversed.

About 67 ML/day, made up of 58 ML/day of pretreated tertiary effluent and 9 ML/day of recovered concentrate, would pass through the reverse osmosis process each day. The process would produce about 50 ML/day of permeate (recycled water) and generate about 8 ML/day of concentrate for transfer to the NSOOS. The estimated recovery rate of the reverse osmosis process would be approximately 85 per cent (ie for 1000 litres of filtered tertiary treated effluent as feed water, 850 litres of recycled water and 150 litres of concentrate would be produced).

The recycled water would be extremely low in salt and impurities, whilst the concentrate would be have a salinity of 3,000 to 4,000 parts per thousand.

3.4.3 Post-treatment process

Post-treatment is likely to involve pH correction, breakpoint chlorination and dechlorination. Following the reverse osmosis process, the recycled water is typically acidic, with a pH of about five.

An increase in pH is required to reduce the corrosiveness of the recycled water. Carbon dioxide stripping (or a similar process which increases the pH from about five to seven) would be used.

Breakpoint chlorination (the addition of hypochlorite solution to the recycled water) would be applied to remove residual ammonia that remains after passing through the reverse osmosis membranes. Recycled water would be treated with sodium metabisulphate to remove any residual chlorine (dechlorination).

Following completion of the post treatment process, the highly treated recycled water would be suitable for release into the Hawkesbury-Nepean River as replacement flows.

Following completion of the post treatment process, the highly treated recycled water would be suitable for release into the Hawkesbury-Nepean River as replacement flows.

3.4.4 Buildings and physical infrastructure

The AWTP would generally be housed inside a single building (of approximately 10 metres internal height), with some external ancillary infrastructure (as shown in **Figure 3.3b**). The building would contain:

- ultrafiltration/microfiltration modules and filtrate tank
- reverse osmosis pumps
- reverse osmosis skids (bank of tubes that hold the membranes)
- chemical "clean in place" systems
- temporary water storage tanks.

The building would also contain a switch room, control room, administrative offices, training facilities, amenities, laboratory, store and a maintenance workshop.

The external infrastructure may include:

- a tank to store incoming tertiary treated effluent flows from the STPs
- a tank to hold recycled water prior to pumping to Penrith
- a tank to store concentrate prior to pumping to the NSOOS
- an ultrafiltration/microfiltration backwash water tank
- a bulk chemical storage area
- a reverse osmosis balance tank
- post treatment facilities, including a breakpoint chlorination tank
- high voltage transformers and access roads.

The AWTP would typically be operational for 24 hours a day, seven days a week, except for periodic maintenance activities and possible shutdown during emergencies or prolonged wet weather (refer to **Section 3.7**).

3.5 Pipelines

Pipelines would be required for the transfer of the tertiary treated effluent from the three STPs to the AWTP, the transfer of recycled water to Penrith STP and the transfer of the concentrate from the AWTP to Quakers Hill STP and then to the NSOOS at Vineyards Creek, Dundas. Where practicable, the pipelines could be co-located in a common trench. Where space is available separate trenches may be provided.

The length and depth of boring will be determined at detailed design stage. The need to avoid waterways, areas of vegetation and other sensitive areas is discussed in **Chapter 8**.

3.5.1 Effluent transfer pipelines

Two effluent transfer pipelines would be constructed as part of the Project. One pipeline would be constructed between Penrith STP and St Marys STP for the transfer of tertiary treated effluent from Penrith STP to the AWTP at St Marys STP. The other pipeline would be constructed between Quakers Hill STP and St Marys STP for the transfer of tertiary treated effluent from Quakers Hill STP to the AWTP at St Marys STP. Both pipelines would be 500 millimetre (mm) diameter and constructed below ground. An internal pipe system would transfer tertiary treated effluent from the St Marys STP to the AWTP.

The proposed routes for the effluent transfer pipelines are shown on **Figure 3.5a,b** and in more detail in **Appendix A**. The Penrith to St Marys pipeline is approximately 8 kilometres (km). The pipeline would leave the Penrith STP site along the northern boundary of Hickeys Park and pass in a north easterly direction through the Nepean Rugby Union Oval before following Andrews Road to the east and turning north onto The Northern Road. The pipeline would extend approximately 300 metres (m) along The Northern Road before turning east and travelling along a bushfire protection zone adjacent to the northern extent of existing residential development of Cambridge Gardens, Werrington Downs and Werrington County. The pipeline would then follow an existing sewer pipe alignment to the north of Dunheved Golf Course, before joining Links Road and entering the St Marys STP site.

The Quakers Hill to St Marys effluent transfer pipeline would be approximately 12 km. The pipeline would leave the Quakers Hill STP site, then pass under Quakers Hill Parkway and travel west to Oakhurst, between the Westlink M7 Motorway and existing residential development. At Oakhurst, the pipeline would then extend under the Westlink M7 Motorway and continue adjacent to the northern extent of existing residential developments of Hassall Grove, Bidwill and Shalvey. The pipeline would then turn to the south west, passing through Peter Van Hasselt Park, before joining and following Forresters Road to Links Road and on to the St Marys STP.

The effluent pipelines would be designed to minimise maintenance and access requirements. A number of small underground access chambers and surface access covers would be required. Routine inspections would focus on assessing the condition of the pipeline and periodic cleaning of the pipeline may be required.

Figure 3.5a Pipeline route - Penrith to St Marys





Figure 3.5b Pipeline route - St Marys to Quakers Hill

3.5.2 Concentrate pipeline

A 375 mm diameter pipeline for the transfer of concentrate from the AWTP to Quakers Hill STP, would be constructed below ground, adjacent to the effluent transfer pipeline between St Marys and Quakers Hill STPs.

A new pump station at Quakers Hill STP would pump the concentrate about seven km to Seven Hills via an existing 300 mm diameter pipeline. A new 12 km section of 375 mm diameter sub-surface pipeline would then be constructed to transfer the concentrate from the existing pipeline to the NSOOS at Vineyard Creek (refer to **Figure 3.6a,b**). The alignment is shown in detail in **Appendix A**.

No modifications of the NSOOS system would be required as part of this project, other than at the point of connection between the concentrate pipeline and the NSOOS.

3.5.3 Recycled water pipeline

A recycled water pipeline would be constructed below ground between St Marys STP and Penrith STP, adjacent to the effluent pipeline (refer to **Section 3.5.1**), for the transfer of highly treated recycled water from the AWTP at St Marys STP to the Hawkesbury-Nepean River at Penrith. The pipeline would be about 750mm in diameter, with a nominal capacity of 50 ML/day.

The highly treated recycled water would be discharged via the existing discharge outlet from Penrith STP into Boundary Creek (refer to **Figure 3.7**). Boundary Creek flows into the Hawkesbury-Nepean River immediately downstream of Penrith Weir, approximately 20 km downstream of Warragamba Dam. No modification of the existing discharge outlet at Penrith STP would be required as part of this project.



Figure 3.6a Concentrate pipeline route

Figure 3.6b Concentrate pipeline route





Figure 3.7 Penrith STP

3.6 Other infrastructure

3.6.1 Storage pond

A storage pond with a capacity up to 25 ML would be constructed at Quakers Hill STP (refer to **Figure 3.8**). The storage pond would be used to provide storage for concentrate in the event that discharge to the NSOOS is not possible during periods of extended wet weather. Operation of the AWTP would be reduced or possibly stopped if the capacity of the storage pond were to be exceeded (see **Section 3.7**).

3.6.2 Pumping stations and balance storage tanks

Balance storages and pumping stations would be required at the Penrith, St Marys and Quakers Hill STPs to transfer tertiary treated effluent to the AWTP. The pump station capacities would be about 25 ML/day, 38 ML/day and 25 ML/day respectively. They would be constructed underground, although switchrooms to service the pump stations at Quakers Hill and Penrith STP will be above ground. The switch stations would be about 12m x 4m x 3m high and their locations are shown in **Figure 3.7** and **Figure 3.8**.

A pumping station with a capacity of about 50 ML/day would be required at St Marys STP for the transfer of recycled water to Penrith, as well as a second pump station with a capacity of 8 ML/day to transfer concentrate to Quakers Hill STP. These are shown in **Figure 3.3b**, along with the balance storage tanks.

An 10 ML/day capacity pumping station may also be required at Seven Hills to pump the concentrate along the new 12 km section of pipeline to Vineyard Creek. If required it would be placed underground in the International Peace Park, adjacent to the existing NSOOS access point away from residences on Jean Street.

3.6.3 Chemical storages and deliveries

Chemicals would be stored at the AWTP and at the STPs. Approximate storage volumes of these chemicals are shown in **Table 3.1**. At the STPs there may be opportunity to make use of the existing hypochlorite dosing facilities, without the need to provide additional storage on site.

Additionally, speciality/proprietary chemicals for membrane cleaning (eg citric acid) would be required at the AWTP. These would be delivered and stored in small tanks or supplied in bulk boxes (1000 litre plastic containers).

Chemicals would be stored according to the requirements of AS1940: *The Storage and Handling of Combustible and Flammable Liquids* and the Dangerous Goods Storage Codes. An assessment of potential hazards from chemicals is provided in **Chapter 8**.

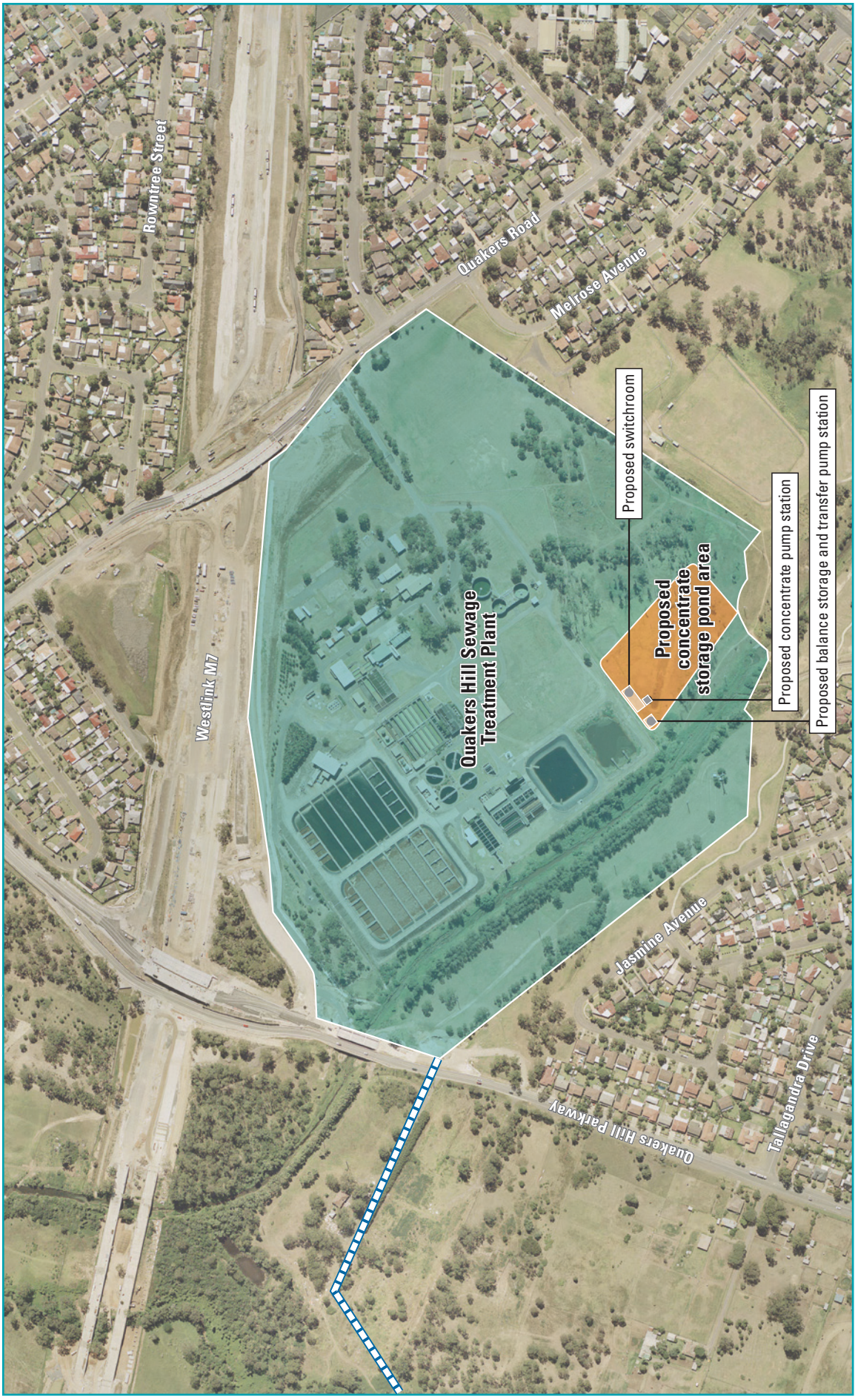


Figure 3.8 Quakers Hill STP

Table 3.1 Estimated quantities and types of chemicals

Chemical	Use/Purpose	Days supply	Delivery size (tonnes)	Volume (kilolitres) of on-site storage tanks
Quakers Hill STP				
Sodium hypochlorite	Added to tertiary effluent to form monochloramines. Chloramines are an effective disinfectant to control biological fouling of reverse osmosis membranes.	20	20	24
St Marys STP				
Sodium hypochlorite	Added to tertiary treated effluent to form monochloramines.	20	20	26
Penrith STP				
Sodium hypochlorite	Added to tertiary treated effluent to form monochloramines.	20	10	13
AWTP at St Marys STP				
Sodium hypochlorite	Added to tertiary treated effluent to form monochloramines.	20	20	48
Ammonia	Added to tertiary treated effluent to form monochloramines.	30	6	8
Antiscalent[1]	Added to tertiary treated effluent to prevent mineral deposits or scaling of the reverse osmosis membranes.	30	6	7
Sodium bicarbonate	Added to feed water during maintenance cleaning of the reverse osmosis membranes. Added during post treatment to adjust the pH of the recycled water.	20	20	31
Sodium metabisulphite	Added to remove free chlorine from the recycled water.	30	6	5
Sodium hydroxide	Added to concentrate to eliminate scaling, principally from calcium carbonate.	10	20	44
Hydrochloric Acid	Added to tertiary treated effluent to eliminate scaling, principally from calcium carbonate.	10	20	55

1 eg sodium hexametophosphate, organophosphonate or polyacrylates.

3.7 Operation and performance

3.7.1 Highly treated recycled water quality

The estimated nutrient and total dissolved solids concentrations in the highly treated recycled water to be used as replacement flows is presented in **Table 3.2**. For comparison and to show the performance expected of the AWTP, typical tertiary treated effluent concentrations are also shown.

Table 3.2 Likely water quality of highly treated recycled water

Stage	Water quality (Concentration in mg/L)				
	Ammonia (NH_4)	Oxides of nitrogen (N0x)	Total nitrogen (TN)	Total phosphorus (TP)	Total dissolved solids (TDS)
Tertiary treated effluent	0.10	2.96	4.5	0.05	400-600
Highly treated recycled water (Replacement Flows)	0.00	0.44	0.79	0.01	25-35

The effective characteristics of the highly treated recycled water are a total of 0.44 milligrams a litre (mg/L) of readily available nitrogen, total nitrogen of 0.79 mg/L and total phosphorus of 0.01 mg/L. The total dissolved solids concentration would be approximately 35 mg/L.

3.7.2 Pre-treated backwash water

Consideration was given to the potential impacts of backwash water from the pre-treatment process on the operation of the St Marys STP. Based on the likely concentrations in the backwash water, there would not be any significant biological or solids loading to the St Marys STP.

The returned backwash water would represent about 14 per cent of the average dry weather flow through the STP. Hydraulically, the peak treatment capacity of St Marys STP is limited by the secondary treatment facilities that are currently capable of handling a peak loading of 120 ML/day. Planned works would increase this to 180 ML/day in the future.

Sydney Water's design standard for secondary treatment is 3 times the average dry weather flow. As current dry weather flow is 36 ML/day, the secondary treatment capacity required to meet the design standard is 108 ML/day. Backwash water would increase flow through the secondary treatment facilities by 7 ML/day to 115 ML/day. This is within the current processing capacity of the plant, although the discharge of backwash flows to St Marys STP would accelerate the need for the planned works to increase the hydraulic processing capacity of the secondary treatment facilities. An hydraulic assessment would be undertaken during detailed design to assess the impacts of the return of backwash water at St Marys STP.

An assessment was undertaken to determine the effects of load from the pretreatment material on St Marys STP. **Table 3.3** shows the return flow would not provide any significant loading to the St Marys STP, with most parameters increasing by less than one per cent.

The concentrations of suspended solids with backwash and the relatively low load increase indicate there would be negligible increase in biosolids. The low backwash concentrations also suggest there would be no

contaminant accumulation in the system. Solids and contaminants are effectively discharged with the concentrate.

Table 3.3 Assessment of backwash load on St Marys STP

Parameter	Concentration (mg/L)		Load (kg/d)		Increase Load %
	MF Backwash	St Marys Sewage	MF Backwash	St Marys Sewage	
Suspended Solids (SS)	20.5	294	133.3	11172	1.2%
Ammonium (NH_4)	0.05	41	0.3	1558	0.0%
Oxidised Nitrogen as Nitrogen (NOx-N)	2.86	N/A	18.6	N/A	N/A
Total Kjeldahl Nitrogen (TKN)	0.98	59	6.4	2242	0.3%
Total Nitrogen (TN)	3.84	59	25.0	2242	1.1%
Total Phosphorus (TP)	0.06	11.1	0.4	422	0.1%
Biochemical Oxygen Demand (BOD)	5	215	32.5	8170	0.4%

Assumptions:

1. MF backwash return based on a 90% recovery from the process
2. MF feed concentration has been averaged from the feed concentration from Penrith and St Marys
3. MF will only remove solids. Nutrients will pass through. TP & TN are unlikely to change in the backwash
4. MF filtrate used for backwashing
5. NOx in St Marys STP raw sewage assumed to be zero in calculation of the TN load
6. All concentration and loads estimated using average concentrations and average dry weather flow data

3.7.3 Concentrate quality

The average volume of concentrate generated by the AWTP is expected to be about 8 ML/day. The concentrate would contain between 3000 and 4000 mg/L of total dissolved solids (TDS), approximately 7 times greater than the concentrations in the tertiary treated effluent from the STPs and approximately one tenth that of seawater (35,000 mg/L). The concentrate would also contain high concentrations of sulphate (500 to 1000 mg/L), chloride (1000 to 1500 mg/L), calcium (130 to 200 mg/L) and alkalinity (480 to 850 mg/L as CaCO3). It would have a pH of 7.5 to 8.0 and contain the majority of nutrients originally within the effluent from the STPs.

The composition of the concentrate means that it may be prone to mineral deposition or scaling during transfer from the AWTP to the NSOOS. This would lead to blockages or reduced flow capacity in the pipeline. Anti-scalents would be added in the pre-treatment phase, to minimise scale formation as the treated effluent passes through the reverse osmosis membranes. The concentrate quality would be monitored and additional anti-scalent added during the post treatment phase if required.

3.7.4 Maintenance of the Advanced Water Treatment Plant

Regular maintenance of the reverse osmosis membranes would be required to prevent blockages of the membrane pores. The need for membrane cleaning would be typically triggered by a pressure drop across the membrane, which indicates an increase in the fouling of the membrane surface. The AWTP would be highly automated and would include a chemical 'clean in place' (CIP) system. A CIP system allows the addition and circulation of cleaning chemicals through the membranes and eliminates the need to dismantle the reverse osmosis process equipment. This system also largely eliminates human contact with the chemical cleaning agents. The operation of the AWTP would be able to continue during cleaning as each module would be cleaned independently while off-line.

Some maintenance activities may require short-term shutdowns, lasting from a few days to weeks. Maintenance procedures would be developed to protect the reverse osmosis membranes. These may include the flushing of membranes every 12 hours and the use of biocides to protect the membranes if the shutdown extends beyond a few days.

Longer-term shutdowns may result under certain conditions. These may occur if:

- there is ample water available (storage levels are high) in Warragamba Dam and it is more effective to provide releases from the dam than from the AWTP
- there is an extended power outage (back up power sources will not be provided)
- there is an incident within the NSOOS that would preclude the discharge of the concentrate and the storage capacity of the pond at Quakers Hill STP is exceeded
- there is an incident in the recycled water pipeline
- there is flooding.

Long-term shutdowns would require the development of a preventative operation and maintenance strategy to secure the works and protect the membranes.

3.7.5 Wet weather operation

Prolonged wet weather events increase sewage flows in the NSOOS due to stormwater inflows and infiltration into the sewer system. The NSOOS may not be able to accept the additional volumes during these weather conditions, as the concentrate flows may increase the risk of wet weather overflows from the NSOOS system. A decision to divert the concentrate to the storage pond at Quakers Hill STP would be based upon rainfall in the NSOOS catchment area and/or data on depth and flows from a number of control points in the NSOOS. Sydney Water has undertaken hydraulic modelling of the NSOOS to determine specific guidelines to define cessation and recommencement levels for the concentrate discharge. The results of this modelling and the options for the storage pond size are discussed in **Chapter 7**.

During these wet weather periods, the AWTP could continue to operate, with the concentrate temporarily stored in the storage pond at Quakers Hill STP. Once the storage pond reaches a specified volume, the AWTP operation would be reduced to a 'single train' or would temporarily cease. The temporary reduction or cessation of operations would reduce or eliminate production of the recycled water and the concentrate. Reduced volumes of recycled water would continue to be discharged into the Hawkesbury-Nepean River at Penrith during periods of reduced operations and would cease during periods of complete shutdown. During these periods of reduced production or shut-down, the STPs would resume their current operation of discharging tertiary treated effluent to the receiving waterways.

3.7.6 Energy use

The estimated energy requirements for the operation of the AWTP and the pumps are about 27.4 gigawatt-hours per year (GWh/year), or approximately 1.5 kilowatt-hour (kWh) of electricity per 1000L of highly treated recycled water produced.

In comparison desalination of seawater for potable water and pumping would require around 4.5 kWh of electricity per 1000L of water. Conventional treatment of sewage requires 0.47 kWh of electricity per 1000L and treatment of water requires 0.26 kWh of electricity per 1000L. It should be noted that these energy usage figures do not include the pumping energy associated with collection and/or distribution of the water/ wastewater.

Energy would be sourced from the existing power grid and 'green power' sources. Sydney Water currently sources 6 per cent of energy from 'green energy' sources in accordance with the NSW Government's Energy Management Policy.

3.7.7 Other performance requirements

Hours of operation

The Project would generally operate 24 hours a day, 7 days a week. Temporary shut downs of the infrastructure may occur for maintenance or operational reasons.

Workforce

Once operational, the Project is expected to employ approximately 12 personnel.

Noise

The AWTP would operate within a building, located on the St Marys STP site in an existing industrial area. The building would be designed to ensure the operation of AWTP meets the noise criteria outlined in the *NSW Industrial Noise Policy* (NSW EPA 2000). This is further discussed in **Chapter 8**.

Odour

There would be minimal potential for odour from the Project. Effluent, recycled water and concentrate are generally enclosed within the AWTP or associated pipes. Any odour potential relates to the concentrate that may occasionally be stored in the open pond at Quakers Hill STP. The concentrate would not normally be odorous, and this is further discussed in **Chapter 8**.

3.8 Construction methods

3.8.1 Construction schedule

Construction is anticipated to start in mid 2007, with completion scheduled for the end of 2009. During that time, the major elements and their duration would be:

- contract, design and mobilisation from mid 2007 to early 2008 (about 9 months)
- pipeline construction and testing from early 2008 to early 2009 (about 12 months)
- AWTP construction and construction works at the STPs from early 2008 to early 2009 (about 12 months)
- commissioning and proving periods from early 2009 to late 2009 (about 9 months).

3.8.2 Pipelines

The effluent, recycled water and concentrate transfer pipelines would typically require a combined 2 to 3 m wide trench about 2 m deep to allow for installation. Some sections of the pipeline would be constructed by boring under sensitive surface features such as watercourses, significant vegetation, potential archaeological deposits, major roads, railways and other services to avoid impacts. Underground boring of sensitive waterways will include the full width of the watercourse, the core riparian zone and riparian buffer. The main activities to construct the pipeline are listed in **Table 3.4**.

The railway crossings would be constructed by under-boring the railway corridor. The construction method and depth of cover would be determined after detailed consultation and agreement from RailCorp.

The 32 km of pipeline is expected to be constructed over a 12 month period. Typically, work would be undertaken in sections of between 60 and 100 m and each section would be completed before moving on to the next. The time spent at each section would be up to three weeks. Some pipeline alignments would be constructed concurrently.

Table 3.4 Pipeline construction works

Description of construction works
Trenching construction works would include: • establishment of temporary site compounds at appropriate locations along the pipeline route • site preparation (including pavement, footpath, road and/or vegetation removal) • traffic management through construction and implementation of construction traffic management measures • trenching and excavation including stockpiling of spoil materials • provision of temporary access to individual properties while trenching is affecting driveways • supply, installation and testing of pipelines • concrete anchor blocks or piles in ground where there is a change in direction of the pipeline • backfill and compaction of trench fill • restoration of pavements, driveways, roads, footpaths, turf and vegetation • removal of excess spoil.
Underground boring construction works would include: • establishing sites which will include controls for protection of waterways, storage of equipment (including Bentonite[1]), fencing and security • excavation of bore pit where the rig unit will be placed and the receiving pit where sections of pipe will be joined together before being pulled into the bore hole. Typical launch site would be 20 metres square; typical retrieval pits about 10 metres square • boring under the road or creek. Bentonite slurry would be used to lubricate the cutting head and drilling equipment • removal of spoil and insertion of pipes in the hole • connection to the pipeline • backfilling the bore and receiving pits • removal of excess spoil • restoration of affected areas.

[1] Bentonite is a non-toxic, naturally occurring clay which would be processed and re-used in the drilling process.

3.8.3 Advanced Water Treatment Plant

Construction methods for the various components of the AWTP are described in **Table 3.5** below.

Table 3.5 Advanced Water Treatment Plant construction works

Description of construction works
Site preparation works: • establishment of site compounds and access for construction works • site levelling, removal of excess soil, vegetation and other earthworks • provision of services for construction.
Building and chemical storages: • excavation for connecting services pipelines and building floors • formwork erection for concrete floor slabs • concrete pours for floor slabs • installation of steel building structures • installation of metal sheeting for walls and roof (or block work where appropriate) • electrical and other services installation • fit out of buildings based upon their use: for the main building – the installation of reverse osmosis membrane vessels and associated equipment; for chemical storage – the installation of tanks, pumps, bunds • commissioning • permanent site access road.
Tanks and Pre-treatment process units: • excavation for connecting services, pipelines and infrastructure slabs • foundation preparation and possibly piling • formwork erection for concrete base slabs, tank stands and tank walls • concrete pours for the above • installation of steel roofing structures (for covered process units) or steel tanks. • installation of metal sheeting for walls and roof (for covered process units) • electrical and other services installation • fit out of process units based upon their use e.g. dosing equipment, sensors • commissioning.
Internal pipelines: • site preparation • trenching and excavation including stockpiling of spoil materials • supplying, laying and testing pipelines • concrete anchor blocks or piles in ground at changes in direction of the pipeline • backfill and compaction of trench fill • restoration of disturbed area.
Other works: • internal road works including earthworks, compaction and asphalting • landscaping and site restoration • fencing, security.

3.8.4 Pumping stations

The construction methodology for the pumping stations would include site preparation (including safety fencing), excavating and concreting works, construction of a metal sheeting or brick building, using standard techniques, and construction of the access road and security fence.

The installation of electrical and mechanical equipment including pumps, switchboards, transformer, flow meters, dosing pit and equipment would then be undertaken prior to commissioning.

3.8.5 Water storages

The construction methodology for the in-ground water storages would include site preparation (safety fencing, clearing), earthworks which would include the excavation of spoil and battering, the installation of inlets, outlets and other connecting infrastructure, the installation of storage liners (generally plastic), the construction of access roads and security fences and commissioning.

3.8.6 Traffic

Penrith, St Marys and Quakers Hill STPs are accessible via Castlereagh Road, Links Road and Quakers Road, respectively.

The proposed pipeline routes would be located within the road reserve of the following roads (or would cross these roads):

- Westlink M7 Motorway
- Andrews Road
- The Northern Road
- Links Road
- Forrester Road
- Palmyra Road
- Richmond Road
- Quakers Hill Parkway
- Prospect Highway
- Old Windsor Road
- Hammers Road
- Kleins Road
- Castle Street
- Belmore Street
- James Ruse Drive
- Prince Street
- Greens Avenue
- Bells Road.

Construction of the pipelines has the potential to cause localised traffic delays and diversions, due to:

- additional vehicle movements associated with the transport of construction workers, equipment and machinery to and from the pipeline sites
- short-term closures of sections of road reserve and traffic lanes, to allow the safe installation of pipelines within existing road easements
- restricted or modified access to adjacent properties.

The road verge and one lane of traffic would be closed during trenching and installation of the pipelines in or adjacent to roads (for the minimum section necessary at any one time) to allow safe access and operation of construction equipment. All directly affected landholders would be notified prior to commencement of construction activities and access to private properties would be maintained, in consultation with individual landholders. Approximately 4 to 5 km of the proposed 20 km pipeline would be located in or adjacent to roads. It is anticipated that road works in or adjacent to roads would be undertaken progressively, with any one area being disturbed for approximately three weeks.

All road diversions and traffic management activities would be undertaken by qualified traffic controllers, in accordance with Sydney Water's standard operating procedures. Additional mitigation measures, designed to minimise traffic delays and disruption, may include:

- consultation with the RTA and local government regarding works that may impact roads or traffic
- consultation with affected property owners to maintain access during construction
- measures to manage construction traffic.

For pipeline crossings of major roads (e.g. Westlink M7 Motorway, Northern Road), underground boring techniques would be used to minimise any damage or disruption.

3.8.7 Hours of construction work

Construction works would generally be undertaken between 7am and 6pm Monday to Friday and from 8am to 1pm on Saturday. Night-work may also be required for the construction of the pipelines, where they cross major roads or intersections, to minimise traffic impacts.

3.8.8 Construction workforce

The construction phase is expected to last for approximately 18 months. During this period, construction workforce numbers would vary depending on the construction activities being undertaken, but would peak at approximately 130 personnel.



Consideration of alternatives

This chapter describes the different technologies, site locations and operational aspects that were considered in the selection of the preferred Replacement Flows Project (the Project).

4.1 Introduction

Alternatives for key aspects of the Project were developed and assessed, and a preferred scheme identified.

The objective of providing highly treated recycled water to replace current releases from Warragamba Dam was based upon the collection and further treatment of tertiary treated effluent from three sewage treatment plants (STPs) in Sydney's north west, namely St Marys, Penrith and Quakers Hill. This would provide up to 50 million litres a day (ML/day) of highly treated recycled water as replacement flows in the Hawkesbury-Nepean River system. To achieve this, alternatives for key aspects of the Project were developed and assessed, and a preferred scheme identified. The major considerations in evaluating the options were:

- saving up to 18 billion litres a year of current Warragamba Dam discharges by providing high quality recycled water to the Nepean River as a replacement for existing Warragamba Dam releases
- reducing the discharge of nutrients from Penrith, Quakers Hill and St Marys STPs into the Hawkesbury-Nepean River and South Creek
- maintaining appropriate flows for irrigation
- ensuring environmental values are maintained – including aquatic ecosystems, primary industries, recreation and aesthetics and drinking water.

The key aspects of the Project where alternatives were developed and considered included:

- treatment options for the Advanced Water Treatment Plant (AWTP)
- recycled water discharge locations.

The key issues in selecting a preferred water treatment process and a discharge location are the nutrient levels and loads in the recycled water and the avoidance or prevention of any increase in eutrophication (excessive algal and macrophyte growth) downstream of the discharge location. Nitrogen was considered to be the nutrient which had the greatest risk of increasing eutrophication, as the levels of phosphorus in the treated effluent from the three STPs is already very low (although further reducing phosphorus loads would have an environmental benefit).

In considering appropriate water treatment processes and a discharge location for the replacement flows, an assessment of nutrient concentrations in receiving waters resulting from the nutrient levels and load discharges from various combinations of options was undertaken.

In considering appropriate water treatment processes and a discharge location for the replacement flows, an assessment of nutrient concentrations in receiving waters resulting from the nutrient levels and load discharges from various combinations of options was undertaken. Environmental values and in-stream water quality guideline values for total phosphorus, total nitrogen, oxidised nitrogen and ammonia were derived to provide risk categories against which the various technology options could be assessed. Water quality guidelines for the Hawkesbury-Nepean River were derived from the Healthy River Commission (1998) and ARMCANZ/ANZECC (2000). The water quality in the Hawkesbury-Nepean River, predicted from the operation of the various treatment combination technologies, was compared with the 2009 base case (the predicted water quality resulting from release of water from Warragamba Dam and the Upper Nepean dams and tertiary treated effluent from the three STPs). The selection of the preferred option for a water treatment process and a discharge location was then based upon achieving, at a minimum, equivalent environmental values to the existing condition (ie no deterioration in water quality or environmental values). It should be noted that, although maintaining equivalent environmental values was the objective, there could also be substantial improvement in water quality associated with the Project.

Once the preferred water treatment process and discharge location were determined, alternatives for other aspects of the Project were also considered. These included:

- the AWTP location and configuration
- pipeline routes
- concentrate removal and disposal.

4.2 Water treatment process and discharge location

4.2.1 Main treatment process options

The main treatment process would largely determine the pre-treatment and post treatment processes at the AWTP. The main treatment process alternatives considered were:

- nanofiltration
- ion exchange
- denitrification
- reverse osmosis.

Nanofiltration removes smaller particles and dissolved solids in the range of one nanometer (0.001 microns). The rejection rate (the amount of material which is rejected by the membrane and as such does not pass through, but enters the concentrate stream) of dissolved substances is typically 30-70 per cent for monovalent (or smaller) anions such as chloride and nitrate, and above 95 per cent for divalent or trivalent (larger) ions such as calcium, sulphate, and phosphate. Nanofiltration would not be able to reduce nitrate concentrations significantly.

Ion exchange generally uses insoluble synthetic resin that contains exchangeable anions or cations that capture many ionic pollutants in the tertiary treated effluent as it is pumped through the resin. Ion exchange can be used to reduce nutrient concentrations, but it does not remove non-ionic species such as organic compounds and it has not been proven in the large-scale treatment of wastewater.

Denitrification, using a dedicated biological reactor, could be used to reduce the concentration of nitrogen species. This process is particularly effective in the removal of oxidised nitrogen. It would not, however, remove any pathogens or chemicals. As well as being considered as a main treatment process option, denitrification could be considered as an ancillary treatment process to any of the other alternatives.

The remaining treatment option reviewed was reverse osmosis, as it is capable of removing all dissolved solids and organic molecules with molecular weight greater than approximately 100, which is typically 95-99 per cent of all dissolved chemicals. Reverse osmosis plants of a similar size provide advanced treatment of sewage effluents in other locations in Australia and abroad. These sites include the Kwinana Water Reclamation Plant in Western Australia, the Recycled Water Plant at Wollongong in NSW and the NEWater plant in Singapore.

Reverse osmosis also provides a barrier to pathogens and would remove complex chemicals such as pesticides, herbicides and pharmaceuticals. Phosphorus concentrations would be reduced to very low levels. The removal of nitrogen species (nitrate, ammonia and chloramines) is less effective and would depend upon the membrane type and the number of passes through the membrane. Chloramine is a disinfectant commonly used to prevent biological fouling of the reverse osmosis membranes. This is created by adding chlorine to water containing ammonia and is a widely used water supply practice. After the disinfected water passes through the reverse osmosis membranes, the addition of excess chlorine (known as breakpoint chlorination) could be incorporated to remove residual ammonia and chloramine.

Comparison of options

Reverse osmosis was considered the most suitable technology for the main treatment process to achieve the goals of removing nutrients from the tertiary treated effluent.

Reverse osmosis was considered the most suitable technology for the main treatment process to achieve the goals of removing nutrients from the tertiary treated effluent, in particular the bioavailable forms of phosphorus and nitrogen. Various combinations of reverse osmosis and denitrification options were considered to achieve the target nutrient levels in the discharge which would result in no deterioration in water quality or environmental values in the receiving waters. Ion exchange was not considered feasible and was not assessed.

Options considered for the main treatment process were:

- denitrification only
- single pass reverse osmosis only
- single pass reverse osmosis with denitrification
- two pass reverse osmosis
- two pass reverse osmosis with denitrification
- the options listed above, with breakpoint chlorination.

The combinations assessed were:

- the base case (ie discharge of 15 ML/day of tertiary treated effluent from Penrith STP – and about 65 ML/day of tertiary treated effluent from Quakers Hill and St Marys STPs)
- discharge of 50 ML/day of tertiary treated effluent (sourced from Penrith, Quakers Hill and St Marys STPs), with and without denitrification - and the continued discharge of about 35 ML/day of tertiary treated effluent from Quakers Hill and St Marys STPs into South Creek
- discharge of 50 ML/day of recycled water (sourced from Penrith, Quakers Hill and St Marys STPs) after treatment by single or two pass reverse osmosis with or without denitrification and breakpoint chlorination - and the continued discharge of about 20 ML/day of tertiary treated effluent from Quakers Hill and St Marys STPs into South Creek.

Table 4.1 provides a comparison of the quality of the recycled water produced as a result of each of the main treatment process options.

Table 4.1 Comparison of recycled water qualities from main treatment process alternatives

Treatment	Ammonia	Organic Nitrogen	Oxidised Nitrogen	Chlormines	Total Phosphorus
	Approximate percentage reduction in initial tertiary treated effluent concentration				
Denitrification	0%	20%	75%	0%	0%
Single Pass RO	90%	60%	85%	50%	90%
2 Pass RO	98%	80%	96%	75%	98%
	Recycled water quality (concentration in mg/L)				
Initial effluent concentration	0.10	0.88	2.96	0	0.05
Denitrification	0.10	0.68	0.74	0	0.1
Single Pass RO	0.03	0.35	0.44	0.27	0.01
Single Pass RO + dentrification	0.03	0.27	0.11	0.27	0.01
2 Pass RO	0.01	0.18	0.11	0.14	0.002
2 Pass RO + denitrification	0.01	0.14	0.03	0.14	0.002

Table 4.2 provides a summary of the combinations of main treatment processes considered and their suitability for application.

Table 4.2 Comparison of main treatment options

Technology	Description	Suitability
Denitrification only	Denitrification can be used to reduce total nitrogen concentrations. Denitrifying organisms convert nitrate into nitrogen gas, provided there is a source of readily available degradable carbon present. For low concentrations of nitrate such as in tertiary treated effluent, a fixed film reactor bed supplied with a carbon source (eg methanol) would be used.	Denitrification is particularly effective at reducing oxidised nitrogen, although it is less effective on other nitrogen compounds such as ammonium. It does not remove total phosphorus or pathogens. Due to its relatively poor performance in removing nitrogen (other than oxidised nitrogen), total phosphorus and pathogens denitrification alone **would not be suitable for the main treatment process**.
Single pass reverse osmosis	The removal of nitrogen species depends upon the membrane type, membrane configuration and system design. Single pass reverse osmosis results in an approximate reduction in oxidised nitrogen and ammonium concentrations in the recycled water of approximately 85% and 90% and reduction in total phosphorous concentrations of 80%.	Single pass reverse osmosis is less effective in reducing concentrations of organic nitrogen and chloramines removing 60% and 50% respectively. **This option would be suitable for the main treatment process and is improved with additional processes for removal of ammonia and chloramines.**
Single pass reverse osmosis with additional denitrification	Denitrification would occur prior to the membrane process and it is anticipated that it would achieve a reduction of 75% oxidised nitrogen. The following single pass reverse osmosis process would reduce oxidised nitrogen levels by a further 85%.	**This option would be suitable for the main treatment process.**
Two pass reverse osmosis	Two pass reverse osmosis results in a reduction in oxidised nitrogen and ammonium concentrations of approximately 96% and 98% respectively and a total phosphorus reduction of 96% compared to 80% reduction achieved through single pass reverse osmosis.	Higher quality recycled water will be produced if subjected to a further reverse osmosis process. **This option would be suitable for the main treatment process.**
Two pass reverse osmosis with additional denitrification	Prior denitrification of the tertiary treated effluent would be undertaken before passing through two pass reverse osmosis stage. Two pass reverse osmosis results in an approximate reduction in oxidised nitrogen of 96%. Addition of the initial denitrification process would result in 99% removal of oxidised nitrogen.	This option would provide the highest quality recycled water and **would be suitable for the main treatment process.**

The water quality results identified that if denitrification alone were the main treatment process this would result in a significant increase in total nitrogen and phosphorus downstream of Penrith Weir, compared with the base case in 2009. Therefore, denitrification could only be considered as an ancillary process to the main treatment.

For release of highly treated recycled water below Penrith Weir, single pass reverse osmosis with breakpoint chlorination would be necessary to achieve total nitrogen and phosphorus loads equivalent to or better than the base case in 2009. Release of water treated by reverse osmosis with breakpoint chlorination just below the weir would result in about 17 per cent reduction in total nitrogen load and about 80 per cent reduction in total phosphorus load in this location, compared with the base case in 2009 (see **Table 4.3**).

Release of water treated by reverse osmosis with breakpoint chlorination just below the weir would result in about 17 per cent reduction in total nitrogen load and about 80 per cent reduction in total phosphorus load in this location.

Due to the reduced flows from St Marys and Quakers Hill STPs there would be significant reductions in the load of nutrients discharged into South Creek, with up to a 70 per cent reduction in loads of both total phosphorus and nitrogen (see **Table 4.4**).

This reduction in nutrient loads would maintain (and potentially improve) the relevant environmental values of the river relating to water quality.

Pre-treatment options

As reverse osmosis would be the preferred main treatment process, pre-treatment would be required to remove any remaining solids in the tertiary treated effluent. Microfiltration removes particulates greater than the range of 0.1 to 1.0 micrometres (microns) whereas ultrafiltration removes particles greater than 0.002 to 0.1 microns. Both options would be suitable for pre-treatment and the choice of options would be based on the final design requirements.

4.2.2 Options for discharge to the river

As part of the assessment of the main treatment processes, the location of the discharge of highly treated recycled water into the Hawkesbury-Nepean River system was also considered. The two locations assessed for discharge of the recycled water were:

- discharge from Penrith STP via the existing discharge facilities into Boundary Creek. This creek flows into the Nepean River immediately downstream of Penrith Weir
- discharge near where the Warragamba River flows into the Nepean River, via a new pipeline from the AWTP at St Marys to the Nepean River at Wallacia Bridge.

Table 4.3 Load estimates for the base case, effluent transfers, denitrification and reverse osmosis cases downstream of Penrith Weir

Case	Break Point Chlorination	Flow (ML/d)	Nutrient Loads (kg/year)					
			Ammonia	Total Kjeldahl Nitrogen	Oxidised Nitrogen	Chloramines	Total Nitrogen	Total Phosphorus
Base Case	No	16	287	6,361	11,232	0	17,593	458
Tertiary Treated Effluent	No	50	1,825	17,885	54,020	0	71,905 (+309%)	913(+99%)
Denitrification only	No	50	1,825	14,673	13,505	0	28,178 (+60%)	913 (+99%)
	Yes	50	0	14,673	13,505	0	26,353 (+50%)	913 (+99%)
Single Pass Reverse Osmosis	No	50	548	6,972	8,103	4,928	20,002 (+14%)	91 (-80%)
	Yes	50	0	6,972	8,103	0	14,527 (-17%)	91 (-80%)
Single Pass Reverse Osmosis + Denitrification	No	50	548	5,687	2,026	4,928	12,640 (-28%)	91 (-80%)
	Yes	50	0	5,687	2,026	0	7,165 (-59%)	91 (-80%)
Single Pass Reverse Osmosis	No	50	183	3,395	2,026	2,464	7,884 (-55%)	18 (-96%)
	Yes	50	0	3,395	2,026	0	5,238 (-70%)	18 (-96%)
Single Pass Reverse Osmosis + Denitrification	No	50	183	2,752	506	2,464	5,722 (-67%)	18 (-96%)
	Yes	50	0	2,752	506	0	3,076 (-83%)	18 (-96%)

Note: numbers in parentheses represent the per cent (%) change in loads compared to the base case.

Table 4.4 Load estimates in South Creek for the base case and with Replacement Flows Project using reverse osmosis

		Nutrient Load kg/year			
		Ammonia	Oxidised Nitrogen	Total Nitrogen	Total Phosphorus
Quakers Hill	Base Case	2153	32010	41975	474
	Replacement Flows Project	1095	16206	21243	219
St Marys	Base Case	584	47559	58436	474
	Replacement Flows Project	73	6898	8468	73

In-stream water quality was assessed for each discharge location and each main treatment process option (SKM 2006). Current water quality at the two options for discharge location was determined and then compared with predicted water quality from the different main treatment process options, to assess whether there would any increase in concentrations of key nutrients. As nutrient concentrations in the Nepean River near Wallacia were relatively low, a higher level of treatment would be required to ensure that the replacement flows discharge would not result in an increase in nutrient concentrations in the river. Only the two pass reverse osmosis treatment options would result in similar nutrient concentrations to those currently measured in the Nepean River near Wallacia. Although nutrient concentrations in the recycled water would be similar with higher levels of treatment, a discharge at Wallacia Weir would result in higher loads of nutrients being discharged into the Penrith Weir pool. Given the long residence of time of water in the weir pool (about 180 days) this could result in increased eutrophication of the weir pool.

Only the two pass reverse osmosis treatment options would result in similar nutrient concentrations to those currently measured in the Nepean River near Wallacia.

Below Penrith Weir, current nutrient concentrations are relatively high and therefore a lower level of treatment (ie single pass reverse osmosis process with breakpoint chlorination) would result in a decrease in nutrient concentrations. The river is relatively free flowing downstream of Penrith Weir and there would be opportunities for further dilution and assimilation of nutrients.

Based upon the increased costs for the higher-level treatment options to discharge at Wallacia Bridge, the additional construction impacts from 20 km of new pipeline between St Marys and Wallacia and the risk of transferring increased nutrient loads into Penrith Weir pool, discharge into the Nepean River below Penrith Weir was selected as the preferred option. This discharge location would maintain the relevant environmental values of the river relating to water quality and flow.

4.3 Advanced water treatment plant location

The options considered for the location of the AWTP were at the Penrith STP and St Marys STP sites. Quakers Hill STP was not considered due to the high pumping costs associated with pumping highly treated recycled water to a discharge point in the Hawkesbury-Nepean River near Penrith Weir. In addition much of the tertiary treated effluent from Quakers Hill STP is to be used for servicing the north west sector residential growth areas with dual reticulation recycled water and would only be used to supplement water volumes from Penrith and St Marys STPs for the Replacement Flows Project.

Sufficient land is currently available at both Penrith STP and St Marys STP. St Marys was chosen as the preferred site as:

- the St Marys STP site is centrally located and would allow for more efficient connection with other regional STPs, should the Project be expanded
- the central location of St Marys STP may well promote the implementation of other as yet unidentified opportunities to recycle water
- the available land area at St Marys STP is larger than the land available at Penrith STP and would allow for future development opportunities
- the geotechnical conditions are better at the St Marys STP site where it can be built on vacant land rather than a filled lagoon on the Penrith site, thereby reducing the construction risk
- the site access for the AWTP would be independent from the STP at the St Marys site, allowing the operation of a completely independent plant from the existing facility
- the Penrith STP site lies within the 1 in 100 year flood level, St Marys does not. As such the St Marys STP site is not subject to the same risk of flooding
- the St Marys STP site does not require the de-commissioning and emptying of lagoons to site the AWTP which would be required at Penrith STP
- the St Marys STP is a larger plant than the Penrith STP and so can more easily accommodate the volumes of backwash water from the pre-treatment process
- choosing the St Marys STP site for the AWTP allows the location of the concentrate storage pond at Quakers Hill STP.

4.4 Pipeline routes

Tertiary treated effluent, highly treated recycled water and concentrate pipelines between the STPs would be laid within the same trench where practicable to minimise the extent of excavation and tunnelling. Where space allows, separate trenches may be used for ease of future maintenance.

Tertiary treated effluent, highly treated recycled water and concentrate pipelines between the STPs would be laid within the same trench where practicable to minimise the extent of excavation and tunnelling.

Options for pipeline routes were developed and, where possible, assessed against the following:

- functional criteria (eg engineering risks, effective access)
- social and economic criteria (eg traffic impacts, private property access, amenity, heritage impact)
- natural environmental criteria (eg impact on flora, fauna, aquatic habitat).

The pipeline routes were chosen to minimise impacts on the local community, road users and the natural environment. Where possible, route options within existing infrastructure easements, including asset protection zones (fire-breaks), were selected in preference to local roads. Three route options were considered:

- between St Marys and Penrith
- between Quakers Hill and St Marys.

These are shown in **Figure 4.1a**, **b** and described further in **Table 4.5** and **Table 4.6**.

Table 4.5 Comparison of route options between St Marys and Penrith STPs

Route	Description	Engineering feasibility	Environmental/social considerations
SP1	After leaving St Marys STP the route passes west along Links Rd, then follows a sewer easement across South Creek, through cleared land to the rear of the fence line of houses in the Werrington Down/Cambridge Garden suburbs. The route then follows Andrews Drive and turns southward through Kingswood Park and into Penrith STP along the north of Hickeys Park.	• 20% of route in urban areas • majority of remainder is cleared land.	• route avoids significant urban areas, schools and community facilities • minor vegetation clearing required • **This is the preferred route.**
SP2	The route follows Christie St then Dunheved Rd as far as Richmond Rd where it continues west, parallel to Illawong Ave in a high voltage (HV) power transmission easement for a few hundred metres, and then down cleared land in Kingswood park to the north off Hickeys Park into Penrith STP.	• 60% of route in urban areas	• Dunheved Rd is a significant transport arterial Road connecting St Marys and Penrith • minor vegetation clearing required.
SP3	The route follows Christie St then Dunheved Rd for a short distance. It diverts through Werrington Creek Park, exiting via William St/Oxford St, crossing Richmond Rd then down O'Brien Ave. The route then turns north into an industrial estate via Coombes Rd, then east of Hickeys Park before turning west along the north side and into Penrith STP.	• about 50% of the route is along roads/urban areas • majority of route is single lane carriageway. O'Brien Ave is relatively steep and winding	• route passes shopping centre, community centre and primary school in Cambridge Park • requires several creek crossings and passes through Werrington Creek Park.

The pipeline route, comprising SP1 and QS1, was chosen as the preferred option as it would be located along the northern edge of the urban development in areas that have been cleared for use as road and service easements or asset protection. Only 20 per cent of this route is located within suburban areas.

Table 4.6 Comparison of route options between Quakers Hill and St Marys STP

Route	Description	Engineering feasibility	Environmental/social considerations
SP1	This route follows the M7 from Quakers Hill as far as Oakhurst and then continues west through cleared land adjacent to and outside of suburban fence lines as far as Shalvey. The pipeline then turns southwards through Peter Van Hasselt Park, and down Forrester Rd, crosses Ropes Creek and then follows Links Rd to St Marys STP.	• 20% of route is through urban areas • crossing of the M7 required • route avoids construction of pipelines near HV power lines	• route avoids significant urban areas, schools and community facilities • minor vegetation clearing required • **This is the preferred route**
SP2	This route goes from the Quakers Hill STP via a sewer easement, southwards roughly parallel to Eastern Creek as far as Richmond Rd. The route then follows Richmond Rd east towards Hassall Grove. It then heads south running parallel to Rooty Hill Drive, before heading west along Luxford Rd through to Shalvey. The route joins onto Forrester Rd, crossing Ropes Creek and following Links Rd to St Marys STP.	• 90% of route is through urban areas • crossing of the M7 Motorway is required • Luxford Rd is a wide and gently winding two lane road	• route passes Shalvey High School and Hassall Grove Primary, as well as a school and nursing home on Richmond Rd • minor vegetation clearing required
SP3	The route goes from the Quakers Hill STP via a sewer easement , southwards to Lamb St. It then follows Lamb St and Jersey St as far as Emerton. The route then follows a southwest direction along Manila Rd and Ellsworth Dr through Tregear emerging on Forrester Rd, crosses Ropes Creek and then follows Links Rd to St Marys STP.	• 80% of the route is through urban areas • crossing of the M7 Motorway is required • Lamb Rd is single carriageway, Jersey Rd is dual carriageway • Manila Rd/Ellsworth Dr are single carriageway	• Lamb Rd is partially industrial • Jersey Rd is the location of Capuchin Conference Centre, Plumpton Marketplace and Mt Druitt High School, as well as a primary school and commuter facilities in Tregear • minor vegetation clearing required

Positioning the pipeline routes away from houses would minimise the potential disturbance associated with routine maintenance.

Access to the pipeline would be required for routine inspections to assess its condition and for periodic cleaning. Access would be obtained through access chambers, the number and location of which has not been determined. Positioning the pipeline routes away from houses would minimise the potential disturbance associated with routine maintenance.

None of the options would require significant vegetation clearance and impacts associated with creek crossings would be minimised by under boring to avoid creek vegetation and landscape features.

Figure 4.1a Transfer pipeline route (alternatives) - Penrith to St Marys

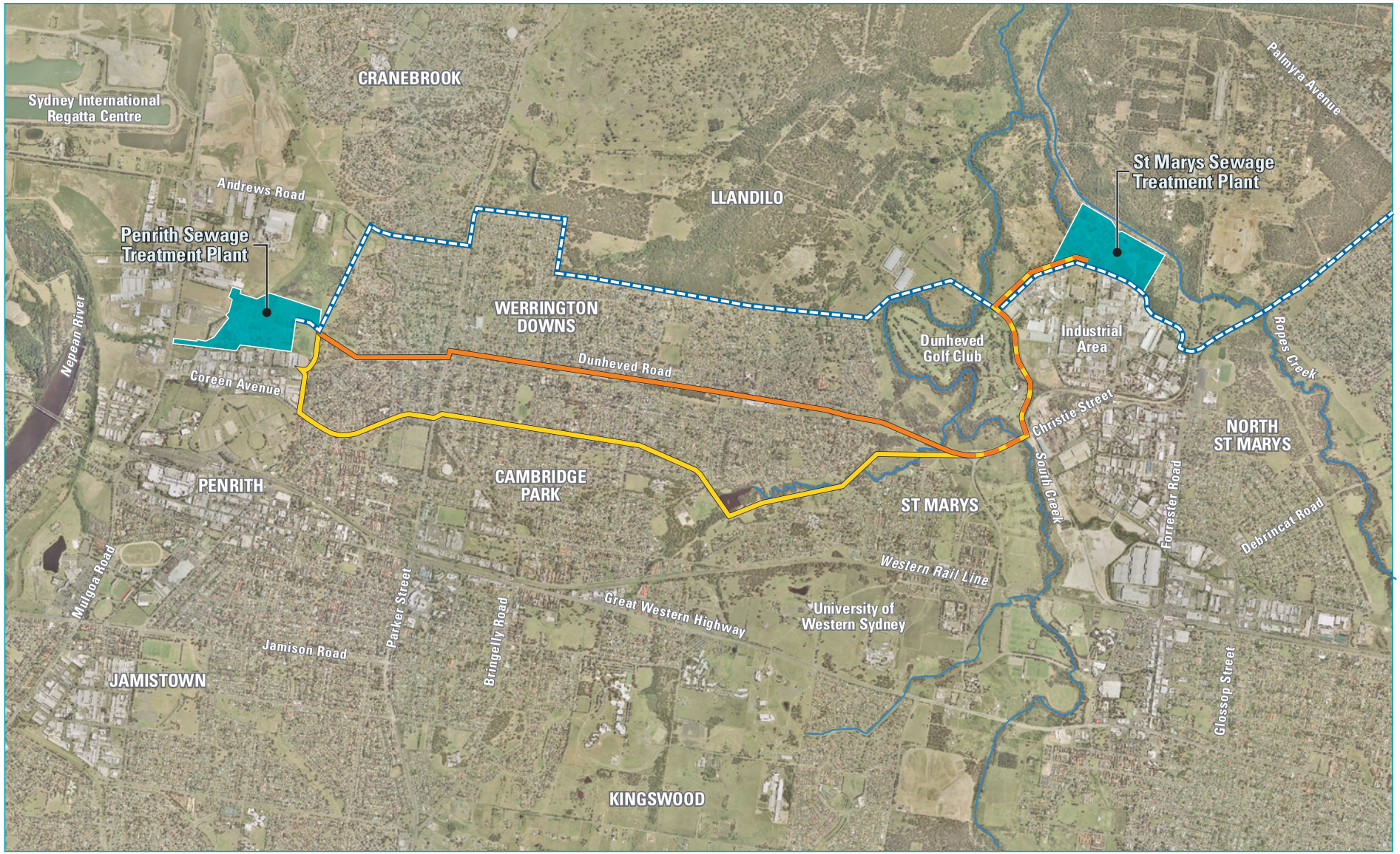
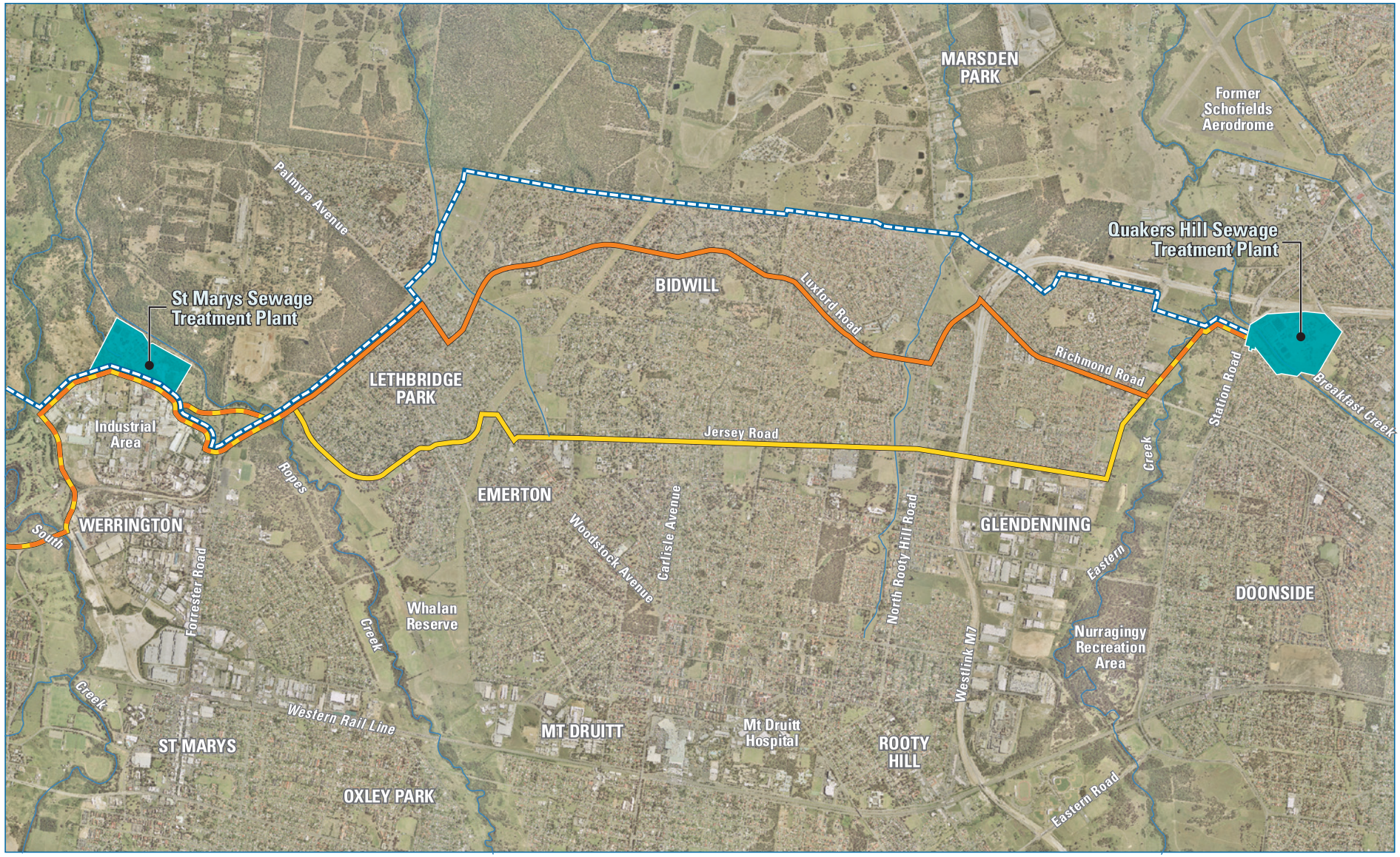


Figure 4.1b Transfer pipeline route (alternatives) - St Marys to Quaker Hill



4.5 Management of concentrate

4.5.1 Concentrate storage site

A concentrate storage pond is required to allow the AWTP to continue to operate when there are high wet weather flows in the NSOOS (see **Section 3.7**).

Penrith STP was not considered a suitable site for the concentrate storage lagoon due to limitations in site access, availability of land, the distance between Penrith STP and the NSOOS and the costs associated with the length of pipelines required to transport the concentrate from St Marys to Penrith. St Marys STP and Quakers Hill STP were the two options considered for the location of the concentrate storage lagoon.

A concentrate storage pond is required to allow the AWTP to continue to operate when there are high wet weather flows in the NSOOS.

There are two possible locations for the concentrate storage lagoon at St Marys STP. One is on the east side of the site which would require the removal of up to two hectares of vegetation (predominantly regrowth), the other is on the southern side of Trigg Street in an area that contains a maintenance yard and residential housing owned by Sydney Water.

There is more land available at Quakers Hill STP and several suitable locations exist within the STP site boundary. The preferred location is a cleared area to the south east of existing facilities.

Due to the potential social and ecological issues and restricted space at St Marys STP, Quakers Hill STP was selected as the preferred site for the concentrate storage lagoon.

4.5.2 Concentrate discharge options

Two broad options for the disposal of concentrate were considered. These comprised transfer to and discharge of the concentrate stream to the Parramatta River or to one of Sydney Water's ocean outfall systems, namely:

- South Western Suburbs Ocean Outfall Sewer (SWOOS) / Malabar STP
- NSOOS / North Head STP.

The option to extract the solid component from the concentrate and dispose of it via landfill was also considered.

Table 4.7 provides an analysis of the potential discharge options and their suitability. Discharge to an ocean outfall sewer was identified as the preferred discharge option. This was further investigated to identify the feasibility of disposal to either the NSOOS or SWSOOS.

Table 4.7 Potential concentrate discharge options

Discharge option	Details	Conclusion
Parramatta River (estuarine section)	Discharge was considered into the estuarine section in the vicinity of the NSOOS near Vineyard Creek.	This option has potential negative environmental impacts due to release of the nutrient rich concentrate into a watercourse with insufficient dilution. This option was not considered further.
Ocean outfall system	Both of the outfall systems are a similar distance from the proposed AWTP. There are rehabilitation works occurring or planned for sections of the SWSOOS. NSOOS has potential capacity.	This is considered the most environmentally sustainable and cost effective method for concentrate management. **Disposal to the NSOOS is the preferred option.** Options for the discharge point to the NSOOS have been investigated.
Extracting dry salt from the concentrate	This involves an energy intensive process to remove the dissolved salts from the concentrate. The resulting solid waste would need to be disposed of to landfill.	Extraction of the salt from the concentrate is energy intensive process and extremely costly. The Western Sydney area is prone to dry land salinity and any salts would need to go to an appropriately licensed landfill. This option was not considered further.

The SWOOS/Malabar system has sections with limited hydraulic capacity and necessary rehabilitation works are planned for this system over the next decade, particularly in the North Georges River Submain (NGRS) which would be the nearest likely acceptable discharge point. As such, disposal at this location is not a viable option. The NSOOS has some available capacity to receive concentrate discharges, and there is an existing pipeline from Quakers Hill STP to Seven Hills, which is available to transfer the concentrate towards the NSOOS. The NSOOS is in good condition. Consequently, disposal of concentrate to the NSOOS was selected for further evaluation.

Among the key requirements for selecting the point of discharge is that the average level of dilution should desirably be around 10:1 to manage the risk of sulphide corrosion.

Four potential options for discharge of the concentrate stream into the NSOOS were considered. Total dissolved solids (TDS) and sulphate concentrations at these discharge points were calculated based on the average dry weather flow (ADWF) in the sewer. Details of these discharge options and the conclusions reached in terms of potential use are provided in **Table 4.8**. The TDS and sulphate concentrations presented in the table represent the worst-case result.

Table 4.8 Maximum predicted TDS and sulphate concentrates for the discharge options to the NSOOS

Discharge option	Details	Conclusion
Jean St, Seven Hills where the existing sludge disposal line joins with the NSOOS	Average dry weather flow is approximately 4.3 ML/day: • maximum TDS concentrations would be approximately 2400 mg/L • maximum sulphate concentration would be 420 mg/L.	This would result in an increased concentration of TDS and sulphate compared to the existing situation at this location in the NSOOS.
Peter Parade, Toongabbie	Average dry weather flow is approximately 30 ML/day: • maximum TDS concentration would be approximately 1340 mg/L • maximum sulphate concentration would be 190 mg/L.	This would result in an increased concentration of TDS and sulphate compared to the existing situation at this location in the NSOOS.
Downstream of the junction of the Vineyard Creek carrier with the NSOOS	Average dry weather flow is approximately 110 ML/day: • maximum TDS concentration would be 1050 mg/L • maximum sulphate concentration would be 115 mg/L.	This would result in an increased concentration of TDS and sulphate compared to the existing situation at this location in the NSOOS. **This is the preferred discharge point.**
At North Head STP	Average dry weather flow is approximately 320 ML/day: • maximum TDS concentration would be approximately 950 mg/L • maximum sulphate concentration would be 90 mg/L.	TDS and sulphate concentrations would be within the range currently experienced at the STP.

The closer the discharge point is to North Head STP, the lower the potential is for the concentrate to impact on existing assets. However, construction of the transfer system to take the concentrate closer to North Head STP would have higher costs. The costs of pipeline construction and protection against the potential for asset deterioration need to be balanced.

Based on the issues identified in **Table 4.8** and taking a conservative approach to asset management, discharge of concentrate into the NSOOS just downstream of Vineyard Creek was identified as the preferred location.

The overall condition of the NSOOS and the potential for the concentrate stream to impact on the NSOOS are discussed in **Chapter 7**.

Pipeline route options for the connection between Seven Hills and Vineyard Creek are described in **Section 4.3.7**.

4.5.3 Pipeline to Vineyard Creek

A single principal route was identified that is reasonably direct between Seven Hills and Vineyard Creek. There are a number of different options along the route. These are shown in **Figure 4.2** and described further in **Table 4.9**.

The routes have been split into the western section from the International Peace Park to the beginning of B5 at Peachtree Avenue, and the eastern section from B5 through to Dundas Railway Station.

Table 4.9 Comparison of route alternatives to the NSOOS from Seven Hills to Vineyard Creek

Route	Description	Engineering feasibility	Environmental/ social considerations
B1-B4	The pipeline commences in the International Peace Park. It crosses Blacktown Creek then passes into Hartley Rd. This then joins B2 at Prospect Rd. B2 follows along the southern side of the railway line, then passes into Carter St, then McCoy. It crosses over the railway line to join B3. B3 passes through McCoy Park just north of the residential area. Exiting the Park it joins B4 which runs parallel to Windsor Rd along a narrow 500m long service road. Option B1-B2(a) provides an alternative route through the International Peace Park. It heads south across the park, then heads east, joining up with B2 at Best Road Park. Option B1-B2(b) follows the route of B1 through the International Peace Park but continues along the north side of the railway corridor. It crosses Prospect Highway and the Bus Depot, then moves into Powers Rd then Station Rd where it joins B3. Option B3-B4 (a) continues on from the end of B2. From Portico Pde it follows a footpath northwards under the railway line, then travels eastwards along Fitzwilliam Rd to join route option B5.	• options B1 and B2 and B1-B2(a) require boring under the railway line • B1-B2(a) requires boring under Blacktown Creek • B1-B2(b) requires boring beneath three creeks but avoids crossing the railway line • boring under Greystanes Creek is required for B3, as well as a crossing of the railway line • B3-B4(a) requires boring beneath three creeks (Greystanes, Pendle and Toongabbie)	• **option B2, B3, B4 is the preferred option with option B1 preferred at the western most end** • trenched construction at Boomerang/ Hills Cres to be undertaken at night to minimise traffic disruption along B1 • night work is required for section B2 to minimise disruption to Seven Hills station • major disruption to the Seven Hills Shopping Centre would result from construction of B1-B2(a) • traffic management is required for busy Powers and Station Rds along B1-B2(b) • potential disruption to McEvoy St during B3 construction • disruption to Fitzwilliam St through construction of B3-B4(a) • for B4 the service road has been impacted by construction of the NW transitway

Route	Description	Engineering feasibility	Environmental/ social considerations
B5-B8	This section includes B5 which follows the route of Peachtree Ave. This section joins one of two options either B6 which follows the alignment of Hammers Rd then Kleins Rd, or B6(2) which takes the pipeline south-east following Briens Rd, then crosses into Redbank, joining back with B6 near the Cumberland Hospital. The route then follows the alignment of B7 through the car park of the Parramatta Correction Centre, across Belmore Park, along Belmore Rd, into Prince St, then Bettington St to Greens Ave where it joins B8. B8 continues along Greens Ave, down into Bells Rd, then crosses Robertson Pk to Dundas Railway Station.	• a 350m long boring is required for B5 under Old Windsor Rd • boring under Toongabbie Creek is required for B6 and B6(2) • B6(2) requires boring under Briens Rd. Access is difficult around Quarry Branch Creek • B7 requires boring under Pennant Hills Rd • It may be possible to connect to one of the NSOOS main carriers at Vineyard Creek, otherwise boring under Vineyard Creek and Kissing Point Rd is necessary.	• **B5, B6, B7 to B8 is the preferred route** • for B6(2) construction between Leigh Cl and Christine St would be very close to the Parramatta River • potential for disruption to the hospital during construction of B6(2) • the pipelines pass through residential areas. Traffic and social issues would need to be managed during construction.

The preferred pipeline route was selected to minimise the impacts on residences, traffic movements and watercourses.

The land use between Seven Hills and the NSOOS is predominantly residential, and as such all options considered could potentially have impacts on amenity and traffic during construction. The preferred pipeline route was selected to minimise the impacts on residences, traffic movements and watercourses.

Figure 4.2 Concentrate pipeline route (alternatives)





Part 3A process

This chapter provides an overview of the processes followed under Part 3A of the *Environmental Planning and Assessment Act 1979* for the Replacement Flows Project (the Project). It also describes the process following submission of this Environmental Assessment.

5.1 Overview

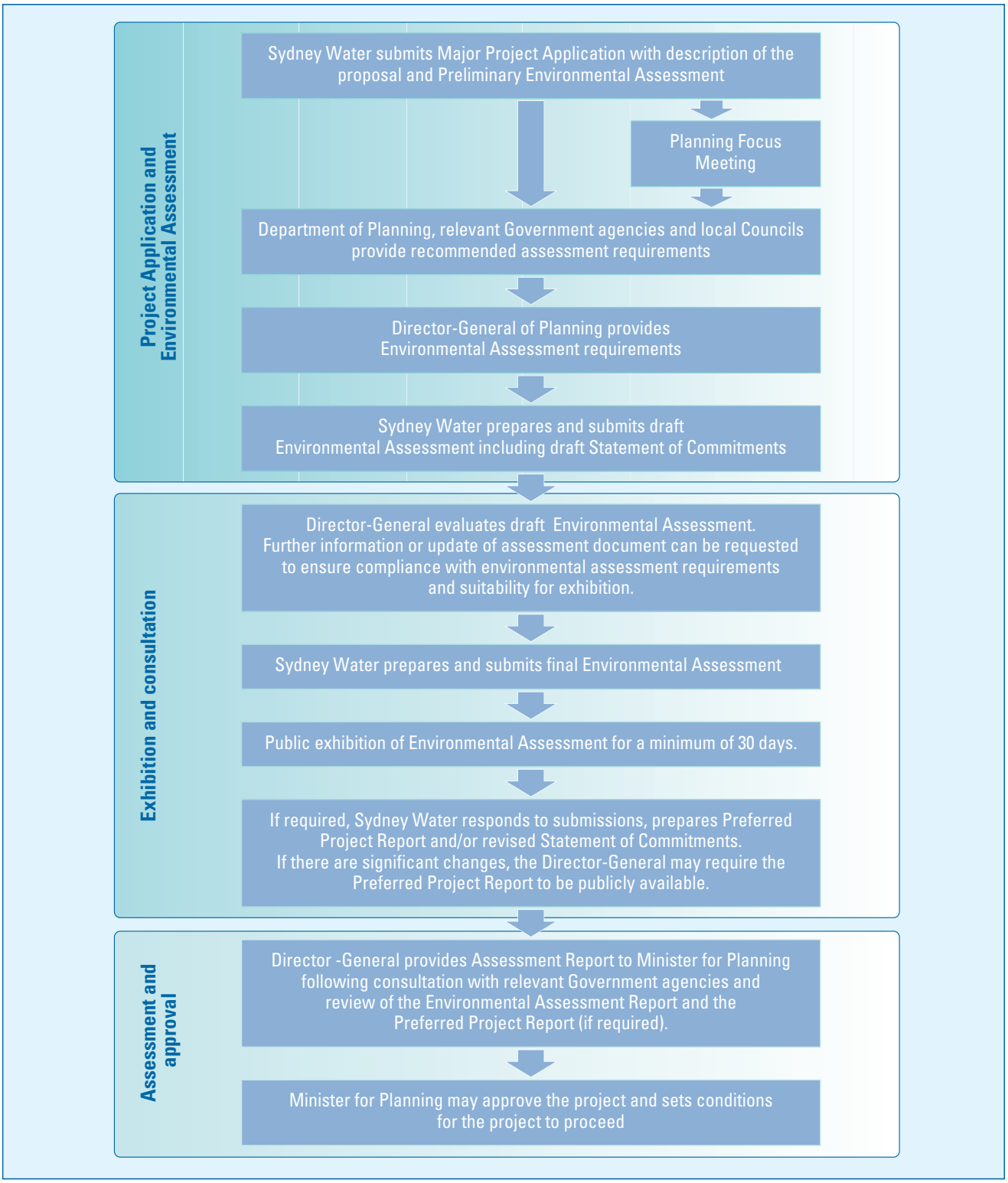
The Replacement Flows Project is to be assessed under Part 3A of the *Environmental Planning & Assessment Act 1979* (EP&A Act), which provides the assessment and approvals process for major infrastructure projects. The Minister for Planning is the approval authority for all projects assessed under Part 3A.

On 23 October 2006 the Minister for Planning declared the Replacement Flows Project to be a project under Part 3A of the EP&A Act. A copy of the Ministerial order is attached in **Appendix B**. The assessment and approval process followed for this project is described below and illustrated in **Figure 5.1**.

A project can be designated a linear infrastructure project by the Director-General for the purposes of clause 8F of the *Environmental Planning and Assessment Regulation 2000* (EP&A Regulation) if the development is for the purposes of linear transport or public utility infrastructure, or any other development on land with multiple owners. On 23 September 2006, the Director-General designated the Replacement Flows Project as a linear infrastructure project.

As the Project has been designated linear infrastructure, the consent of owners of land on which the Project is to be carried out will not be required. In accordance with clause 8F(3)(a) of the EP&A Regulation, Sydney Water placed an advertisement in local newspapers in the Project area on 17 and 18 October 2006, giving notice of the project application.

Figure 5.1 The Part 3A process for the Replacement Flows Project



5.2 Preliminary Environmental Assessment

In accordance with Department of Planning guidelines for Part 3A projects, Sydney Water submitted a Major Projects application and a Preliminary Environmental Assessment (PEA), seeking approval for the proposal from the Minister for Planning. This application, which is distinct from the Environmental Assessment, included identification of key issues for the Project. The PEA was undertaken to identify the likely key environmental issues associated with the Project. The assessment also identified:

A risk assessment process was used to establish issues that would have potentially significant impacts but may not be readily managed using standard mitigation procedures.

- the location of the Project
- any applicable planning provisions
- approvals and licences that may be required.

A risk assessment process was used to establish issues that would have potentially significant impacts but may not be readily managed using standard mitigation procedures. The issues identified by Sydney Water to be the 'key issues' were primarily related to the impact of potential changes to river water quality and quantity that may occur from the operation of the Project, and included their effect on human health, primary industries (irrigation/agriculture activities), recreational activities and aquatic ecology.

5.3 Planning Focus Meeting

The Planning Focus Meeting (PFM) was convened by the Department of Planning on 27 July 2006. The PFM provided stakeholders / statutory authorities with the opportunity to be briefed on the Project to help them identify key environmental assessment issues. It also provided a forum for participants to discuss the scope of issues and level of assessment that would be required in the Environmental Assessment. At the meeting, Sydney Water identified and discussed key technological and environmental issues associated with the main components of the proposal. Participants were invited to identify any additional key issues that would need to be addressed in the Environmental Assessment. The following stakeholders / authorities were invited to attend the meeting:

The Planning Focus Meeting (PFM) was convened by the Department of Planning on 27 July 2006.

- Department of Planning (Convenor)
- Sydney Water Corporation (Proponent)
- Western Sydney Area Health Services, NSW Health
- Department of Environment and Conservation (DEC)
- Department of Primary Industries (DPI)
- Department of Natural Resources (DNR)
- Sydney Catchment Authority (SCA)
- Premiers Department
- Hawkesbury-Nepean Catchment Management Authority
- Penrith City Council
- Hawkesbury City Council
- Blacktown City Council.

The Department of Planning also sought written recommendations for key issues from the PFM participants, including comments on the relative level of importance of these issues in the establishment and operation of the Project and hence the level of detailed assessment required in the Environmental Assessment.

Sydney Water separately contacted Baulkham Hills Shire Council and Parramatta City Council to obtain any issues and forwarded those to the Department of Planning.

Following this process, the Director-General of Planning issued requirements for the Environmental Assessment based on the outcomes of the PFM, authority consultation and the Major Projects application submitted by Sydney Water.

5.4 Environmental Assessment

The Director-General of Planning issued the requirements for the Environmental Assessment to Sydney Water on 1 September 2006. The requirements are attached in **Appendix B**.

The Environmental Assessment has been prepared in accordance with the draft guidelines for assessment of major projects under Part 3A of the *Environmental Planning & Assessment Act 1979* and the Environmental Assessment requirements issued by the Director General of Planning for the Project. **Table 5.1** presents a summary of the requirements and where they are addressed in the Environmental Assessment.

Table 5.1 Environmental assessment requirements and where they are addressed in the document

Item to be addressed	Requirement	Chapter of Environment Assessment
General Requirements	Executive summary	Summary of Environmental Assessment
	Description of the proposal including construction operation and staging	Chapter 3
	Assessment of environmental impacts with a focus on key issues	Chapters 7 and 8
	Justification for undertaking the proposal with consideration of benefits and impacts	Chapter 10
	Draft Statement of Commitments	Chapter 11
	Certification by the author	Front of Environmental Assessment
Project Scope, Technology and Operation	Detailed description of the Project, its components and technology, any staging and interfaces with existing sewage treatment plants and infrastructure	Chapter 3
	Consideration of wastewater technologies for removal of key water quality constituents. Particular consideration must be given to readily bioavailable forms of nutrients	Chapters 4 and 7
	Details of proposed wastewater treatment process, evaluation of alternative processes	Chapters 3 and 4

Table 5.1 Environmental assessment requirements and where they are addressed in the document *(cont'd)*

Item to be addressed	Requirement	Chapter of Environment Assessment
Project Scope, Technology and Operation *(cont'd)*	Details of brine management, including measures to ensure overflows in exceptional circumstances only. Considerations to include options for storage capacity at St Marys STP, or elsewhere, increased sewer capacity or reduced wet weather infiltration, reduction of throughput of AWTP	Chapters 3 and 7
	Details of current NSOOS condition, capacity and future capacity to accept brine waste	Chapter 7
	Details of the expected composition of brine	Chapters 3, 4 and 7
	Likely frequency and volume of overflows and loads discharged during these events	Chapters 3, 4 and 7
	Capacity of St Marys STP to receive backwash waste and any impacts on the STP	Chapter 3
	Pipeline routes, construction methods and construction environmental management	Chapters 3 and 8
	Maps of Project components including pipelines and showing an indication of land tenure and zoning	Chapter 3
Strategic Planning and Project Context	Strategic content of the Project, with regard to *2006 Metropolitan Water Plan*. Context of the Project within suite of other relevant water supply, recycling and demand management projects	Chapter 2
Water Quality and Water Cycle Management	Position of the Project within Hawkesbury-Nepean system, alteration of flows due to the Project. Effect on flow rates and water balance across the system during wet and dry weather	Chapter 7
	Design and operation of the Project to meet ANZECC guidelines (STP and AWTP)	Chapter 7
	Likely water quality impacts of replacement flows in wet and dry weather with reference to total nitrogen, phosphorus, ammonia and total dissolved solids	Chapter 7
	Likely water quality impacts from reduced St Marys and Quakers Hill STP discharges	Chapter 7
	Likely impacts from cessation / alteration of Warragamba flow releases from dam wall to Penrith Weir	Chapter 7
	Protection or not compromise water quality and river flow objectives and contribution to the achievement of these objectives	Chapter 7
	Monitoring framework for impacts on water quality and aquatic ecology	Chapter 7

Table 5.1 Environmental assessment requirements and where they are addressed in the document *(cont'd)*

Item to be addressed	Requirement	Chapter of Environment Assessment
Impacts on ecology	Terrestrial and aquatic ecological impact assessment (direct and indirect impacts)	Chapters 7 and 8
	Consistency with *NSW State Rivers and Estuaries Policy*	Chapters 2 and 7
	Focus on Warragamba Dam to Penrith Weir and downstream of the three STPs addressing: • fish movement (past Boundary Creek and Penrith Weir) • migratory fish species • aquatic weed growth • flow regime changes in South, Eastern, Breakfast and Ropes Creeks and ecological impacts • stability of Boundary Creek, measures to rehabilitate banks and beds	Chapter 7
	Demonstrate design philosophy of avoiding and minimising impacts. Identify any impacts on terrestrial endangered ecological communities and, where relevant, detail mitigation, management and off-set measures	Chapter 8
Human Health impacts	Detailed assessment of impacts on current users of the Hawkesbury-Nepean River system, including microbiological and chemical hazards (including cumulative effects) including: • consumers of drinking water drawn from the river with and without further treatment • recreational users including swimming, water skiing, use of water craft • irrigators and potential implications from use of water on produce • residents using water for non potable private use • irrigation of public open spaces • any other significant use that may impact on human health	Chapter 7
Noise and vibration impacts	Consider noise and vibration impacts during construction and operation and in a cumulative context through: • assessment of noise impacts in accordance with *NSW Industrial Noise Policy* (EPA 2000) and noise control guidelines *Construction Site Noise* • assessment of vibration in accordance with DEC's *Environmental Noise Management - Assessing Vibration: a Technical Guideline*	Chapter 8

Table 5.1 Environmental assessment requirements and where they are addressed in the document *(cont'd)*

Item to be addressed	Requirement	Chapter of Environment Assessment
Waste generation and management	Detail the likely quantities and qualities generated during construction and operation. Focus on sludges, solids and aqueous wastes during operation, including details of appropriate waste management and disposal options	Chapter 8
General environmental risk analysis	Include an environmental risk analysis to identify potential impacts (construction and operation), proposed mitigation measures and potentially significant residual environmental impacts after the application of proposed measures Any additional key environmental impacts identified through the risk analysis as significant, to undergo appropriately detailed impact assessment	Chapter 8
Consultation Requirements	Appropriate and justified consultation with: • Department of Environment and Conservation • NSW Department of Primary Industries • NSW Department of Health • NSW Department of Natural Resources • Hawkesbury-Nepean Catchment Management Authority • Sydney Catchment Authority • Relevant local Councils Appropriate consultation with the local community should be undertaken Indicate issues raised by stakeholders during consultation and how they have been addressed in the EA	Chapter 9

5.4.1 Key issues

The Environmental Assessment requirements nominate 'key issues' to be addressed in the Environmental Assessment. As identified in **Table 5.1**, the 'key issues' relate to the Project scope, technology and operation, strategic context of the Project, water quality and water cycle management, impacts on ecology and human health, noise and vibration and waste generation and management.

Chapters 3 and **4** deal with the scope of the Project, treatment technologies and processes and the operation of the Project.

Chapter 7 addresses water quality and water cycle management, integrating the assessment with the management of impacts on aquatic ecology, human health and waterway usage. It provides a comprehensive assessment of the effects of changes to water quantity and quality that could occur from the operation of the Project and how these changes may affect the economic, social and environmental values of the waterways. Specifically, the issues addressed are human health, primary industries (irrigation/agricultural activities), recreational activities and aquatic ecology.

The assessment is undertaken in the context of waterway reaches, as follows:

- Warragamba River (downstream of the dam wall)
- Hawkesbury-Nepean River
  - Nepean River (Wallacia Weir to Penrith Weir and Penrith Weir to Yarramundi)
  - Hawkesbury River (Yarramundi to South Creek and South Creek to Sackville)
  - Tributaries (Eastern Creek and South Creek).

Other key issues comprising terrestrial ecology, noise and vibration and waste management are addressed in **Chapter 8**.

5.4.2 Other issues

The Environmental Assessment requirements also refer to a range of 'other issues' that are not considered to be 'key issues'. These issues are considered to be of minor significance following a general environmental risk analysis and can be readily mitigated by standard work practices and safeguards. These issues do not present any significant constraints for the Project. 'Other issues' for the Project are addressed by identifying risks and formulating measures that can mitigate those risks. Other issues are addressed in **Chapter 8**.

5.5 Exhibition

The Environmental Assessment was finalised following the Director-General's pre-exhibition evaluation of the document's adequacy. In accordance with EP&A Act the Environmental Assessment for the Project will be publicly exhibited for at least 30 days. During this time Sydney Water will provide community information on the Project, in accordance with Department of Planning guidelines.

In accordance with EP&A Act the Environmental Assessment for the Project will be publicly exhibited for at least 30 days.

The Department of Planning will receive any submissions in response to the Environmental Assessment and forward them to Sydney Water. The Director-General may require Sydney Water to respond to issues raised in those submissions, prepare a Preferred Project Report that outlines any proposed changes to the Project to minimise its environmental impact and provide a revised Statement of Commitments. If any significant changes are proposed to the nature of the Project, the Director-General may require the Preferred Project Report to be made available to the public.

Following Sydney Water's response to submissions and/or a Preferred Project Report, the Director-General will prepare an assessment report giving consideration to the submissions received. This report will be provided to the Minister for Planning who may issue an approval and set conditions for the Project.



6 Regulatory requirements

This chapter outlines local, NSW and Commonwealth regulatory requirements for the Replacement Flows Project (the Project) and their relevance. It also summarises any licences and approvals required.

6.1 Local and regional planning

Land use planning in NSW is controlled by the requirements of the *Environmental Planning and Assessment Act 1979* (EP&A Act) (as amended) and its regulation. The EP&A Act allows the creation of environmental planning instruments, which include local environmental plans, regional environmental plans and state environmental planning policies, as well as other policies and guidelines including development control plans.

The Project is located within the Penrith, Parramatta, Baulkham Hills and Blacktown Local Government Areas. The Local Environmental Plans (LEPs) relevant to the proposed Project are:

The Project is located within the Penrith, Parramatta, Baulkham Hills and Blacktown Local Government Areas.

- Penrith Local Environmental Plan 1996
- Parramatta Local Environmental Plan 2001
- Baulkham Hills Local Environmental Plan 2005
- Blacktown Local Environmental Plan 1988.

The local planning zonings through which the development passes are indicated in **Table 6.1** and shown in **Appendix A**. Land use zoning also applies in certain regional environmental plans and these are described in **Table 6.2** and shown in **Appendix A**. The proposed works are mostly permissible under the current land zonings and are generally consistent with the objectives of these local and regional environmental plans.

The construction and operation of the proposed pipelines are permissible under all local land use zonings identified in **Table 6.1**, except "Public Transport Corridor (Church St) Clause 13" under the Parramatta LEP. This zoning is defined by the Sydney Regional Environmental Plan (SREP) 18 – Public Transport Corridors, and discussed in **Table 6.2**. In this area public utility undertakings are prohibited. In SREP 28 – Parramatta public utility undertakings (as indicated in **Table 6.2**) are prohibited in a number of precincts through which the concentrate pipeline passes.

It should be noted that the Project is not wholly prohibited in either SREP 18 or SREP 28 and therefore the Minister for Planning is able to grant project approval for the whole project under Section 75J of the EP&A Act. In addition, environmental planning instruments (other than SEPPs) do not apply to an approved project under Part 3A of the Act.

Table 6.1 Applicable zonings under local environmental plans

Local Government Area	Zonings
Penrith	General Industrial 4 (a) Public Recreation 6 (a) State Road and State Road Widening 5 (c) Regional Open Space (SREP 30) Regional Parkland (SREP 30) Urban (SREP 30) Drainage (SREP 30) Residential – Low Density 2 (b) Special Uses - Notation
Blacktown	Special Uses – General 5(a) Special Uses – Arterial Road and Arterial Road Widening Special Uses – Local Road and Local Road Widening 5 (c) Residential A County Open Space 6 (c) Public Recreation 6 (a) General Business 3 (a)
Parramatta	Residential 2 (a), (b), (c) & (e) Employment Special Uses Public Open Space 6 (a) Environmental Protection (Bushland) Mixed Use Public Transport Corridor (Church St), Clause 13
Baulkham Hills	Residential 2 (a2) Special Uses - Existing and Proposed Roads 5 (b)

Full details on the applicability of regional environmental plans are described in **Table 6.2.**

Table 6.2 Regional environmental plans

Plan	Relevance to this Project
Sydney Regional Environmental Plan 20 - Hawkesbury -Nepean River (No. 2 1997)	The Project is consistent with the aims of the Sydney Regional Environmental Plan No. 20 – Hawkesbury-Nepean River No. 2 1997.
Sydney Regional Environmental Plan 18 – Public Transport Corridors	The aim of this plan is to make provision for future public transport facilities. The plan identifies areas as public transport corridors which include Church Street at North Parramatta (beneath which the concentrate pipeline is proposed). Only work for public transport purposes and reconstruction, improvement, maintenance or repair of any road is permitted in a public transport corridor; all other activities are prohibited.
Sydney Regional Environmental Plan 19 – Rouse Hill Development Area	The Rouse Hill Development Area covers approximately 9,400 hectares and occurs along the north east boundary of the project area to the east of Stoney Creek Road and generally north of the M7 Motorway. The northern extent of Quakers Hill STP and the proposed transfer pipelines from Quakers Hill STP to St Marys STP are situated within the Rouse Hill Development Area.
Sydney Regional Environmental Plan 28 - Parramatta	This plan divides the Parramatta Primary Centre into 8 precincts and establishes regional planning aims for each precinct. The concentrate pipeline passes through "Precinct 3 – Government, Precinct 4- Westmead and Precinct 7 - North". The SREP adopts the model provisions and thus permits construction of the pipeline without consent in Precinct 3. Public utility undertakings are prohibited in Precincts 4 and 7.
Sydney Regional Environmental Plan 30 – St Marys	The proposed transfer pipelines generally follow the southern boundary of land covered by the Sydney Regional Environmental Plan 30 – St Marys, passing through the Urban Zone, Regional Park Zone, Drainage Zone and Regional Open Space Zone. The Sydney Regional Environmental Plan 30 – St Marys adopts Schedule 1 of the Model Provisions and allows public utility undertakings without development consent.
Sydney Regional Environmental Plan 31 – Regional Parklands	The proposed transfer pipelines are located within the northern most extent of the Sydney Regional Environmental Plan 31 – Regional Parklands between Quakers Hill STP and Dean Park residential area. The Sydney Regional Environmental Plan 31 – Regional Parklands adopts Schedule 1 of the Model Provisions and allows public utility undertakings without development consent.

6.2 State environmental planning policies

Two State environmental planning polices of relevance to the project are described in **Table 6.3**.

Table 6.3 State environmental planning policies and their requirements

Policy	Relevance to this Project
State Environmental Planning Policy 29 – Western Sydney Recreation Areas	The primary aim of this policy is to enable carrying out of development for recreational, sporting and cultural purposes within the Western Sydney Recreation Area. The policy allows public utility works to be undertaken within the Western Sydney Recreation Area without development consent.
State Environmental Planning Policy (SEPP) 4 - Development without Consent and Miscellaneous and Complying Development	Under SEPP 4, Sydney Water may undertake development, being construction of sewage treatment works, without development consent. This policy applies as the advanced water treatment plant (AWTP) is treating sewage effluent and the associated pipelines leading to the plants (STPs and AWTP) are part of the sewage treatment works.

6.3 Other NSW legislation

NSW legislation relevant to the Project is described in **Table 6.4.**

Table 6.4 NSW State legislative requirements

Legtislation	Relevant requirements	Analysis of project application
Occupational Health & Safety Act 2000 & Regulation 2001	Requires a manifest to be kept at premises where dangerous goods are stored and handled in quantities that exceed the relevant quantities specified in Schedule 5 of the Regulation.	Chemical storage and handling of dangerous goods will be required for the operation of the Project. The requirement for a manifest and notification to WorkCover is assessed for each site in Chapter 8.
National Parks and Wildlife Act 1974	This Act provides for the protection, preservation and management of all Aboriginal relics throughout New South Wales.	Desktop studies indicate that Aboriginal sites may be located in undisturbed areas, particularly along creeklines. Aboriginal archaeology surveys have been undertaken within those areas, and the results are discussed in Chapter 8. Appropriate management actions would be implemented, such as pipeline route diversions, to minimise indigenous cultural impacts and flora and fauna impacts.
Protection of the Environment Operations Act 1997	This Act is administered by the DEC. It requires licences for environmental protection including waste, air, water and noise pollution control. Under this Act it is an offence to pollute without an environment protection licence.	Environmental Protection Licences would be required for the construction and operation of the Project. Liaison with the DEC would determine appropriate licence requirements.

Table 6.4 NSW State legislative requirements *(cont'd)*

Legtislation	Relevant requirements	Analysis of project application
Threatened Species Conservation Act 1995	The *Threatened Species Conservation Act 1995* provides protection for threatened plants and animals native to NSW (excluding fish and marine vegetation, which are protected under the *Fisheries Management Act 1994*), endangered ecological communities and critical habitat. It integrates the conservation of threatened species into development control processes under the *Environmental Planning and Assessment Act* 1979.	Flora and fauna surveys have been conducted to determine the presence of threatened species within areas containing native vegetation or native fauna habitats at locations where significant construction disturbances would occur. Potential impacts would be managed by adopting the design principle of placing the proposed infrastructure within previously disturbed areas which do not contain significant flora or fauna or by boring the pipeline under sensitive areas. This is discussed in Chapter 8.
Fisheries Management Act 1994	The Act provides for the conservation of the State's aquatic resources and is administered by the Department of Primary Industries. The Act requires that potential impacts on threatened species and aquatic habitat be addressed during the environmental planning and assessment process.	Reviews of available data on fish and other aquatic species have been conducted to determine the presence of threatened species within the relevant parts of the Hawkesbury-Nepean catchment. Potential impacts would be managed by managing water quality and flow within the waterways. This is discussed in Chapter 7. An assessment was made of the potential for effects on fish passage at Penrith Weir. This would be managed by managing flows and discharge locations. This is discussed in Chapter 7.
Water Management Act 2000	This Act applies for waterways subject to a gazetted Water Sharing Plan. A Water Sharing Plan is in preparation for the Sydney area/ Hawkesbury-Nepean River.	The Project will conform with the requirements of the Water Sharing Plan, once gazetted.
Water Act 1912	The current releases from Warragamba Dam are defined in a licence issued under Part 9 of the *Water Act*. The licence is held by the SCA.	Any licences for water discharge will be obtained or existing licences modified, as required.
Heritage Act 1997	This Act provides for the conservation of the State's natural and built heritage.	The pipeline passes close to two State Heritage Register items – Parramatta Correctional Centre and Seven Hills Railway Group.The pipeline will be directionally bored and will be several metres below the ground surface to avoid any impacts.

6.3.1 Plans made under legislation

Fish Habitat Protection Plan No. 1 General and Habitat Protection Plan No.3 – Hawkesbury Nepean

To assist in the protection of key fish habitats, the *Fisheries Management Act 1994* enables the Minister for Fisheries to make habitat protection plans for the protection of any fish habitat, whether the habitat is critical for the survival of the species or required to maintain harvestable populations of fish. The Department of Primary Industries - Fisheries has prepared and administers three habitat protection plans: *Fish Habitat Protection Plan No.1 General, Fish Habitat Protection Plan No.2 Seagrasses and Habitat Protection Plan No.3 - Hawkesbury-Nepean River System*. The Project would not have an impact on the marine environment and this assessment does not address the objectives of *Fish Habitat Protection Plan No.2 Seagrasses*.

The Project would not have an impact on the marine environment.

Fish Habitat Protection Plan No.1 General deals broadly with dredging and reclamation activities, fish passage requirements, the protection of mangroves, seagrasses and other marine vegetation and the importance of snags. The Project would not include activities that would be inconsistent with the objectives of *Fish Habitat Protection Plan No.1 General*. An assessment of the effects of the Project on fisheries matters is provided in **Section 7.5.**

Habitat Protection Plan No.3 - Hawkesbury-Nepean River System recognises the role of total catchment management and integrated management, whilst helping authorities to recognise their responsibilities in relation to fish habitat protection. It outlines management strategies and protection measures for aquatic habitats essential for the spawning, nursery, shelter and feeding requirements of fish in the river. Habitat Protection Plan No.3 states that "a public authority is required to incorporate the conservation of fish habitat as a criterion in their decision making and management processes. In practical terms, public authorities must notify NSW Fisheries whenever they (1) intend to undertake works or activities that may affect fish habitat or (2) consider such a proposal by a third party. These authorities must then fully consider any advice given to them by NSW Fisheries regarding such works, activities or proposals." An assessment of potential affects of the Project on fish habitat matters is provided in **Section 7.8**. The NSW Department of Primary Industries - Fisheries have been consulted in regards to the affects of the Project on fish habitats within the Hawkesbury-Nepean River system.

NSW State Rivers and Estuaries Policy

The volumes discharge to Boundary Creek from Penrith STP would be increased, but this would not result in an increased level of erosion of Boundary Creek .

The overall objective of this policy is to encourage sustainable development of the natural resources in order to reduce and where possible halt declining water quality, loss of riparian vegetation, damage to riverbanks and channels, loss of biodiversity and declining natural flood mitigation. The Project would be consistent with the intentions of this policy in that the flow changes in Hawkesbury-Nepean River would be such that there would be no impacts on bank erosion. Eastern and South Creeks currently receive discharges from Quakers Hill and St Marys STPs. Flow volumes in these creeks would be reduced. The volumes discharge to Boundary Creek from Penrith STP would be increased, but this would not result in an increased level of erosion of Boundary Creek .

6.4 Commonwealth legislation

The project has the potential for effects upon the threatened species, Grey-headed Flying Fox, Macquarie Perch and Australian Grayling, and the endangered ecological community, Cumberland Plain Woodland, all of which are listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The Project was referred to the Commonwealth Department of Environment and Heritage under the EPBC Act to determine whether the proposed action constitutes a "controlled action" and requires approval under the EPBC Act.

On 10 October 2006 the Commonwealth Minister for Environment and Heritage advised that the Project is not likely to have a significant impact on any matters protected under the EPBC Act and is therefore not a controlled action.

6.5 Licences and approvals

Licences and approvals required for the Project are summarised in **Table 6.5**.

Table 6.5 Licences and approvals

Reference	Requirements	Licence/ approval to be obtained	Timing
Occupational Health & Safety Act 2000 & Regulation 2001			
Section 135A (Act) Section 174ZN (Regulation)	Keep a manifest of specified dangerous goods and notify Workcover	Goods exceeding the transported and stored volumes have been identified. Preparation of a manifest and notification will occur for these goods	Prior to operation
Protection of the Environment Operations Act 1997			
Section 43 (a), 55, 122.	The owner or operator of a premise that is engaged in scheduled activities is required to hold an environment protection licence	Construction licence Operation licence	Construction licence - Prior to construction Operation licence – Prior to operation



River health and water users

This chapter describes the existing condition of the project area and includes an assessment of the potential impacts of the Project on the key issues of river health (such as water quality, flows and aquatic ecosystems) and existing uses (such as boating, swimming, fishing, providing water for agriculture and drinking).

7.1 Overview

The Replacement Flows Project (the Project) and its associated infrastructure would be located in the Hawkesbury-Nepean River catchment. The Project's primary objective is to produce highly treated recycled water using tertiary treated effluent from three existing sewage treatment plants (STPs) in the catchment to replace environmental flow releases from Warragamba Dam. As well as changes in flows, resulting from the cessation of the Warragamba Dam flow release and its replacement with up to 50 ML/day of highly treated recycled water, there would be changes in water quality due to the discharge of the highly treated recycled water and the reduction in discharges of tertiary treated effluent from the three STPs.

Key issues have been identified based on an initial risk assessment undertaken by Sydney Water, issues identified by Government agencies in the Environmental Assessment Requirements and preliminary consultation with other stakeholders groups. The Project must consider the key assessment requirements (key issues) for:

- Water Quality and Water Cycle Management – This includes impacts upon water quality (see **Section 7.4**), flow volumes and patterns (see **Section 7.3**), and water users (see **Section 7.7** and **7.8**) in the study area.
- Ecology – Aquatic ecosystems in the river are sensitive to changes in flow and water quality (see **Section 7.5**).
- Human health – The potential risks to human health of the replacement flows discharge needs to be assessed for a number of possible scenarios (see **Section 7.6**).

This chapter provides a description of the existing condition of the project area, characteristics of the key issues and an assessment of the potential impacts of the Project on these key issues. As noted earlier, changes in water quality and flows in the study area would largely determine the

impact upon the key issues, and therefore a detailed assessment of the changes in these environmental aspects will provide the basis for the assessment of the key issues. A detailed impact assessment containing studies specifically undertaken for the Project is contained in **Appendix C**.

Other key issues requiring detailed consideration include terrestrial ecology, noise, vibration and waste generation and management. These issues are assessed in detail in **Chapter 8**.

It is recognised that the Project could potentially have impacts upon other environmental aspects such as heritage, hazards, soils and air quality. The Project has been developed to minimise its impacts on these environmental aspects, wherever possible, and the impacts would be minor and/or able to be managed through recognised procedures. Information on the impact of the Project on these other aspects is also presented in **Chapter 8**.

In 2009, a number of river and water cycle management activities will be implemented in addition to the Replacement Flows Project. They are:

- modification of weirs in the Upper Nepean River to allow environmental flows to be passed downstream
- greater control over the volume and timing of agricultural water extraction from the Upper Nepean River to protect low flows
- increased environmental flow releases from the Upper Nepean dams, as described in the *2006 Metropolitan Water Plan*
- the upgrade of West Camden STP to improve the quality of effluent discharged into the Upper Nepean River
- implementation of new local and residential water recycling schemes.

In undertaking the assessment of the impacts and benefits of the Project, it has been assumed that all of these activities will be in place when the Project begins operation. As a result, the impacts and benefits of the Project cannot be considered in isolation of these activities. Therefore, the assessment of the Project's predicted impacts in 2009 includes the water flow and quality conditions that would result from the river and water cycle management activities listed above. These conditions are referred to as the '2009 flow' and 'water quality conditions' within this assessment.

7.2 Description of study area

The Hawkesbury-Nepean River system extends from the freshwater reaches of the Nepean River and its tributaries into a freshwater tidal environment below Yarramundi and into an estuarine environment generally downstream of Sackville.

The Hawkesbury-Nepean River system extends from the freshwater reaches of the Nepean River and its tributaries into a freshwater tidal environment below Yarramundi and into an estuarine environment generally downstream of Sackville. Impacts on recreation, water extraction, river flows, water quality and aquatic ecology of the river system vary, depending upon land use practices within the catchment, inflows from further upstream and the presence of tidal flushing.

The Nepean River drains a large catchment area, and the river itself can be divided into the upper, mid and lower Nepean River. The upper Nepean River includes the Nepean, Avon, Cataract and Cordeaux Dams and the tributaries downstream of the dams. The mid Nepean River catchment is controlled by numerous weirs, including Maldon Weir at its upper reaches and Wallacia Weir at its downstream end. Intensive rural and agricultural areas, urban areas and West Camden STP also affect the mid Nepean River.

The lower Nepean River catchment extends from Warragamba River inflow to Yarramundi upstream of the Grose River inflow, where it becomes the

Hawkesbury River. This section of the river drains a variety of land uses including agricultural and grazing land and urban and industrial areas such as Penrith. The river also receives the discharge of tertiary treated effluent from Penrith STP (downstream of Penrith Weir) and Winmalee STP (near the Grose River). It is the lower Nepean River that forms the key part of the study area for this assessment. This section of the Nepean River has been separated into two reaches for consideration of impacts (see below).

Below Yarramundi, the Nepean River becomes the Hawkesbury River. Like the Nepean, the Hawkesbury River drains a large catchment area and can be divided into the Upper and Lower Hawkesbury River. The upper Hawkesbury River extends from the tidal limit of Yarramundi to Lower Portland. Water quality and aquatic health are influenced by the quality of the Nepean River inflow and by the catchment it drains. The catchment comprises the urban areas of North Richmond, Richmond and Windsor, agriculture and inflows from South, Eastern and Cattai Creeks. The Lower Hawkesbury River is a tidal estuary, extensively used for recreational and commercial fishing. Its water quality and aquatic health are influenced by the upper Hawkesbury River and inflows from Colo and Macdonald Rivers, and Mangrove and Mooney Mooney Creeks. Due to regular tidal flushing, the water quality in the lower estuary is generally considered to be good.

For the purposes of this assessment the Hawkesbury-Nepean River and its tributaries have been separated into a series of reaches that are assessed in a downstream direction from the freshwater reaches of the Nepean and Warragamba Rivers to the freshwater tidal zone.

For the purposes of this assessment the Hawkesbury-Nepean River and its tributaries have been separated into a series of reaches that are assessed in a downstream direction from the freshwater reaches of the Nepean and Warragamba Rivers to the freshwater tidal zone. These are river reaches that would be potentially affected by the Project and include (see **Figure 7.1**):

- Warragamba River
- Wallacia Weir to Penrith Weir (Nepean River)
- Penrith Weir to Yarramundi (Nepean River)
- Yarramundi to South Creek (Hawkesbury River)
- South Creek to Sackville (Hawkesbury River)
- South and Eastern Creeks.

7.2.1 Description of river reaches

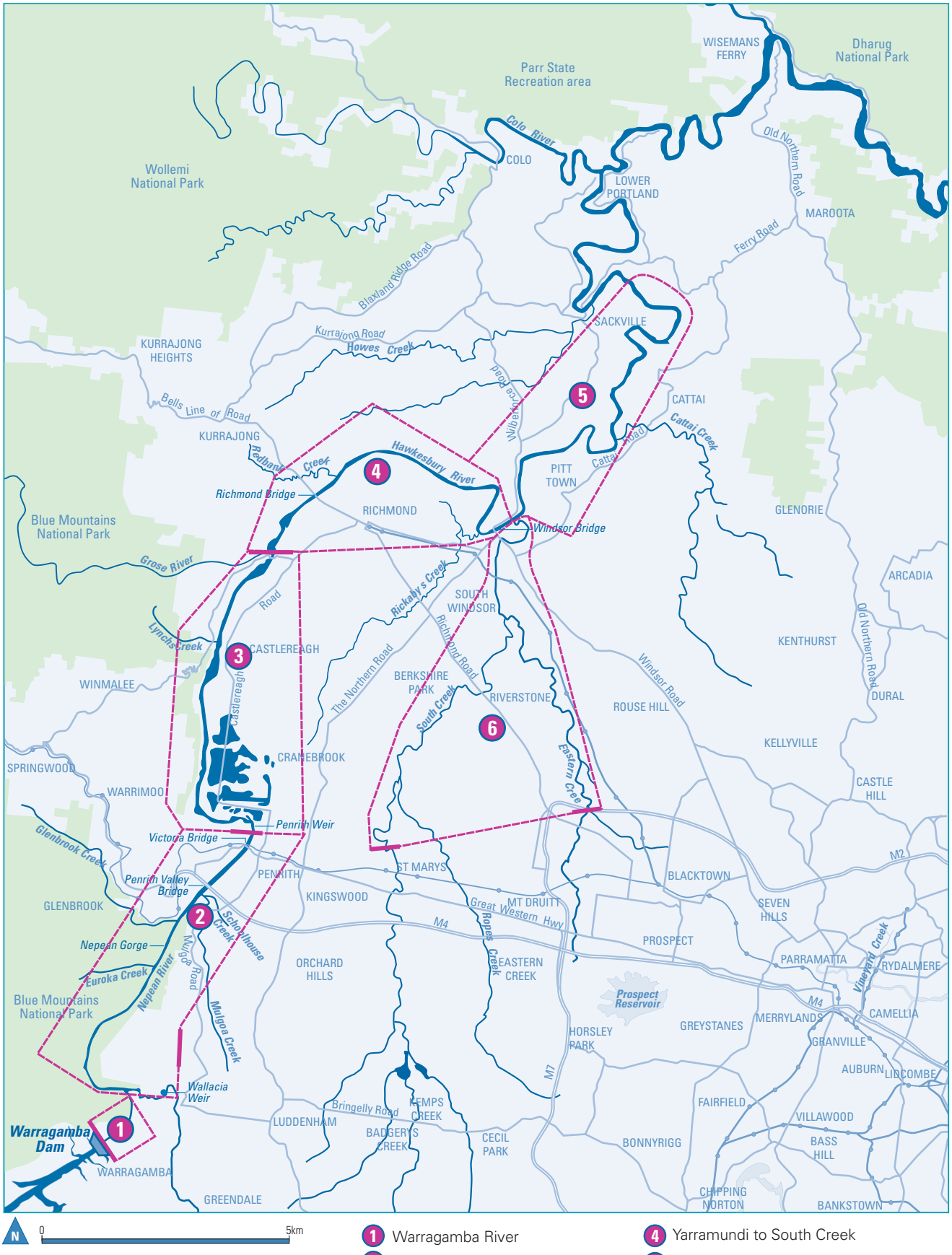
Warragamba River

The Warragamba River catchment supports the major water supply system for Sydney - Lake Burragorang (Warragamba Dam). The study area includes the section of the river downstream of the dam wall and extends to its junction with the Nepean River.

The Warragamba River downstream of Warragamba Dam to the Nepean River comprises:

- a 1.4 km reach immediately downstream of the dam to the Warragamba River weir. This reach does not receive any environmental flow releases and has been reduced to minor flows comprising dam seepage, groundwater discharge, catchment runoff and very occasional dam spills
- a further 2.1 km, comprising drowned pools and rock-bar sequences. The Penrith Weir pool backs up the Warragamba River almost to the Warragamba River Weir, drowning out the pools and rock-bars to depths ranging from approximately 0.5 – 11 m depth. Flow releases from Warragamba Dam and the new Wallacia STP currently discharge into this section.

Figure 7.1 River reaches



Hawkesbury-Nepean River

- Wallacia Weir to Penrith Weir (Nepean River)

  This reach is situated upstream of Boundary Creek (the discharge location of Penrith STP and the Project). Wallacia Weir, the upstream extent of the study area, controls flows from the upper Nepean River and its dams. Below Wallacia Weir, the river traverses through gorge country and receives inflows from the Warragamba River, which includes current flow releases from Warragamba Dam. Flow velocities slow as the river approaches Penrith Weir. This river reach is regulated by Penrith Weir, behind which a 6000 ML weir pool has formed. The typical residence time for dry weather flow releases from Warragamba Dam is 180 days.

- Penrith Weir to Yarramundi (Nepean River)

  This reach commences downstream of Penrith Weir and includes Boundary Creek, which is the current discharge location for Penrith STP and would be the discharge location for the replacement flows. Winmalee STP also discharges into this reach of the river further downstream.

  This reach of the river generally has higher flow velocities in comparison with other river reaches, as it is unregulated (.e. no downstream dams or weirs). Flow velocities decrease, however, near Yarramundi due to the effects of the natural freshwater tidal pool in the downstream river reaches. There are still some remaining riffle zones in this river reach, although sedimentation and other river processes have resulted in a decrease in their quality. There are a number of tributaries which inflow into this river reach, most notably the Grose River that provides significant volumes of water, even in dry weather.

- Yarramundi to South Creek (Hawkesbury River)

  This reach commences at Yarramundi and extends to the junction of South Creek. Tertiary treated effluent from Quakers Hill and St Marys STPs enters at the lower end of this reach via South Creek. The reach is in the freshwater tidal section of the river, with its hydrology dominated by the freshwater tidal pool that forms behind the saline intrusion from the estuary and ocean. The vast majority of water in the freshwater tidal pool is from large, wet weather events rather than dry weather inflows. This reach is a source of water for irrigated agriculture and horticulture. It is from this reach that North Richmond Water Filtration Plant extracts water from the river to supply drinking water for local urban areas. This plant treats up to 50 ML/day and supplies high quality drinking water to 16,000 lots in the Hawkesbury region, including North Richmond, Richmond, Toorah, South Windsor, Pitt Town, Wilberforce, Kurrajong and Glossodia.

- South Creek to Sackville (Hawkesbury River)

  The South Creek to Sackville reach has largely the same characteristics as described for the Yarramundi to South Creek reach. This river reach is affected more substantially by the inflow of South Creek, especially in dry weather when STP discharges dominate flows. Water extraction for agriculture and horticulture are important existing uses of this reach.

South and Eastern Creeks

South Creek originates north of Narellan and flows into the Hawkesbury River at Windsor, downstream of Fitzroy Bridge. The tributaries feeding South Creek include Badgerys, Ropes, Kemps and Rileys Creeks. South Creek is freshwater tidal at its downstream reaches.

There are a number of land uses that influence the water quality of South Creek, its tributaries and the Hawkesbury River near Windsor. These land uses include rural, grazing and market gardeners, intensive agriculture such as poultry farming, and both urban and industrial land uses. South Creek also receives tertiary treated effluent discharged from St Marys STP and Hawkesbury Council's South Windsor STP.

Eastern Creek is a major tributary of South Creek and their confluence is near Riverstone. Eastern Creek receives tertiary treated effluent from Riverstone and Quakers Hill STPs.

7.2.2 Existing impacts in the catchment

The Hawkesbury-Nepean catchment supports a variety of land uses including agricultural, rural, industrial and urban. Each of these land uses contributes to the health of the river system. Direct impacts include discharges from industrial sites and STPs. Catchment runoff also transports pollutant loads, including nutrients and bacterial contamination, to the river.

High nutrient levels can result in eutrophic conditions and are a contributing factor for increased growth of exotic aquatic plants and the occurrence of algal blooms. During drought and dry weather conditions, STPs contribute the majority of nutrient loads to the Hawkesbury-Nepean River and its tributaries. During normal (non-drought) conditions, diffuse sources contribute the greatest load of nutrients to the Hawkesbury-Nepean River catchment. The following provides an overview of the diffuse and non-diffuse sources that affect water quality within the Hawkesbury-Nepean River system with a focus on nutrients.

Diffuse sources

Agricultural run-off is one of the most significant diffuse pollutant sources in the catchment, with run-off from improved and irrigated pasture, market gardening, pig and poultry production and processing, dairying and turf farms. Other diffuse sources such as run-off from coal mining, transport and urban areas also contribute significant pollutants.

The relative contribution of nutrient sources to the whole catchment (including areas outside the study area) is shown in **Figure 7.2** and **Figure 7.3**.

Diffuse sources contribute 88 per cent of total nitrogen and 94 per cent of total phosphorus loads to the river.

The catchment is diverse and certain sections are also significantly stressed by urban stormwater run-off. Stormwater run-off into the river contains suspended solids, nutrients, oils and grease, faecal coliform bacteria, toxic chemicals and litter. The discharge of nutrients and other pollutants from run-off is most concentrated during wet weather (EPA 1995).

Point sources

The main source of non-diffuse discharge (point source) of nutrients within the Hawkesbury-Nepean River system is the discharge of treated effluent from STPs.

There are 14 STPs operating in the study area within the Hawkesbury-Nepean River System (upstream of the junction with South Creek), 11 of which are owned or operated by the Sydney Water, two are owned and operated by Hawkesbury Council and one owned and operated by the

Figure 7.2 Sources of total nitrogen within the Hawkesbury-Nepean Catchment (median flow conditions)

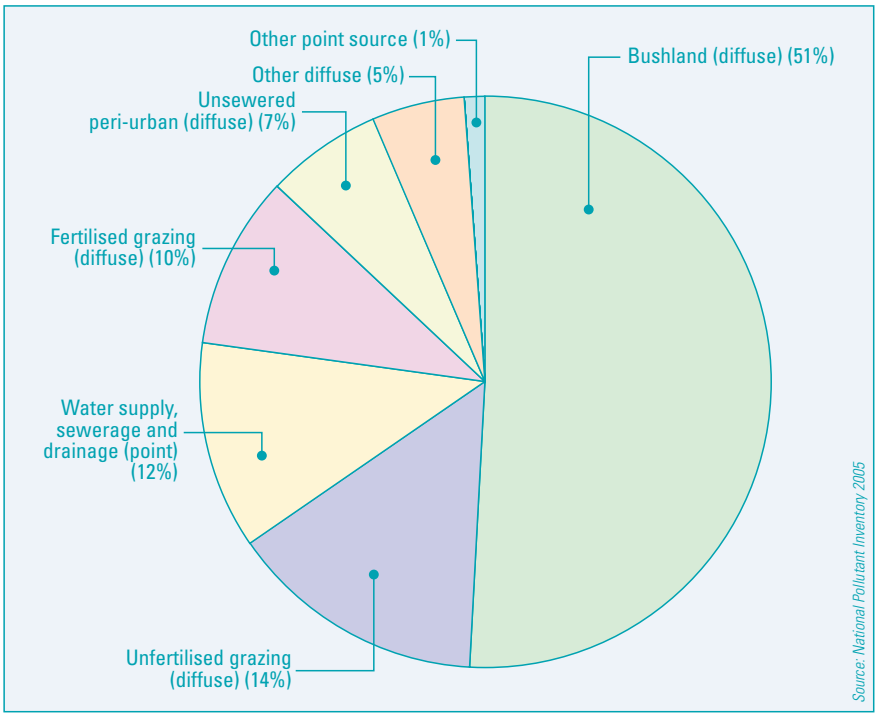
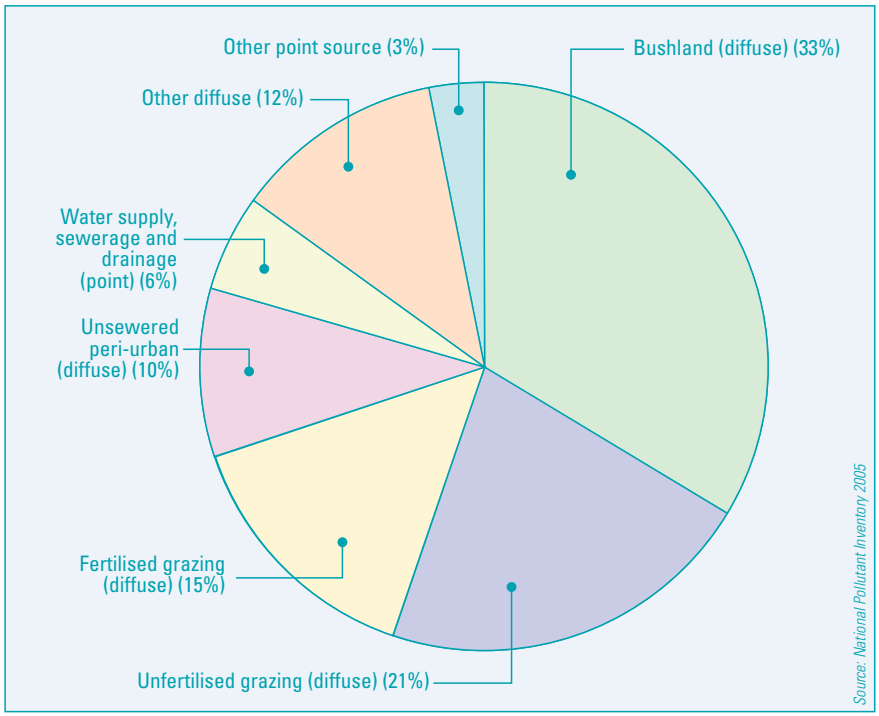


Figure 7.3 Sources of total phosphorus within the Hawkesbury-Nepean Catchment (median flow conditions)



Department of Defence. This includes three STPs owned or operated by Sydney Water in the South Creek / Eastern Creek catchment. There are also a number of privately owned and operated sewage treatment package systems located in the study area.

Median flow within the Hawkesbury-Nepean River system is significantly greater than the flow from the combined STP discharges. The contribution of STP discharge to flows in the Nepean River ranges from one per cent at Penrith Weir, just above the junction with Boundary Creek, to eight per cent just below the confluence with the unnamed creek into which the Winmalee STP discharges (Bickford and Smith 2006). Based on average flow conditions, the contribution of STP discharges to the net flow of the Hawkesbury River ranges from approximately seven per cent just below the junction with the Grose River to 18 per cent just below the junction with South Creek.

These flow patterns and percentages would change in 2009 with the implementation of the Project and other changes in river management detailed in the *2006 Metropolitan Water Plan*.

7.3 Water quantity

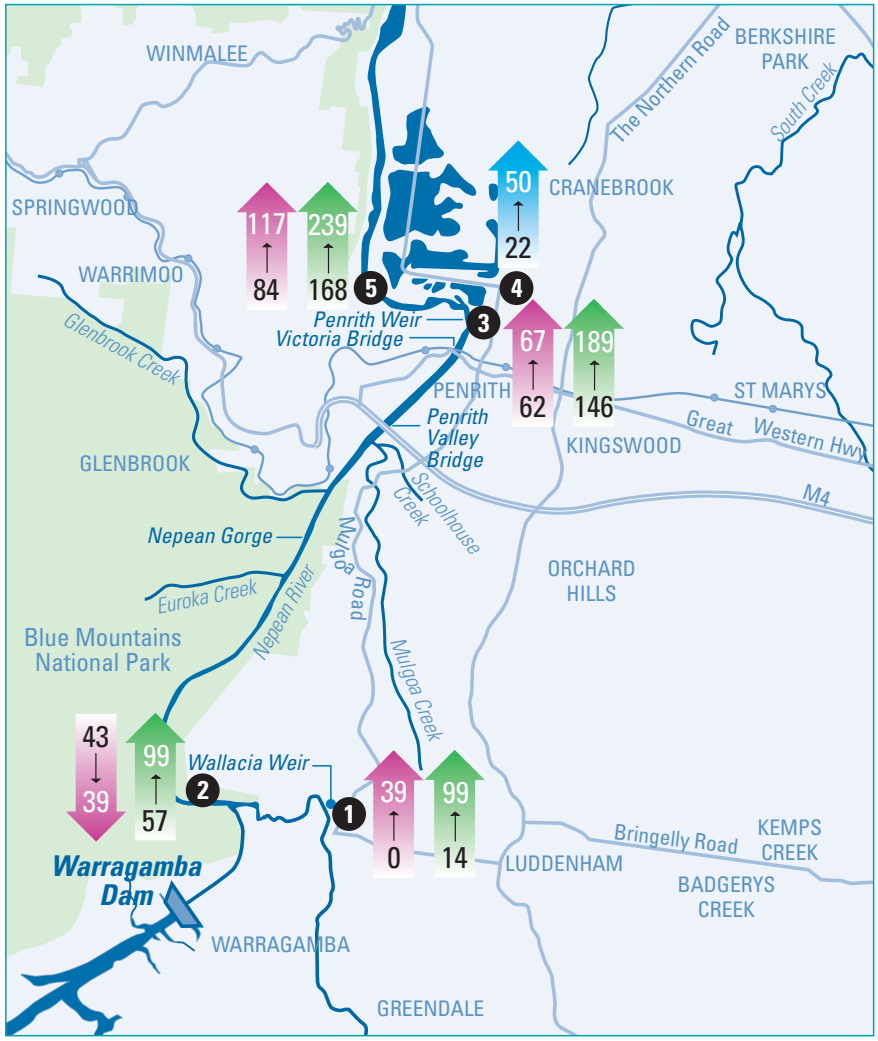
The impacts of the Project on the hydrology of the Hawkesbury-Nepean River were assessed through hydrologic modelling (SMEC 2006). This included simulating daily flows over a 25 year time period for a range of different scenarios. The modelling also considered the planned changes in river management and environmental flow releases identified in the *2006 Metropolitan Water Plan* due to be implemented in 2009. These included:

- increased environmental flow releases from the upper Nepean dams as recommended by the Hawkesbury-Nepean River Management Forum and committed to in the *2006 Metropolitan Water Plan* (see **Chapter 2** for a description of the changes in environmental flow releases)
- modifications to weirs in the upper Nepean River to allow environmental flows to be passed downstream
- protection of low flows through 'cease to pump' rules for irrigators
- cessation of Warragamba Dam water releases.

Figure 7.4 and **Figure 7.5** present very low flows (95th percentile) and median flows (50th percentile) at key locations currently in the study area and as predicted in 2009. The flow data for the predicted 2009 flow conditions is based on implementation of the river management measures detailed above. The arrows presented in the figures provide an indication of predicted changes in flow and the current and 2009 estimated flow volumes in ML/day are also included. **Figure 7.4** presents changes in flow volumes for normal (ie non-drought) conditions when releases from Warragamba Dam are 43 ML/day. **Figure 7.5** presents changes in flow volumes for drought conditions when releases from Warragamba Dam are only about 22 ML/day.

The following provides a summary of the hydrology assessment presented in **Appendix C**.

Figure 7.4 Comparison of existing non-drought flows with predicted 2009 flows (with Replacement Flows Project)



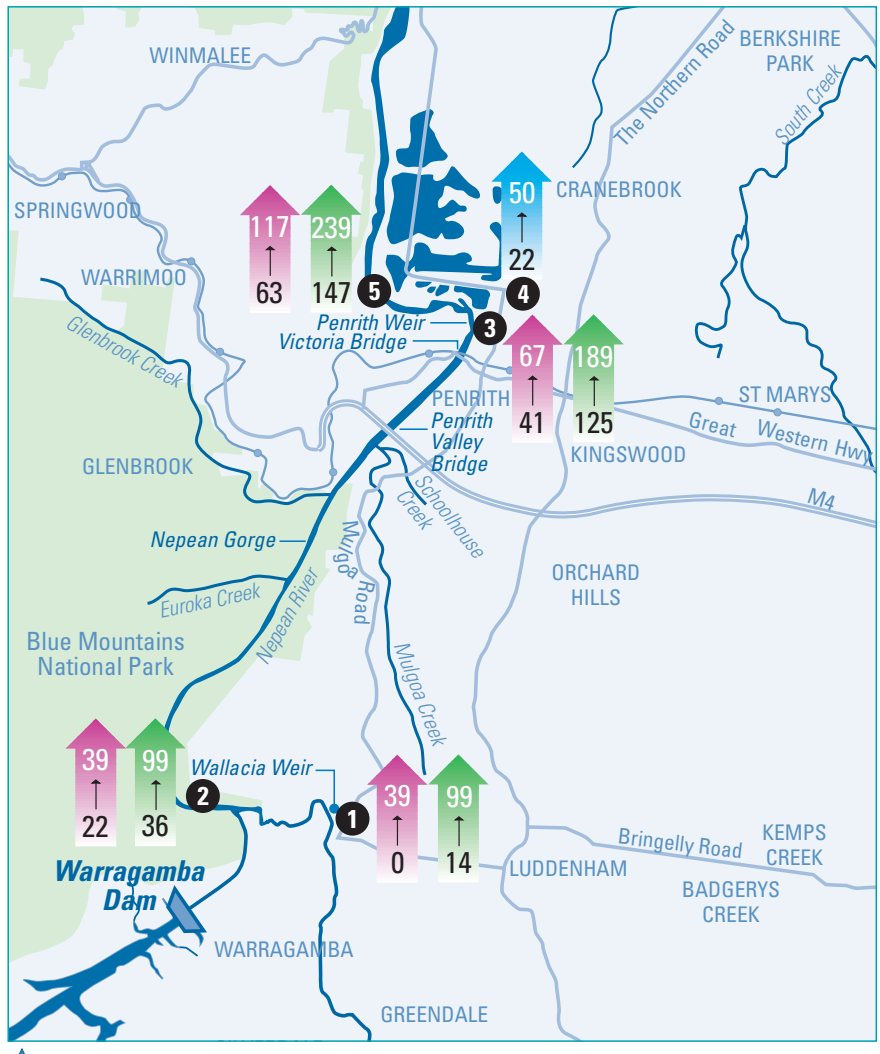
1. Wallacia Weir
2. Junction of Warragamba River and Nepean River
3. Penrith Weir
4. Discharge via Boundary Creek
5. Downstream of Penrith Weir

Current 43 / 2009 39 — Low flows

2009 99 / Current 14 — Median flows

2009 50 / Current 22 — All flow conditions (STP or AWTP discharges)

Figure 7.5 Comparison of existing drought flows with predicted 2009 flows (with Replacement Flows Project)



1. Wallacia Weir
2. Junction of Warragamba River and Nepean River
3. Penrith Weir
4. Discharge via Boundary Creek
5. Downstream of Penrith Weir

Current 43 ↓ 2009 39 — Low flows

2009 99 ↑ Current 14 — Median flows

2009 50 ↑ Current 22 — All flow conditions (STP or AWTP discharges)

7.3.1 Warragamba River

Existing conditions

Under current operating rules, the Sydney Catchment Authority is required to make a constant interim environmental flow release equivalent to the 95th percentile flow (which is 33.3 ML/day) and an additional 10 ML/day to provide for extractions by irrigators. Under the current drought conditions the interim flow release has been decreased to approximately 22 ML/day.

There is also a requirement to maintain a minimum flow of 50 ML/day over Penrith Weir

There is also a requirement to maintain a minimum flow of 50 ML/day over Penrith Weir, which sometimes requires Warragamba Dam to make larger releases, since flows from the Upper Nepean system are often negligible (ie there is no flow from upper Nepean River more than 40 per cent of the time). In wet years the dam may spill several times, with spills persisting for many weeks. During droughts, however, it is common to experience periods of up to ten years without spills occurring. The reach downstream of Warragamba Dam and upstream of the Nepean River junction is very short, being only 3.5 km.

The reach is divided into two distinct sections by Warragamba Weir. Environmental flow releases are discharged into the river downstream of the weir. Environmental flow releases are made from the Warragamba River to Prospect water supply pipeline into Megarritys Creek which discharges into Warragamba River. Hence, the 1.4 km reach between the dam and the weir receives no environmental flow. The only flows in this reach of the river are from the very small local catchment, dam seepage water and occasional spills. The reach downstream of Warragamba Weir contains a sequence of rock bars and pools that are drowned, due to back water from Penrith Weir. The new Wallacia STP is designed to discharge less than 1.5 ML/day into the river downstream of Warragamba Weir.

Assessment of impact

The reach upstream of Warragamba Weir (and upstream of the current discharge location for environmental flow releases from Warragamba Dam) would only continue to receive flow through dam spills, seepage from the dam and small volumes of local catchment runoff.

The section of Warragamba River downstream of the weir would not receive the flow releases from Warragamba Dam. Hence, this reach would experience long periods without effective flow with the implementation of the Project, although the Penrith Weir pool would ensure the river does not run dry.

Flow releases from Warragamba Dam will be reviewed in 2009 and final rules established in 2015 as part of the Water Sharing Plan. This may result in increased discharges into Warragamba River. This review would also recognise the replacement flows as a substitution for any Warragamba Dam releases.

7.3.2 Wallacia Weir to Penrith Weir (Nepean River)

Existing conditions

Key features of this reach include the long pool formed by Penrith Weir (which extends for a distance of 18 km upstream from the weir). Under current conditions, environmental flow releases from the Upper Nepean dams often do not reach the Nepean River at Wallacia Weir, due to water users extractions and poor design of the weirs (see **Figure 7.4**). Flows greater than approximately 60th percentile are required to produce a measurable flow over Wallacia Weir. Below approximately the 60th percentile, the only flow in the Nepean River immediately downstream of the Warragamba River junction is from the Warragamba Dam releases (ie 43 ML/day in non-drought conditions but currently 22 ML/day due to the drought).

Between the junction of Warragamba River and Penrith Weir, the Nepean River receives inflow from a number of tributaries and the surrounding catchment. Currently very low flows (ie 95th percentile) are approximately 62 ML/day over Penrith Weir. The median flow (ie 50th percentile) over Penrith Weir is approximately 146 ML/day.

Assessment of impact

Apart from very low flows, the flows over Wallacia Weir would be higher than the current flows. This is particularly evident for median flow, where flows would be almost twice the current flow volumes.

With the proposed 2009 river management changes, higher flows than are currently experienced would reach Wallacia Weir (see **Figure 7.4**). However, due to the cessation of the interim flow releases from Warragamba Dam, the flow over Wallacia Weir would be the major source of inflow into this reach. Apart from very low flows (95th percentile), the flows over Wallacia Weir would be higher than the current flows in this section of the river. This is particularly evident for median flow, where flows would be almost twice the current flow volumes.

For very low flows (95th percentile), there would be a small decrease in flows (38.7 ML/day) in comparison to the non-drought situation (43 ML/day) at the junction of Warragamba River and Nepean River (see **Figure 7.4**). However, downstream of this location, flows would increase (primarily due to the protection of low flows from extraction) until Penrith Weir, where very low flows (67 ML/day) would be equivalent to the non-drought existing conditions (62 ML/day). The median flows over Penrith Weir (189 ML/day) would also be higher than the non-drought existing conditions (146 ML/day).

Compared with the existing drought situation, where only approximately 22 ML/day of water is released from Warragamba Dam, there would be an increase in flows in this river reach for all flow conditions.

7.3.3 Downstream of Penrith Weir

Existing conditions

Immediately downstream of Penrith Weir, Boundary Creek flows into the Nepean River. Boundary Creek is the discharge location for Penrith STP, which currently discharges approximately 22 ML/day of tertiary treated effluent into the creek. Existing flows downstream of Penrith Weir vary from 84 ML/day in very low flow conditions to 168 ML/day during median flow conditions.

Further downstream Winmalee STP discharges approximately 15 ML/day of tertiary treated effluent and small tributary inflows contribute approximately 3 ML/day. The Grose River, which is just upstream of Yarramundi, contributes approximately 60 ML/day in low flow conditions.

Downstream of Yarramundi is tidal, since water levels vary under the influence of the tide. However, freshwater flows dominate this reach. In particular, there are large freshwater inflows from the Grose River, which enters just downstream of Yarramundi and from South Creek, which discharges at Windsor. The freshwater inflows form a large freshwater tidal pool, which is trapped behind saline water from the estuary.

Assessment of impact

Boundary Creek currently receives 22 ML/day from Penrith STP. The discharge due to the Project would increase to up to 50 ML/day, providing an additional source of flow for this section of the river. Combined with the increased flow associated with the changes to river management, the flows downstream of Penrith Weir (117 ML/day) would be higher in very low flow conditions compared with the existing situation (84 ML/day). For median flows (50th percentile) flows (239 ML/day) would also be higher than the existing flows (168 ML/day) (see **Figure 7.4**).

Up to 70 per cent of the tertiary treated effluent discharged into South Creek by Quakers Hill and St Marys STP would be diverted to the Advanced Water Treatment Plant (AWTP) as a result of the Project.

Up to 70 per cent of the tertiary treated effluent discharged into South Creek by Quakers Hill and St Marys STP would be diverted to the Advanced Water Treatment Plant (AWTP) as a result of the Project. This would result in a significant decrease in the volume of water flowing into the freshwater tidal pool from South Creek in dry weather.

It should be noted that the freshwater tidal pool is not dependent on dry weather flows to maintain water levels. The vast majority of water in the freshwater tidal pool is from large wet weather inflows, which are trapped behind the saline estuarine water, rather than from dry weather catchment flows and STP discharges. The reduction in flows into the freshwater tidal pool from South Creek would be compensated by the increased flows from the Nepean River upstream of Yarramundi. It is not expected that the reduced discharge would affect water levels or availability in the freshwater tidal pool.

Modelling of the river system indicates that there would be negligible movement of the interface between saline and freshwaters due to the Project.

7.3.4 South Creek and Eastern Creek

Existing conditions

Quakers Hill STP discharges into Breakfast Creek which flows into Eastern Creek approximately 500m downstream of the STP discharge location. St Marys STP discharges into an unnamed tributary of Ropes Creek which then flows in South Creek approximately 500m downstream of the STP discharge location. The creeks upstream of the STP discharge locations generally do not flow in dry weather periods.

Flows in South Creek system are significantly affected by discharge of tertiary treated effluent from the Quakers Hill (31 ML/day), St Marys (34 ML/day) and/or Riverstone STPs (2 ML/day). Currently the tertiary treated effluent discharges from the STPs dominate flows in South Creek system, especially during prolonged dry weather periods when the upstream catchment contribution to flows is approximately 1 ML/day.

Irrigation extractions also occur along South Creek and the STP discharges provide a significant portion of irrigation extraction during dry weather, when catchment flows are naturally low.

Assessment of impact

Detailed modelling of the hydrological impact of the Project on Ropes, Breakfast, South and Eastern Creeks has not been undertaken, as the impacts are relatively straightforward and can be assessed without a more detailed analysis.

As noted above, significant volumes of tertiary treated effluent would be diverted from Quakers Hill and St Marys STP as a result of the Project. The STP discharges would, however, still dominate low flow conditions. In 2009 is it predicted that St Marys STP would still discharge approximately 5 ML/day and Quakers Hill STP would discharge approximately 19 ML/day. In comparison to the upstream dry weather catchment flows of 1 ML/day, these discharge volumes are still significant.

In higher flow conditions the STP discharges would be less dominant and the flows in the creeks would return to a more natural regime.

Discharges from Riverstone STP (which currently discharges 2 ML/day into Eastern Creek) are expected to increase as new urban development in the region occurs.

7.3.5 Flow variability

The planned upper Nepean Dam releases would provide a significant increase in flow variability across all flow conditions.

The planned upper Nepean Dam releases would provide a significant increase in flow variability across all flow conditions. The increase in flow variability would be most notable upstream of Penrith Weir.

Downstream of Penrith Weir there would be some loss in this gained variability, due to the consistent discharge of replacement flows. The loss of variability decreases as flow in the river increases, as the replacement flows would make up a smaller proportion of the total flow. When compared with the existing situation, the future flow regime exhibits greater variability. It should also be noted that the discharge location for the replacement flows is not located far upstream of the freshwater tidal pool in the Hawkesbury River. Flow velocities in the freshwater tidal pool do not vary greatly (except in large wet weather events) due to the regulating effect of the natural saline estuarine barrier.

As described in the *2006 Metropolitan Water Plan,* in 2009 and 2015 when environmental flow releases from Warragamba Dam are reviewed, there may be further increases in variability if translucent dam releases are adopted.

The diversion of flows from Quakers Hill and St Marys STP would result in significantly lower volumes of tertiary treated effluent discharged to South Creek and its tributaries, reducing the dominance of these discharges on flow variability. This would result in greater variability in flows in South Creek and its tributaries, especially in the mid range of flow duration curves. Low flows would still be dominated, however, by STP discharges.

7.3.6 Boundary Creek

Boundary Creek is a small tributary of the Hawkesbury-Nepean River, with a catchment of 304 ha, which flows into the main river channel about 50 m downstream of Penrith Weir. Its relevance to the Project is that approximately 22 ML/day of tertiary treated effluent from Penrith STP is currently discharged into the creek, approximately 500m upstream of its junction with the Nepean River. Boundary Creek flows through the Penrith STP site where its riparian zone has been cleared or contains patchy re-growth of casuarinas and terrestrial and aquatic weed species.

Downstream of the Penrith STP, Boundary Creek crosses under Castlereagh Road through a culvert, before entering an industrial and commercial zone. A 10 - 20 m riparian zone either side of the creek has been maintained through this area, which increases in width as the creek flows towards the Nepean River. The riparian zone is heavily infested with weeds and there is some re-growth of endemic native vegetation. There is evidence of significant erosion of alluvial soils in the lower sections of the creek, near the confluence with the Nepean River.

The creek catchment does not contribute any flows to the creek in dry weather. However, in wet weather, flows in the creek increase significantly. For a 1 in 2 year storm, estimated flows are 3,255 ML/day, increasing to 5,731 ML/day for a 1 in 20 year storm. These volumes are significantly greater than the current Penrith STP discharge of 22 ML/day and the proposed replacement flow of 50 ML/day.

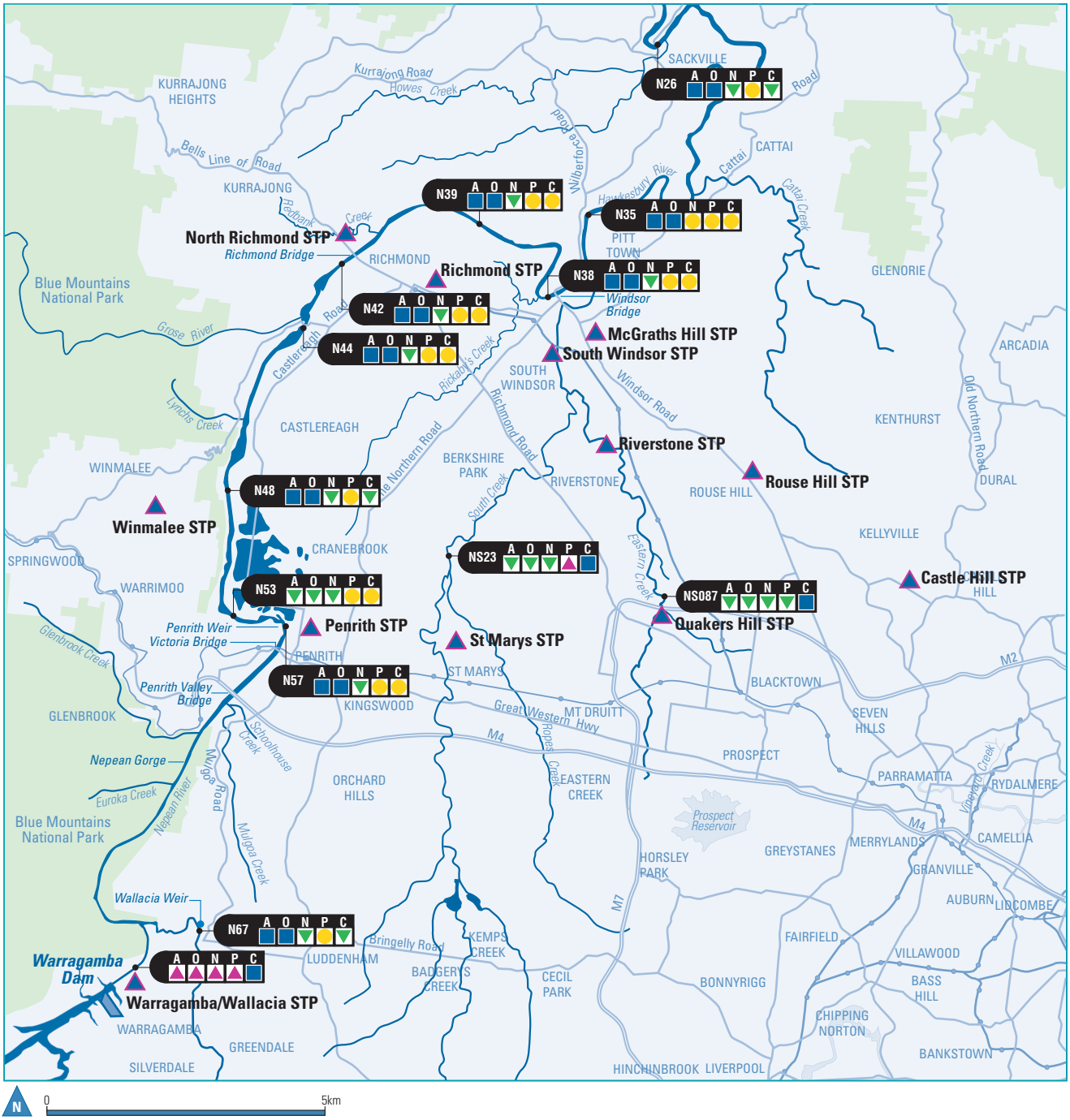
An assessment was undertaken of the potential of the current discharge and proposed replacement flows discharge to cause erosion of the alluvial areas currently affected. In the eroding stretch of the creek, the current discharge has a depth between 0.1 to 0.3m and a velocity between 0.1 to 0.7 m/s. With the discharge of the replacement flows the depth would increase marginally to between 0.1 to 0.5m and velocity to between 0.2 to 0.9 m/s. This water depth is within the natural channel and below the level of alluvial sediments which are eroding. There would also not be sufficient velocity to cause any significant additional erosion. The main causes of the erosion appear to be high wet weather flows and receding floodwaters from the Nepean River. Consequently no additional mitigation measures are required to manage erosion in Boundary Creek, which may result from the operation of the Project.

7.4 Water quality

A detailed assessment of existing and predicted water quality within the study area is presented in **Appendix C**. The following section provides a summary of the key findings from the water quality assessment.

Existing water quality in the study area has been described from monitoring data collected by Sydney Water and the Sydney Catchment Authority between 2000 and 2006. The locations of water quality monitoring sites are shown in **Figure 7.6**. Water quality has been assessed using relevant water quality indicators compared against the following guidelines (see **Table 7.1**):

Figure 7.6 Predicted changes in concentrations of key water quality indicators



- ▼ Concentration decrease
- ▲ Concentration increase
- ● No change
- ■ Not assessed

(N) Total Nitrogen
(O) Oxidised Nitrogen
(A) Ammonia
(P) Total Phosphorus
(C) Chlorophyll-a

NS087 A O N P C

Warragamba River
Wallacia to Penrith Weir
N67 - Nepean River at Wallacia
N57 - Nepean River at Penrith Weir
Penrith to Yarramundi
N53 - Nepean River downstream of Penrith STP
N48 - Nepean River at Smith Road
N44 - Nepean River at Yarramundi Bridge
Yarramundi to South Creek
N42 - Hawkesbury River at North Richmond
N39 - Hawkesbury River at Freemans Reach
N38 - Hawkesbury River at Windsor Bridge
South Creek to Sackville
N35 - Hawkesbury River at Wilberforce
N26 - Hawkesbury River at Sackville Ferry
South Creek
NS087 - Downstream of Quakers Hill STP
NS23 - Downstream of St Marys STP

- default trigger values for chemical and physical stressors for the protection of aquatic ecosystems for south-east Australia for slightly disturbed estuarine and lowland river ecosystems as outlined in the *Australian and New Zealand Guidelines for Fresh and Marine Water 2000* (ANZECC/ARMCANZ 2000)
- recommendations made by the Healthy Rivers Commission (HRC 1998) for nutrients (total phosphorus and total nitrogen) and chlorophyll-a.

Table 7.1 Relevant guidelines for assessment of water quality

Water Quality Indicator	Guideline value	Source
Ammoniacal Nitrogen (mg/L)	<0.02 (lowland river) <0.015 (estuarine)	ANZECC/ ARMCANZ (2000)
Oxidised Nitrogen (mg/L)	<0.04 (lowland river) <0.015 (estuarine)	ANZECC/ ARMCANZ (2000)
Total Nitrogen (mg/L)	<0.7 (mixed use rural areas) <0.5 (urban areas – mainstream) <1 (urban areas – tributary stream) <0.4 (estuarine)	HRC (1998)
Total Phosphorus (mg/L)	<0.035 (mixed use rural areas) <0.03 (urban areas – mainstream and estuarine) <0.05 (urban areas – tributary stream)	HRC (1998)
Chlorophyll-a (µg/L)	< 20 (urban areas – mainstream and tributary stream) < 7 (estuarine and mixed used rural areas and sandstone plateau)	HRC (1998)

Existing water quality was determined for very low flows (>95th percentile flow) and median concentrations for all flow conditions (See **Table 7.2** and **Table 7.3**). Very low flow conditions have been assessed, as it is during these periods that the Project and the existing STP discharges have the potential for the greatest impact. Median water quality conditions for all flows provide an indication of "average" water quality in the river. During higher flows (<50th percentile flows) diffuse pollution sources, such as catchment runoff from agricultural and urban land, have an increased influence on water quality in the study area.

Table 7.2 Existing water quality at key sites in the Hawkesbury-Nepean and Warragamba Rivers

Location	Flow Condition	Ammonium (mg/L)	Oxidised Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Chlorophyll-a (ug/L)
Warragamba River						
	All flow conditions	0.018	No data	0.57	0.025	No data
Wallacia to Penrith Weir						
N67 - Nepean River at Wallacia	Low flow[1]	0.030	0.07	0.70	0.020	5.0
	All flow conditions[2]	0.020	0.33	0.73	0.020	6.4
N57 - Nepean River at Penrith Weir	Low flow	0.010	0.01	0.27	0.010	3.0
	All flow conditions	0.010	0.02	0.33	0.011	2.8
Penrith to Yarramundi						
N53 - Nepean River downstream of Penrith STP	Low flow[1]	0.050	0.92	1.23	0.034	2.7
	All flow conditions[2]	0.030	0.57	0.99	0.038	2.7
N48 - Nepean River at Smith Road	Low flow	0.020	0.06	0.82	0.025	No data
	All flow conditions	0.020	0.28	0.70	0.026	5.0
N44 - Nepean River at Yarramundi Bridge	Low flow	0.020	0.43	0.71	0.020	5.1
	All flow conditions	0.030	0.53	0.91	0.026	5.5
Yarramundi to South Creek						
N42 - Hawkesbury River at North Richmond	Low flow	0.010	0.26	0.46	0.010	2.5
	All flow conditions	0.013	0.28	0.58	0.016	3.9
N39 - Hawkesbury River at Freemans Reach	Low flow	0.010	0.17	0.52	0.020	7.0
	All flow conditions	0.014	0.22	0.54	0.017	4.7
N38 - Hawkesbury River at Winsdor Bridge	Low flow	0.020	0.49	0.94	0.033	12.9
	All flow conditions	0.020	0.49	0.91	0.034	8.8
South Creek to Sackville						
N35 - Hawkesbury River at Wilberforce	Low flow	0.010	0.29	0.79	0.045	27.6
	All flow conditions	0.030	0.52	1.00	0.048	16.7
N26 - Hawkesbury River at Sackville Ferry	Low flow	0.010	0.01	0.55	0.039	31.1
	All flow conditions	0.010	0.19	0.78	0.042	25.5

Shading indicates value is higher than relevant guideline.

[1] Low Flow concentrations have been calculated by identifying sampling events between 2000 and 2006 when flow in the river was less than the 95th percentile and then taking the median of these sampling events.

[2] All flow conditions concentrations have been calculated by taking the median value from all sampling events between 2000 and 2006.

Table 7.3 Existing water quality at key sites in South and Eastern Creeks

Location	Flow Condition	Ammonium (mg/L)	Oxidised Nitrogen (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Chlorophyll-a (ug/L)
South and Eastern Creeks						
NS090 - Breakfast Creek upstream Quakers Hill STP	All flow conditions	0.030	0.05	0.70	0.089	6.0
NS087 - Breakfast Creek downstream Quakers Hill STP	All flow conditions	0.031	2.55	3.63	0.050	1.5
NS24 - South Creek upstream St Marys STP	Low flow[1]	0.040	0.02	0.65	0.041	12.0
	All flow conditions[2]	0.040	0.20	0.90	0.053	10.3
NS23 - South Creek downstream St Marys STP	Low flow	0.015	3.60	4.53	0.043	1.4
	All flow conditions	0.023	2.70	3.61	0.060	1.4

Shading indicates value is higher than relevant guideline.

[1] Low Flow concentrations have been calculated by identifying sampling events between 2000 and 2006 when flow in the river was less than the 95th percentile and then taking the median of these sampling events.

[2] All flow conditions concentrations have been calculated by taking the median value from all sampling events between 2000 and 2006.

The major potential changes in water quality associated with the Project would be nutrients (nitrogen and phosphorus) and chlorophyll-a levels in the river. All of the discussion presented below focuses on nutrient and chlorophyll-a levels and their sources. This includes the main bioavailable nutrients, namely oxidised nitrogen and ammonia. These forms of nitrogen can be used by algae and macrophytes with minimal biological processing and may rapidly stimulate excessive growth of these plants. It is also recognised that some other forms of organic nitrogen may be bioavailable to algae and macrophytes. However, there are no specific data on concentrations of these substances in the study area. Total nitrogen concentrations have been presented below as an indication of all nitrogen in the water.

It is recognised that filterable phosphorus is also a bioavailable nutrient, although levels of this form of phosphorus in the river are generally low and would further decrease with the Project. Data on filterable phosphorus concentrations within the river are also patchy, and as a consequence total phosphorus concentrations have been used to assess existing and future water quality. A detailed discussion of other water quality indicators is contained in **Appendix C**. Human health risks associated with the Project in relation water quality are discussed in **Section 7.6**.

The changes in water quality as a result of the Project and river management changes that would be in place in 2009 have been analysed in terms of trends and absolute concentrations. It should be noted that the Project has not been specifically designed to achieve water quality objectives, rather to achieve equivalent or improved environmental values (including water quality) when compared to existing conditions. However, due to the predicted improvements in water quality, in some locations the implementation of the Project would result in the water quality objectives being achieved where currently they are not.

Trends were analysed for the Hawkesbury-Nepean River from Wallacia Weir to Sackville for total nitrogen, total phosphorus, chlorophyll-a and salinity. The trends were generated using a set of integrated models for catchment hydrology, catchment hydraulics and catchment water quality, irrigation consumption, town water consumption, waterway hydraulics and waterway water quality. Changes in nutrient and chlorophyll-a concentrations assessed with the integrated modelling were focussed on low flow conditions (92nd percentile flow), which were considered representative of flows in drought periods.

The integrated modelling has some limitations, which include the inability to account for some irrigation extractions and the use of older datasets. Nonetheless, when compared with measured data the modelling produces a reliable indication of trends if not for absolute concentrations. Consequently, this model was used to predict trends in water quality in the main channel of the Hawkesbury-Nepean River while absolute concentrations were analysed using a mass balance model for three locations – Warragamba River, the Nepean River downstream of Boundary Creek and in South and Eastern Creeks. The mass balance models were developed to predict the low flow (95th percentile) water quality in 2009, with and without the Project.

The integrated and mass balance models both considered the influence of the implementation of the Upper Nepean Dam releases (under the *2006 Metropolitan Water Plan*), assumed that the current tertiary treated effluent quality would be maintained for Penrith, St Marys and Quakers Hill STPs and accounted for the volumes of wastewater that would be recycled in local schemes. The results of the integrated and mass balance modelling have been summarised in **Figure 7.6**. This figure indicates for each existing monitoring site in the study area, whether concentrations of key nutrients and chlorophyll-a in 2009 are predicted to increase, decrease or remain unchanged when compared to existing conditions.

Water quality in each of the river reaches is discussed below.

7.4.1 Warragamba River

Existing conditions

The water quality of Warragamba River is influenced by seepage from the dam, the discharge of treated effluent from the new Wallacia STP and the release of interim environmental flows from Warragamba Dam.

The new Wallacia STP will eventually discharge 1.35 ML/day of tertiary treated effluent, with concentrations of total nitrogen and total phosphorus in the effluent being 7.5mg/L and 0.15 mg/L, respectively. The dilution effects of the 43 ML/day interim releases from Warragamba Dam and the discharge from Wallacia STP would result in water quality in Warragamba River meeting HRC (1998) objectives.

Current water quality in Warragamba River meets the HRC (1998) and ARMCANZ/ANZECC (2000) guidelines for nutrient and chlorophyll-a concentrations (see **Table 7.1**).

Assessment of impact

As a result of the Project, the dilution of Wallacia STP discharges with interim environmental flow releases from Warragamba Dam would not occur (see **Section 7.3**). A mass balance model was used to assess the effects on nutrient concentrations in Warragamba River.

Without any water releases from the dam, Warragamba River would be dominated by tertiary treated effluent discharges from Wallacia STP, with minor dilution from dam seepage. In the worst case (assuming no assimilation or sedimentation of nutrients) the predicted nutrient concentrations would be approximately 6.7 mg/L for total nitrogen and 0.14 mg/L for total phosphorus, which reflects the characteristics of the STP effluent. However, based upon other studies undertaken to assess the impact of Wallacia STP (Hawkins et al 2003) significant assimilation and loss of nutrients in Warragamba River is known to occur and final concentrations are likely to be lower.

Based upon the volume of the Warragamba River being approximately 108 ML and the final effluent flow of 1.35 ML/day, with some rainwater runoff, the expected residence time in the Warragamba River is greater than 50 days. This long residence time would provide significant potential for excessive aquatic weed and algal growth in Warragamba River if nutrient concentrations were elevated.

Options for ensuring nutrient concentrations in Warragamba River are maintained at an acceptable level to minimise aquatic weed and algal growth are being considered by Sydney Water. These options could include one or more of the following:

- reducing the amount of effluent discharged to the river through recycling
- improving effluent quality by reducing nutrient concentrations
- diverting discharges away from Warragamba River and directly to the Nepean River
- the release of periodic flushing flows from Warragamba Dam.

7.4.2 Wallacia Weir to Penrith Weir (Nepean River)

Existing conditions

In the upper section of this river reach, nitrogen levels are influenced by the discharge of tertiary treated effluent from West Camden STP. At Wallacia Weir (N67), concentrations of all forms of nitrogen (measured as ammonia, oxidised nitrogen and total nitrogen) were above relevant water quality guidelines (see **Table 7.2**). At Penrith Weir (N57), the most downstream site in this reach of the river, nitrogen concentrations had decreased substantially and complied with relevant guidelines.

In contrast to nitrogen, total phosphorus and chlorophyll-a concentrations at both sites in this reach of the river complied with the relevant HRC (1998) guidelines.

Assessment of impact

Improvements to West Camden STP and the implementation of a recycled water scheme at West Camden would significantly reduce nutrient loads discharged upstream of this river reach. Also the increased flows from the Upper Nepean dam releases would further dilute discharges from Camden STP. The combination of these factors would result in a decrease in nitrogen concentrations at Wallacia Weir (N67) and Penrith Weir (N57) (see **Figure 7.6**). Chlorophyll-a concentrations at Wallacia Weir (N67) are also likely to decrease.

Phosphorus concentrations at both sites would remain relatively unchanged.

In comparison to the changes at West Camden STP, the Project would not affect water quality in this river reach.

7.4.3 Penrith Weir to Yarramundi (Nepean River)

Existing conditions

Nitrogen levels in this reach of the river are influenced by the discharge of tertiary treated effluent from Penrith and Winmalee STPs. Concentrations of all forms of nitrogen were higher than relevant guideline levels at all sites in low flows and across all flow conditions (except oxidised nitrogen concentrations at Smith St (N48)) (see **Table 7.2**).

In contrast, total phosphorus concentrations in this reach of the river were relatively low and concentrations at all sites were below the HRC (1998) objectives, except the median of all flow conditions at the site downstream of Penrith Weir (N53).

All sites within this reach of the river recorded low levels of chlorophyll-a below the HRC (1998) objectives.

Assessment of impact

The replacement flow would result in a reduction in nutrient loads to the Hawkesbury-Nepean River compared with the discharge of tertiary treated effluent from Penrith STP.

Under normal operations of the Project, all tertiary treated effluent from Penrith STP that would normally be discharged, would instead be diverted to the AWTP. The replacement flow produced by the AWTP (up to 50 ML/day) would be discharged at the Penrith STP discharge location (downstream of Penrith Weir via Boundary Creek). The replacement flow would result in a reduction in nutrient loads to the Hawkesbury-Nepean River compared with the discharge of tertiary treated effluent from Penrith STP. **Figure 7.7** shows the predicted nutrient loads discharged from Penrith STP in 2009 without the Project and compares this to the nutrient loads that would be discharged at this same point, from the AWTP.

The replacement flows discharge would result in a reduction of approximately 14 per cent in total nitrogen loads and approximately a 75 per cent reduction in total phosphorus loads discharged below Penrith Weir compared with 2009 Penrith STP discharge in the absence of the Project. The microfiltration and reverse osmosis treatment process removes suspended solids and as such no suspended solids loads would be contributed by the Project discharge.

There would also be no ammonia discharged in the replacement flows due to the incorporation of breakpoint chlorination, which converts it to nitrogen gas. Oxidised nitrogen loads discharged downstream of Penrith Weir would be reduced by approximately 2,665 kg/year, or 25 per cent, compared to those estimated for 2009 without the Project.

The reduction in nitrogen loads in combination with the increased flow is predicted to result in decreases in nitrogen concentrations when compared to the existing conditions.

The reduction in nitrogen loads in combination with the increased flow in this reach is predicted to result in decreases in nitrogen concentrations when compared to the existing conditions (see **Figure 7.6**).

Mass balance modelling indicates that concentrations of all forms of nitrogen immediately downstream of the discharge of the replacement flows would be below ANZECC/ARMCANZ (2000) and HRC (1998) guidelines, except for oxidised nitrogen (See **Table 7.4**). This is an improvement over the existing conditions, where instream water quality does not meet guidelines for any of the nitrogen species.

Figure 7.7 Comparison of loads discharged downstream of Penrith Weir in 2009 with and without Replacement Flows Project

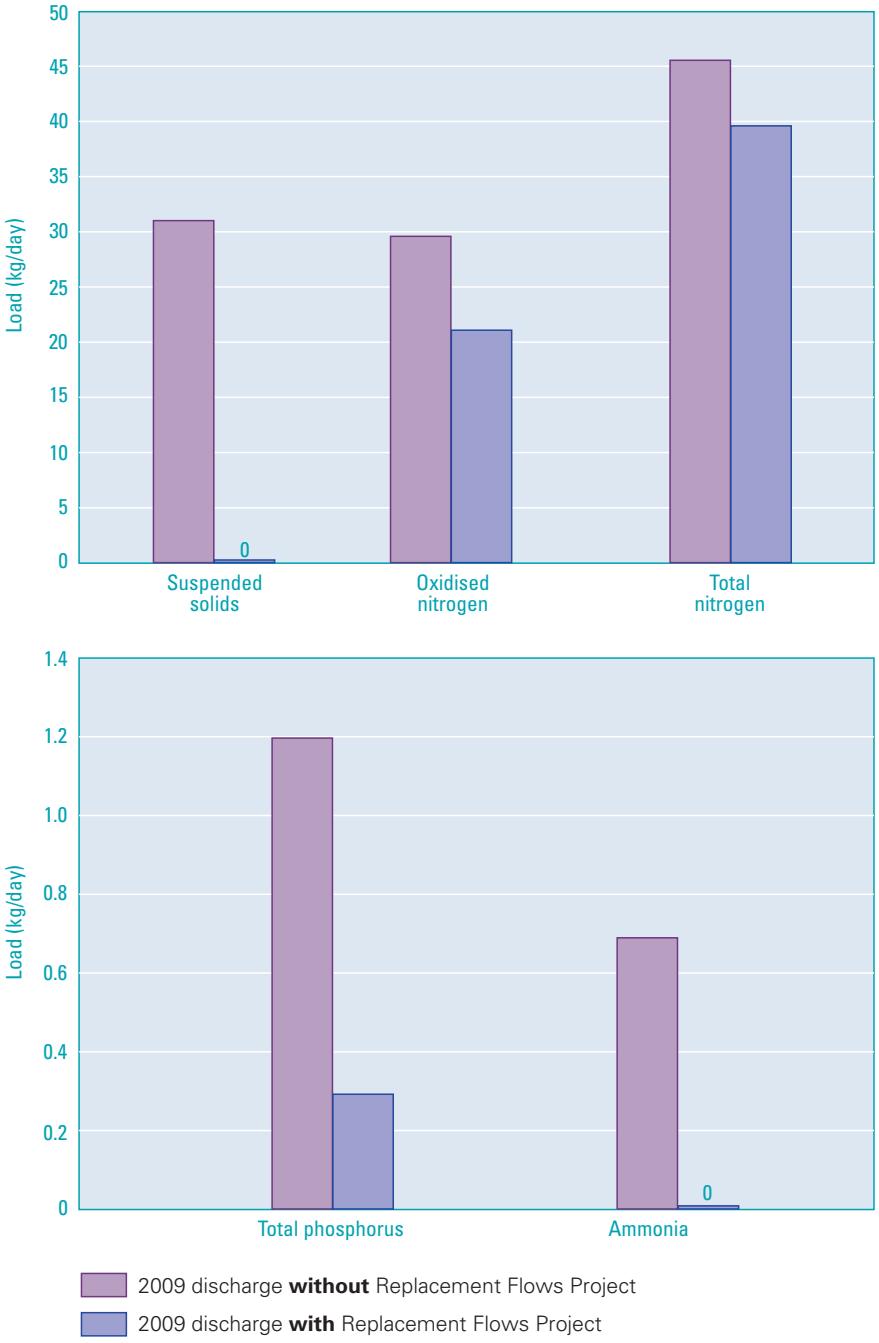


Table 7.4 Predicted water quality in Hawkesbury-Nepean River downstream of Boundary Creek without and with the Replacement Flows Project (RFP)

Scenario	In-stream Nutrient Concentrations (mg/L)			
	Ammonium	Oxidised Nitrogen	Total Nitrogen	Total Phosphorus
Without RFP	0.015	0.243	0.600	0.018
With RFP	0.006	0.195	0.490	0.008

Shading indicates value is higher than relevant guideline.

In the lower sections of this reach water quality is affected by inflows from Winmalee STP. The integrated model predicts that, despite this, improvements in total nitrogen concentrations would occur. This indicates that the Project, in conjunction with increased Upper Nepean dam releases, would improve water quality in this reach.

7.4.4 Yarramundi to South Creek (Hawkesbury River)

Existing conditions

Water quality within the upper section of this reach is affected by upstream flows, while the lower section of this reach is influenced by the inflow of South Creek due to tidal movement. At Windsor Bridge (N38), the most downstream site in this river reach, concentrations of all forms of nitrogen and chlorophyll-a are currently higher than ANZECC/ARMCANZ (2000) and HRC (1998) guidelines, suggesting that high nitrogen levels were promoting algal growth (see **Table 7.2**).

At other sites in this river reach, oxidised nitrogen levels were generally higher than the ANZECC/ARMCANZ (2000) guidelines, although total nitrogen and ammonium levels were lower than relevant guidelines.

Total phosphorus concentrations in this reach of the river generally increase with distance downstream, but were lower than the HRC (1998) guidelines.

Assessment of impact

The integrated modelling indicates that there would be decreases in total nitrogen concentrations at all sites in this reach due to increased flows from upstream and the reduction in nitrogen loads associated with the improved quality of the replacement flows and the significant reduction in the volume of tertiary treated effluent discharged to South Creek (see **Figure 7.6**). Changes in concentrations of oxidised nitrogen and ammonia were not assessed. It would be expected, however, that ammonia concentrations would not change and oxidised nitrogen concentrations would decrease.

Despite the changes in nitrogen concentrations, total phosphorus and chlorophyll-a concentrations are not expected to change significantly with the Project.

7.4.5 South Creek to Sackville (Hawkesbury River)

Existing conditions

All sites in this reach are tidally influenced, although Wilberforce (N35) and Sackville Ferry (N26) have salinity representative of freshwater systems.

The inflow from South Creek influences nitrogen concentrations in this reach, with the highest levels at the site nearest to the South Creek inflow (Wilberforce (N35)) and decreasing levels with distance downstream (see **Table 7.2**). Oxidised nitrogen concentrations consistently exceeded the ANZECC/ARMCANZ (2000) guidelines at all sites, with Wilberforce (N35) recording the highest levels. Wilberforce (N35) also exceeded the total nitrogen and ammonia guideline levels during low and median flow conditions.

Concentrations of total phosphorus were higher than the HRC (1998) guideline at the sites nearest the South Creek inflow (Wilberforce (N35) and Sackville Ferry (N26)).

Chlorophyll-a concentrations were consistently elevated in this reach of the river and were higher than the HRC (1998) guideline. Sackville Ferry (N26), which has historically been the location of blue green algal blooms in the river, recorded the highest values. The combination of high nutrient levels and high residence time of water in the freshwater tidal pool promotes the growth of algae in this reach.

Assessment of impact

The Project would result in up to a 70 per cent reduction in the total volume of tertiary treated effluent discharged from Quakers Hill and St Marys STPs, into South Creek, consequently reducing the impact of nutrients from the South Creek inflow on this reach (especially nitrogen). This is reflected in the integrated modelling results for total nitrogen which indicated that the improvements in water quality would occur downstream of South Creek inflow and continue to Sackville (See **Figure 7.6**). A similar reduction in phosphorus concentrations is not predicted.

A decrease in chlorophyll-a concentrations at Sackville is predicted, mostly likely due to a decrease in available nitrogen.

Changes in concentrations of oxidised nitrogen and ammonia were not assessed, although it is expected that ammonia concentrations would not change and oxidised nitrogen concentrations would decrease. A decrease in chlorophyll-a concentrations at Sackville (N26) is predicted, mostly likely due to a decrease in available nitrogen.

7.4.6 South Creek and Eastern Creek

Existing conditions

Sites upstream of Quakers Hill and St Marys STPs had very little flow in dry periods (<0.5 ML/day) and consequently water quality was poor due to the stagnant nature of the creeks. This typically includes high nutrient levels, high turbidity and low dissolved oxygen concentrations – all of which generally exceed relevant guidelines. In higher flows and especially after rainfall, water quality upstream of the STP discharges further deteriorates due to the influence of catchment runoff from urban and agricultural land.

In low flow conditions water quality at sites downstream of the STPs is primarily influenced by the discharge of tertiary treated effluent from the STPs. Concentration of all forms of nitrogen are significantly higher downstream of the STPs when compared to upstream sites and exceed ANZECC/ARMCANZ (2000) and HRC (1998) guidelines. In contrast, phosphorus levels are generally lower at sites downstream of STP discharges compared to upstream sites. However, apart from downstream of Quakers Hill STP, total phosphorus levels did not comply with HRC (1998) guidelines. It can be concluded that catchment sources are contributing elevated phosphorus loads to the system while STPs are contributing elevated loads of nitrogen to the system.

The high levels of nutrients in these creeks have not resulted in high chlorophyll-a levels, except at one site above the St Marys STP discharge. High flows downstream of the STPs generated by the discharge of tertiary treated effluent is not conducive to algal growth because of low residence times and high turbidity. However, the section of the Hawkesbury-Nepean River affected by the South Creek inflow, with its high nutrient load, is suitable for algal growth due to lower flow velocities and longer residence times for water.

Assessment of impact

The Project would result in a significant decrease in nutrient loads discharged to South and Eastern Creeks.

The Project would result in a significant decrease in nutrient loads discharged to South and Eastern Creeks.

Nutrient loads for 2009 discharges have been calculated by accounting for future urban growth in the sewerage catchment and the implementation of current and planned local recycling schemes. It should be noted that discharges of tertiary treated effluent into South Creek might increase after 2009, with predicted increases in urban development in the region. Although the supply of recycled water to new development areas would minimise the volume of effluent requiring discharge, in the future additional volumes of tertiary treated effluent would be discharged in South Creek compared to predicted volumes in 2009. However, this would still be a significantly lower volume of effluent discharged into South Creek when compared to the existing conditions.

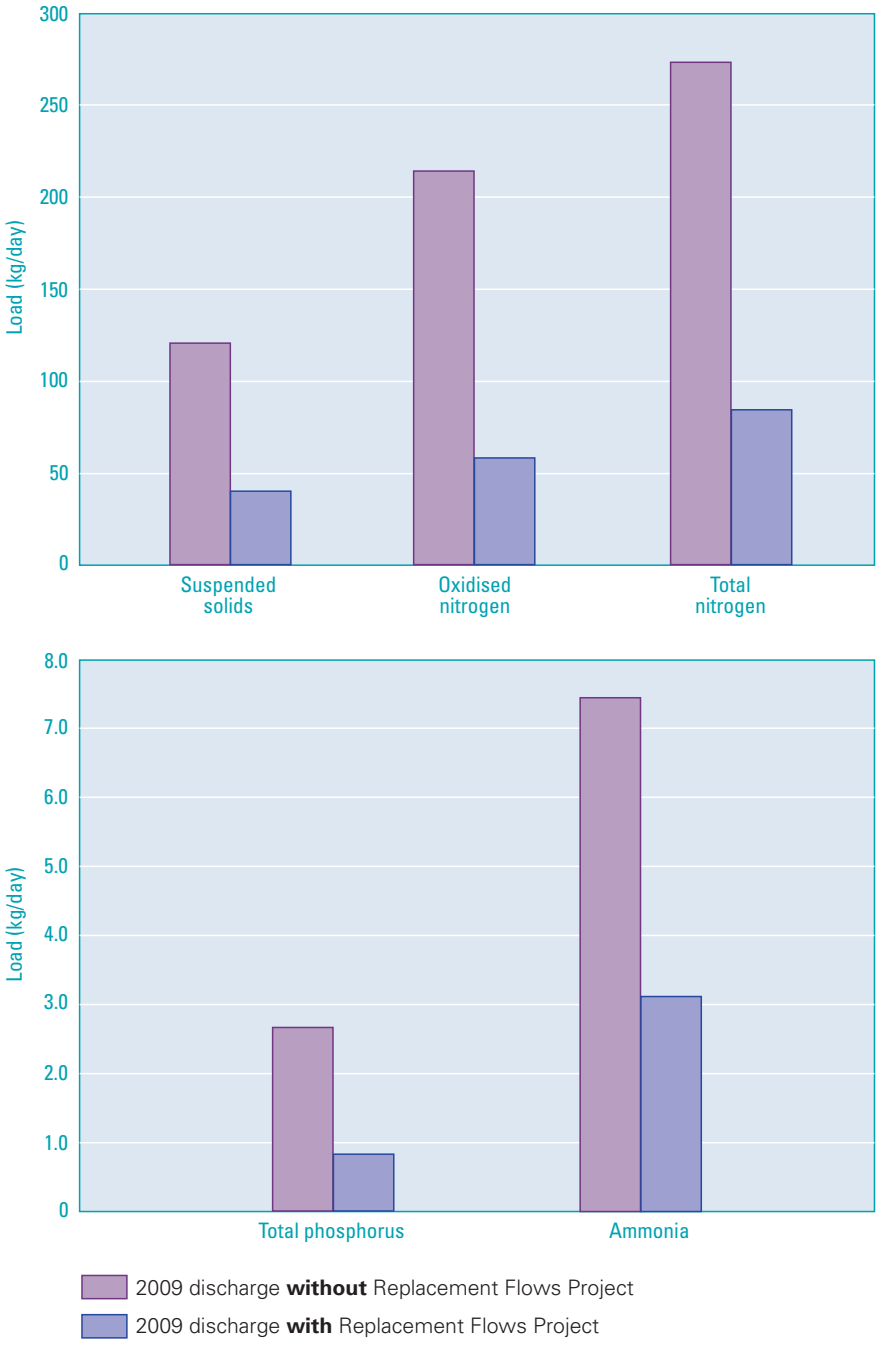
Eastern Creek is a tributary of South Creek and as such is part of the South Creek catchment. The reduction in loads resulting from the diversion of tertiary treated effluent to the AWTP has been calculated for the South Creek catchment and is presented in **Figure 7.8**.

The reduction in discharge volumes from the South Creek STPs in 2009 would result in an approximate 70 per cent reduction in nutrient loads with the exception of ammonia, which would reduce by approximately 57 per cent.

The reduction in discharge volumes from the South Creek STPs in 2009 would result in an approximate 70 per cent reduction in nutrient loads with the exception of ammonia, which would reduce by approximately 57 per cent.

Water quality in South and Eastern Creeks is influenced by catchment runoff and STP discharges. Mass balance modelling results indicate that instream concentrations of all forms of nitrogen and total phosphorus in Eastern Creek in 2009 would decrease when compared to existing conditions, but concentrations would still exceed relevant guidelines for all nutrients (see **Table 7.5**).

Figure 7.8 Comparison of loads discharged into South Creek from St Marys and Quakers Hill STP in 2009 with and without Replacement Flows Project



A similar pattern would occur for South Creek as a result of the changes to discharges from St Marys STP (see **Table 7.6**). Concentration of all forms of nitrogen would decrease (while still being above relevant guidelines). Total phosphorus concentrations would, however, increase slightly due to the loss of the dilution effects of the STP discharges and the continuing high upstream contributions from catchment runoff.

Table 7.5 Predicted nutrient concentrations in 2009 in Eastern Creek downstream of Quakers Hill STP (median flows)

Scenario	In-stream Nutrient Concentrations (mg/L)			
	Ammonia	Oxidised Nitrogen	Total Nitrogen	Total Phosphorus
Without RFP	0.18	2.50	3.42	0.061
With RFP	0.15	2.04	2.91	0.055

Shading indicates value is higher than relevant guideline.

Table 7.6 Predicted nutrient concentrations in 2009 in South Creek downstream of St Marys STP (low and median flows)

Scenario	In-stream Nutrient Concentrations (mg/L)							
	Ammonia		Oxidised Nitrogen		Total Nitrogen		Total Phosphorus	
Flow	Low	Median	Low	Median	Low	Median	Low	Median
Without RFP	0.047	0.045	3.6	2.7	4.5	3.5	0.038	0.043
With RFP	0.046	0.042	2.9	1.1	3.7	1.8	0.039	0.049

Shading indicates value is higher than relevant guideline.

7.4.7 Salinity considerations for the river system

The integrated model also predicted the influence of the Project and other river management changes on the freshwater/saline interface. The model predicts there would be virtually no change in salinity profile of the estuary associated with the Project (see **Appendix C**). Therefore there would be no impact on aquatic ecology and irrigators due to changes in salinity in the freshwater tidal pool.

7.4.8 Management and impact of the concentrate from the AWTP

As described in **Chapter 3,** approximately 8 ML/day of liquid concentrate would be generated by the AWTP and this concentrate would be discharged into the Northern Suburbs Outfall Ocean Sewer (NSOOS). It should be noted that up to 10 ML/day of concentrate may be discharged into the NSOOS during periods when the concentrate storage pond at Quakers Hill STP requires emptying after wet weather. Studies and modelling were undertaken to determine the most suitable location for the discharge of the concentrate into the NSOOS and these considered:

- providing adequate dilution of the concentrate within the NSOOS. The concentrate has relatively high concentrations of dissolved salts which, if not adequately diluted, may affect the structural integrity of the concrete sewer pipes
- locating the discharge of the concentrate in a section of the NSOOS which has adequate capacity.

Based upon these studies, the preferred location for the discharge of the concentrate from the AWTP was the NSOOS near Vineyard Creek, Dundas. The length of the NSOOS between Vineyard Creek and North Head STP is

approximately 30 km. This section of the NSOOS is primarily constructed in tunnels, between 60 and 90m below ground. The tunnels are either concrete lined or constructed in rock. There are also a small number of aqueducts (at Quakers Hat Bay, Brightmore Reserve, Gore Creek, Burns Bay, Morrisons Bay and Herbert Street), box culvert sections (at Manly, Brightmore Reserve and Clontarf) and two inverted syphons (below Lane Cover River and Middle Harbour at The Spit).

The NSOOS between Vineyard Creek and North Head STP is in good condition (based on inspection reports undertaken in accordance with Sydney Water's asset reliability guidelines). Additionally, most of the aqueducts and other sections at or near the surface have been rehabilitated over the last 10 to 15 years. The remaining small number of surface sections will be rehabilitated between 2007 and 2010. The NSOOS is inspected regularly to assess its condition according to requirements identified in Sydney Water's sewers Asset Management Plan. As a result of these inspections, areas are identified for more detailed inspection or rehabilitation works.

In relation to capacity, the average dry weather flow of the NSOOS at Vineyard Creek is approximately 110 ML/day, which would provide adequate dilution (at least 10:1) of the concentrate from the AWTP to protect the sewers against corrosion and loss of structural integrity. There is also sufficient dry weather capacity in the NSOOS downstream of this location to receive the discharge. With the discharge of 10 ML/day of concentrate, total dry weather flow in this section of the NSOOS would be about 60% of the total sewer capacity, providing ample additional capacity for any future increases in flows due to development in the sewerage catchment.

In wet weather, inflow and infiltration of stormwater into the sewer system increase flows within the NSOOS. Discharge of the concentrate from the AWTP to the NSOOS during wet weather would be managed so that the concentrate does not increase the current NSOOS wet weather overflow frequency[1]. As a requirement of the operating licence for the sewerage system, Sydney Water must not allow overflow frequencies from the sewerage system to increase. Based upon the preliminary sewer system modelling undertaken for the Project, discharge to the NSOOS would cease when the sewer capacity at Vineyard Creek or Tarban Creek (which is downstream of Vineyard Creek) reaches 75% and recommence when capacity drops to 70%. By adopting these discharge criteria, the existing overflow frequency at Vineyard Creek (90 events every 10 years) and Tarban Creek (106 events every 10 years) would not change. It is predicted that there would be a less than 1% increase in the volume of wet weather overflows, however, this within the limits of the accuracy of the modelling and is not a performance criteria on the licence for the sewer system.

[1] The overflow target for the NSOOS system in the current licence for the sewerage system is 50% of wet weather overflows having an overflow frequency not exceeding 25 overflows every 10 years and 90% of overflows having an overflow frequency not exceeding 80 overflows every 10 years

During wet weather periods, the AWTP would continue to operate, with the concentrate temporarily discharged to a storage pond (up to 25 ML capacity) located at Quakers Hill STP, rather than being discharged directly to the NSOOS.

During wet weather periods, the AWTP would continue to operate, with the concentrate temporarily discharged to a storage pond (up to 25 ML capacity) located at Quakers Hill STP, rather than being discharged directly to the NSOOS. Once the concentrate storage pond reaches a specified volume, the AWTP operation would be reduced or would temporarily cease. The temporary reduction or cessation of operations would reduce or eliminate the production of the concentrate. However, the discharge of tertiary treated effluent from the three STPs into the Hawkesbury-Nepean River would recommence and the impacts would be similar to the current conditions. The size of the concentrate storage pond would be determined during the design process – and would determine the frequency of the

temporary cessation of the AWTP operations. For example preliminary modelling indicates that a 17.5 ML concentrate storage pond would result on average ceasing operations at the AWTP twice a year for 42 hours each time, whereas a 10 ML concentrate storage pond would result in ceasing operations at the AWTP four times a year for 24 hours each time.

The AWTP, concentrate storage pond and the discharge to the NSOOS would be operated to ensure that overflow frequencies from the sewerage system do not increase (ie no deterioration in overflow frequencies). More detailed modelling of the discharge of the concentrate, the storage pond and the NSOOS in wet weather would be undertaken to develop operating procedures for the concentrate management system and the AWTP.

The only time when there would be the potential for concentrate to be discharged in the Hawkesbury-Nepean River system would be if a significant incident or emergency occurred (eg total power failure). These events would be rare and appropriate response, monitoring and notification procedures would be developed.

Once discharged into the NSOOS, the concentrate would mix and flow with the other wastewater in the sewer system to North Head STP, where it would be treated and then discharged through the North Head deep water ocean outfall. **Table 7.7** compares estimated concentrations of nutrients, sulphates and total dissolved solids (ie salinity) in the concentrate with typical concentrations in dry weather wastewater inflowing to North Head STP. Nutrients in the concentrate from the AWTP would be lower than wastewater inflow to North Head STP. Total dissolved solids and sulphate concentrations would be higher in the concentrate and, as the concentrate (about 8 ML/day) would be significantly diluted by wastewater (330 ML/day) by the time it reaches North Head STP, there would only be a negligible increase in concentrations of these substances.

Nutrients in the concentrate from the AWTP would be lower than wastewater inflow to North Head STP.

Overflows from the NSOOS of wastewater containing concentrate would be rare and would only occur if there was intense heavy rainfall in the sewerage catchment downstream of Vineyard Creek before the concentrate discharge ceases. As described in **Table 7.7**, apart from total dissolved solids and sulphates, the concentrations of other key parameters would be lower in concentrate compared to typical wastewater and would not therefore result in any greater impact than normal wet weather overflows. The wastewater containing concentrate would be further diluted by inflow and infiltration of stormwater in the sewers and, once discharged into the environment, by surface stormwater. Also wet weather overflows downstream of Vineyard Creek predominately discharge to the saline estuarine reaches of Sydney Harbour where total dissolved solid concentrations are high. Consequently in the rare occasions when wastewater containing concentrate overflows after wet weather, the impacts would be negligible.

The increase in nitrogen and phosphorus load discharged via North Head Ocean Outfall would increase by less than 2 per cent and less than 0.5 per cent, respectively. The increase in loads discharged through the North Head deep water ocean outfall of other key marine pollutants such as copper and cadmium would be less than two per cent. The concentrations of most pollutants in the discharge from North Head deep water ocean outfall would actually decrease by a small amount, as the concentrate from the AWTP has lower pollutant concentrations compared to NSOOS wastewater and therefore mixing the two wastes would result in a dilution of the pollutants in the NSOOS wastewater. However, the decrease is likely to be so small that it would not be able to be detected. It should be noted that the ocean outfalls have been designed to maximise the dilution of effluent discharged. It is estimated that the dilution rate for discharges

from North Head deep water ocean outfall are 1:330 within the mixing zone of the discharge. Overall, the management and discharge of AWTP concentrate would have negligible impacts on the environment.

Table 7.7 Comparison of estimated pollutant concentrations

Analyte	Concentrate from AWTP (mg/L)	Existing wastewater at North Head STP (mg/L)	Combined concentrate and wastewater at North Head STP (mg/L)
Total Phosphorus	0.31	10.1	9.9
Total Suspended Solids	5	284	277
Total Nitrogen	32	>50	49
Total Dissolved Solids[1]	3000	770	823
Sulphates	500	55	66

[1] The increase in total dissolved solids concentrations in the NSOOS wastewater would be small and falls within the medium strength classification for effluent (TDS from 600 - 1000mg/L),as defined by the DEC environmental guidelines for the use of effluent by irrigation. It would not limit future recycling projects as typical treatment processes (namely membrane biological reactors and reverse osmosis) are able to cope with levels up to 1500mg/L without any significant impacts.

7.5 Aquatic ecology

This section provides a summary of the existing aquatic ecology of the study area and assesses the impacts of the Project on aquatic ecology. The detailed assessment is provided in **Appendix C**.

Aquatic ecology within the study area is already affected by flow and water quality changes due to catchment disturbance and runoff, the discharge of treated effluent and flow regulation and modification.

Key biological groups that respond rapidly to changes in river health are aquatic flora (including macrophytes and algae), fish and macroinvertebrates. Riparian vegetation was also considered in the study as the structure and diversity of the riparian vegetation strongly depends on the quality of river water, flow rates and disturbances occurring in the floodplain environment. Aquatic threatened species were also evaluated.

7.5.1 Warragamba River

Existing conditions

Riparian vegetation in the Warragamba River catchment consists primarily of Sydney Coastal Riverflat Forest (AMBS 1999) and Riparian Sandstone Scrub (ERM Mitchell McCotter 1996). The dominant riparian vegetation community along Megarritys Creek, a major tributary of the Warragamba River, is Sydney Sandstone Gully Forest (AMBS 1999).

The dominant macrophyte species occurring in the Warragamba River include Ribbonweed (*Vallisneria gigantea*) and Water thyme (*Hydrilla verticillata*) (Cummins et al 1997). Recently small rafts of duckweed *(Lemna minor)* have been found near the Megarritys Creek inflow. In the large pool near where Warragamba River inflows into the Nepean River *Salvinia molesta* was present, presumably having drifted in from extensive accumulations in the Nepean River.

Fish species found in the Warragamba River are similar to those found in the lowland reaches of the Hawkesbury-Nepean River system (Gehrke et al 1996 & 1999). Common fish species identified include Long-finned Eel (*Anguilla reinhardtii*), Australian Bass (*Macquaria novemaculeata*), Freshwater Mullet (*Myxus petardi*), Flathead Gudgeon (*Philypnodon grandiceps*) and Australian Smelt (*Retropinna semoni*) (Gehrke et al 1999). Fish species that are sensitive to flow regulation including Common Galaxia

(*Galaxia maculates*), Empire Gudgeon (*Hypseoleotris compressa*), Sea Mullet (*Mugil cephalus*) and Pacific Blue-eye (*Pseudomugil signifier*), were absent from the Warragamba River (Gehrke et al 1999).

Fish species found in the Warragamba River varied considerably between the two most comprehensive fish surveys undertaken in 1994 and 1995 (Gehrke et al 1996 & 1999). Species found included Australian Bass, European Carp (*Cyprinus carpio*), Cox's Gudgeon (*Gobiomorphus coxii*), Eel-tail catfish (*Tandanus tandanus*), Empire Gudgeon, Firetail Gudgeon (*Hypseleotris galii*), Flathead Gudgeon, Freshwater Mullet, Long-finned Eel, Sea Mullet, Australian Smelt and Striped Gudgeon. Bullrout, Eel-tail catfish and Firetail Gudgeon were absent in the survey in 1994, whilst European Carp, Cox's Gudgeon and Freshwater Mullet were absent from the survey in 1995.

The most common macroinvertebrates found in the Warragamba River include species from the families Chironomidae, Pyraiidae and Ecnomidae, which are commonly associated with macrophyte species Ribbonweed (*Vallisneria gigantea*) and Water Thyme *(Hydrilla verticillata)* (Cummins et al 1997). The abundance and diversity of macroinvertebrate communities indicate that mild-to-moderate impacts exist due to the discharge from the former Warragamba STP, although environmental flow releases from Warragamba Dam have reduced the extent of impacts (PPK 2003).

The Platypus *(Ornithorhynchus anatinus)* has been sighted infrequently in the Warragamba River below the dam wall (Grant 1998). The species is most common in the headwaters of rivers and streams and prefers steep earth banks (Scott and Grant 1997), which are characteristic of the Warragamba River.

The native Water Rat (*Hydromys chrysogaster*), Eastern Snake-neck Turtle (*Chelodina longicollis*), Eastern Water Skink (*Eulamprus quoyii*) and numerous frog species are also likely to occur in the Warragamba River downstream of Warragamba Dam.

Assessment of impact

Section 7.4 identified that the cessation of Warragamba Dam releases would result in an increase in nitrogen and phosphorus levels in Warragamba River. This predicted change in water quality would create favourable conditions for the growth of exotic macrophytes and algae which in turn could impact on the health of aquatic native species. Sydney Water is developing a strategy to reduce the impacts of the discharge of the recently commissioned Wallacia STP to acceptable levels. This would result in a reduced nutrient load into the river to offset the impact of the cessation of environmental flow releases from Warragamba Dam. Provided this is undertaken, excessive growth of exotic macrophytes and algae would be limited and the Project would have a neutral effect on macroinvertebrates, fish and other aquatic and riparian species.

7.5.2 Hawkesbury-Nepean River

Existing conditions

The existing distribution and abundance of riparian vegetation is sparse and highly modified along stretches of the Hawkesbury-Nepean River system where farming and urban development have occurred. However, the riparian vegetation in protected areas, such as the Blue Mountains National Park, is of excellent quality and is largely intact.

Overall the riparian habitat of Hawkesbury-Nepean River between the Nepean Dam and Sackville displays a high level of disturbance (Benson

and Howell 1997). According to the *Stressed Rivers Assessment Report: Hawkesbury-Nepean Catchment* (DLWC 1999), the Nepean River riparian vegetation exhibits moderate environmental stress, whilst the riparian vegetation of the Hawkesbury River has been classified as highly stressed (DLWC 1999). More than 50 per cent of riparian vegetation has been removed from the banks of the Hawkesbury River and the subsequent disturbance of shallow water ecosystems associated with the removal of riparian vegetation has resulted in a decline in aquatic fauna in these areas (DLWC 1999).

Macrophyte species occurring in the Hawkesbury-Nepean River system include both native and invasive, exotic species. The abundance and distribution of macrophyte species has changed considerably as a result of eutrophication, habitat disturbance and alterations to the flow regime of the river (Recher et al 1993). **Appendix C** summarises the common macrophyte species found along each of the river reaches in the study area. The most abundant species include the exotic weed Egeria (*Egeria densa*) and the native Ribbonweed (*Vallisneria gigantea*). Both are submerged species and are common downstream of Penrith Weir.

Since the introduction of Egeria into the Hawkesbury-Nepean catchment the native species Ribbonweed has been rapidly displaced (Roberts et al 1999). Infestations of Egeria extend from the weir pool above Penrith Weir to as far downstream as Wisemans Ferry (Roberts et al 1999; AMBS 2000; Taylor-Woods 2002).

The noxious weed Salvinia (*Salvinia molesta*) has dominated sections of the river during optimum conditions for its growth, resulting in large floating mats of weeds. Elodea (*Elodea canadensis*) and Hydrilla (*Hydrilla verticillata*) are also exotic species found in the river system (AMBS 2000). Elodea is a weed that survives in faster flowing waters, unlike Egeria which requires still to slow moving water. Elodea is currently only found in limited areas in the Hawkesbury-Nepean River and is not yet considered to be a pest (AMBS 2000). Both Egeria and Hydrilla thrive in nutrient rich water that promotes rapid growth of these plants (AMBS 2000). These species are often found downstream of Penrith Weir due to nutrients input from STPs and low flow velocities in this section of the river (AMBS 2000). Native Ribbonweed is intolerant of high nutrient waters and is generally absent in the river immediately downstream of STPs, but is often found in the faster flowing sections of the river.

Key factors affecting the number and distribution of fish in the Hawkesbury-Nepean River include altered flow regimes due to river regulation, barriers to fish movement (eg. weirs), poor water quality, instream and riparian habitat destruction and competition with introduced species (Harris 1995, Gehrke 1996). River regulation and barriers are listed as key threatening processes under Schedule 6 of the *Fisheries Management Act 1994* (FM Act).

Pollard and Growns (1993) identified 164 species in the Hawkesbury-Nepean River of which only a small number are found in the middle and upper Nepean River. Species identified include native species, introduced native species from other Australian catchments (namely the Murray-Darling system) and introduced exotic species (Pollard and Growns 1993). Four species listed as threatened, vulnerable or protected under the *FM Act* (Trout Cod, Macquarie Perch, Australian Grayling and Silver Perch) have also been found in the Hawkesbury-Nepean River (Gehrke 1996).

Fish species at three sites in the Hawkesbury-Nepean River were surveyed in 1983 and 1996 as part of the *NSW Rivers Survey* (NSW Fisheries and the CRC for Freshwater Ecology 1997). The most relevant site in the

context of the Project was the Nepean River at Wallacia. **Appendix C** shows changes in the fish species found in the Nepean River at Wallacia between 1983 and 1996. Five introduced fish species were identified of which two appeared to have have colonised the river between 1983 and 1996 (Carp and Rainbow Trout). Twelve species of native fish were found, of which several were not found in the 1996 survey (after being present in the 1983 survey) including Macquarie Perch, Murray Cod, Common Jollytail, Mountain Galaxia, Empire Fish, Bullrout and Freshwater Herring. The absence of these native species in the 1996 fish survey was potentially due to the survey method, although it was considered that an increase in exotic species and a decline in water quality and flows could have also contributed to their absence (NSW Fisheries and the CRC for Freshwater Ecology 1997).

Williams and Besley (1995) studied the distribution of macroinvertebrate species in the Hawkesbury-Nepean River system, including sites upstream and downstream of STP discharges. Common macroinvertebrates found in the Hawkesbury-Nepean and their associated habitats are listed in **Appendix C**. The diversity of macroinvertebrate communities was generally higher in the upper Nepean River and its tributaries, whilst sites in the lower Nepean River impacted by discharge from STPs displayed a lower diversity. The introduced snail *(Physa acuta)* was the most commonly recorded species at sites impacted by discharge from STPs. This species and other exotic snails and worms thrive in nutrient-rich environments such as areas downstream of STP effluent discharge points.

Assessment of impact

Wallacia Weir to Penrith Weir

The Project would have a generally neutral affect on the aquatic ecology within this reach of the Nepean River. Although there would be increased overall flows in this reach due to the 2009 river management changes and improved water quality due to the upgrade of West Camden STP, the Penrith Weir pool would still largely control the water levels and water quality.

In very low flow conditions there would be a predicted decrease of about 5 ML/day near Warragamba River inflow and an increase of approximately 5 ML/day over Penrith Weir. These changes are not significant and therefore in very low flow conditions, the existing riparian, macroinvertebrate and fish communities would not change in this river reach.

Increased flow over Penrith Weir would improve conditions for migratory fish species. The flow and water quality improvements could also lead to a reduction in exotic macrophyte species

The higher flows predicted for other flow conditions in 2009 due the river management changes would be beneficial to native fish species. Increased flow over Penrith Weir would improve conditions for migratory fish species. The flow and water quality improvements (related to other projects) could also lead to a reduction in exotic macrophyte species, such as the invasive weed Egeria (*Egeria densa*) and improvements in the distribution of the native Ribbonweed (*Vallisneria gigantea*).

Penrith Weir to Yarramundi

The Project (in conjunction with the 2009 river management changes) may have a beneficial effect on the aquatic ecology within this reach of the Nepean River. The combination of increased flow and improved water quality may be beneficial to native fish species. Also the improvement in water quality and flows within the main river channel would most likely favour native macrophytes over exotic macrophytes such as Egeria (*Egeria densa*). The potential for excessive growth of other aquatic weeds including Alligator Weed (*Alternanthera philoxeroides*), Pacific Azolla (*Azolla filiculoides*), Water Hyacinth (*Azolla filiculoides*) and less common Elodea

(*Elodea canadensis*) should also decline with a reduction in nutrient loads.

The increase in flow would continue to support flowing water macroinvertebrate communities. However as the discharge from Winmalee STP would also continue a neutral effect on the macroinvertebrate communities is predicted. No change is expected to riparian vegetation due to the Project.

Yarramundi to South Creek

The reach below Yarramundi to South Creek is within the freshwater tidal pool and would still be subject to bi-directional flow. Increases in upstream inflows are therefore not expected to influence macroinvertebrates or fish in this reach. Improved water quality from the Project especially near the South Creek inflows could, however, lead to a reduction in growth of exotic macrophytes within this reach of the river. No change is expected to riparian vegetation due to the Project.

South Creek to Sackville

The South Creek to Sackville reach is within the freshwater tidal pool and therefore changes in flows or water levels are not expected. Consequently the Project would have no impact on macroinvertebrates and native fish species.

Improved water quality, especially during dry weather due to a reduction in South Creek inflows could lead to a reduction in growth of exotic macrophytes and the occurrence of algal blooms within this reach of the river. No change is expected to riparian vegetation due to the Project.

7.5.3 South Creek and Eastern Creek

Existing conditions

South Creek catchment is highly modified as a result of agriculture and urban development. Past and ongoing land use practices have resulted in a decline in water quality and the health of the aquatic environment. Discharges of effluent from STPs dominate the hydrology and water quality of the creek system downstream of the discharge locations.

The quality and extent of riparian vegetation along Eastern Creek and South Creek is low. Scattered remnants of the endangered Sydney Coastal River Flat Forest are found in the riparian zone and provide a transitional zone to Cumberland Plain Woodland (Penrith City Council 2003). Although the riparian zones is fragmented and highly disturbed, remnant native species such as Cabbage Gum (*Eucalyptus ampliflora*), Swamp Oak (*Casuarina glauca*) and Black Wattle (*Acacia decurrens*) still occur in the area (Penrith City Council 2003).

Macrophyte species in South Creek and its tributaries include both native and exotic species, although the latter dominate the waterway due to their tolerance of poor water quality. Along the more stagnant and low flow zones of the creek, filamentous green algae, Enteromorphis sp. and aquatic weeds were common including Salvinia (*Salvinia molesta*) and Alligator Weed *(Alternanthera philoxeroides)* (Roberts 2003). A weed control program to manage Salvinia and Alligator Weed has been developed by Penrith City Council (2003). The most common native macrophyte found in South Creek is Ribbonweed (*Vallisneria gigantea*). However this species only occurs in reaches with less disturbed catchments.

As the South Creek system is highly disturbed, larger fish species that depend on intact native riparian vegetation are absent in the middle and

upper reaches of the creeks. Introduced species that adapt to the degraded environment dominate the South Creek system including Mosquito Fish (*Gambusia holbrooki*) (Roberts 2003).

There is one major barrier to fish passage in South Creek in the upper catchment (Badgerys Creek Dam). A number of other smaller barriers to fish passage impact the creek in the downstream reaches- primarily road crossings and culverts (Roberts 2003).

Macroinvertebrate communities in South and Eastern Creeks have been regularly monitored to assess the impact of effluent discharges from St Marys, Quakers Hill and Riverstone STPs (SWC 2005). A summary of genera recorded at these sites is presented in **Appendix C**. Monitoring upstream and downstream of the STPs indicates that the system is moderately to highly disturbed (SWC, 2005). According to SWC (2005), effluent discharges from St Marys STP had a continuous impact, while effluent discharges from Quakers Hill STP had an intermittent impact, as did discharges from Riverstone STP.

Assessment of impact

There will be a major reduction in flow and nutrient load in South Creek downstream of the STPs. Although concentrations of phosphorus would increase slightly and nitrogen concentrations would decrease, overall water quality would be relatively unchanged. The South Creek system would remain a relatively degraded environment and the Project would have a neutral effect on riparian, native fish, macroinvertebrate and macrophyte species within South and Eastern Creeks.

7.5.4 Threatened species assessment

Existing conditions

Three threatened dragonfly species (Odonata) and two threatened fish species recorded in the Hawkesbury Nepean River system could potentially be impacted by the Project. These species are:

- Giant Dragonfly (*Petalura gigantea*) is listed as endangered under the *Threatened Species Conservation Act 1995* (TSC Act)
- Sydney Hawk Dragonfly (*Austrocordulia leonardi*) is listed as endangered under the *Fisheries Management Act 1994* (FM Act)
- Adams Emerald Dragonfly (*Archaeophya adamsi*) is listed as vulnerable under the FM Act 1994
- Macquarie Perch (*Macquaria australasica*) is listed under the FM Act as vulnerable and under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) as endangered
- Australian Grayling (*Prototroctes maraena*) is listed under the FM Act as protected and under the EPBC Act as vulnerable. Sightings of the Australian Grayling in the Hawkesbury-Nepean system have been confined to the Grose River (Gehrke 1996).

Descriptions of the species and their status are provided in **Appendix C**. Two other species listed on threatened species schedules, Trout Cod (*Macquaria macquariensis*) and Silver Perch (*Bidyamus bidyanus*), have been recorded in Cataract Dam.

Threatened species, their conservation status and likely presence within the study area are presented in **Table 7.8.**

Table 7.8 Aquatic threatened species

Scientific Name / Common Name	Status	Likely presence in study area
Petalura gigantea Giant Dragonfly	Endangered (TSC Act)	The Giant Dragonfly is an extremely large, and unusual species of dragonfly, which is considered to be largely terrestrial throughout its life cycle. The larvae occupy permanent long chambered burrows, built under swamps. Larvae are not known to swim and avoid open water. The dragonfly lives in permanent wetlands and swamps with open vegetation. The Giant Dragonfly is found along the east coast of NSW from the Victorian border to northern NSW. The Giant Dragonfly is not known to occur within the project area and further assessment is not required.
Austrocordulia leonardi Sydney Hawk Dragonfly	Endangered (FM Act)	The Sydney Hawk Dragonfly is a black and yellow dragonfly with clear wings. Its known distribution is extremely limited, being found in only three locations in a small area south of Sydney, from Audley to Picton. The Dragonfly has specific habitat requirements including deep riverine pools with slow-flowing cooler water in rocky rivers with steep sides that provide shady rest areas. The project area provides potential habitats for this species and further assessment is provided Appendix C.
Archaeophya adamsi Adams Emerald Dragonfly	Vulnerable (FM Act) Vulnerable (TSC Act)	The Adams Emerald Dragonfly is a moderately large, robust dragonfly. This dragonfly is known to occur at only four locations in the greater Sydney region and its estimated potential distribution encompasses the Hawkesbury-Nepean catchment. Larvae are only known to occur in small creeks with gravel or sandy bottoms, in narrow, shaded, riffle zones and intact riparian vegetation. This species is considered very unlikely to occur within the project area due to a lack of suitable habitat. Further assessment is not required.
Macquaria australasica Macquarie Perch	Vulnerable (FM Act) Endangered (EPBC Act)	The Macquarie Perch is a large freshwater fish endemic to the Murray-Darling Basin and part of south eastern coastal NSW, including the Hawkesbury-Nepean catchment. Macquarie Perch are found in both river and lake habitats, especially in the upper reaches of rivers and their tributaries. Macquarie Perch are known to occur in the upper reaches of the Nepean River. They have not been recorded recently within the project area. The project area provides potential habitats for this species. Further assessment is provided in Appendix C.

Table 7.8 Aquatic threatened species *(cont'd)*

Scientific Name / Common Name	Status	Likely presence in study area
Prototroctes maraena Australian Grayling	Vulnerable (EPBC Act) Protected (FM Act)	The Australian Grayling is a moderate to large freshwater fish which occurs in streams and rivers of southeastern NSW and Victoria. The Australian Grayling needs to migrate to and from the sea to complete its life cycle and are therefore not found upstream of physical barriers such as dams. The Australian Grayling is known to occur within the Grose River, a tributary of the Hawkesbury-Nepean River. This population would utilise the Hawkesbury-Nepean River downstream of the Grose River confluence for migration to and from the sea. The project area provides potential habitat for this species and further assessment is provided in Appendix C.
Maccullochella macquariensis Trout Cod	Endangered (FM Act) Endangered (EPBC Act)	The Trout Cod is a large freshwater fish endemic to inland waters of the south eastern Australia region. The Trout Cod was translocated to the Hawkesbury-Nepean in 1915 and survives in Lake Cataract. This translocated population is thought to have hybridised with Murray Cod (Gehrke 1996) and as such have no conservation value as a natural population. Furthermore it is highly unlikely that the Cod survives below Cataract Dam due to the physical barrier created by the dam wall. The Trout Cod is unlikely to occur within the project area due to the presence of a physical barrier upstream. Further assessment is not required.
Bidyamus bidyanus Silver Perch	Vulnerable (FM Act)	The Silver Perch is a moderate to large freshwater fish native to the Murray-Darling river system. Along with the Trout Cod it was introduced to Lake Cataract in 1915. It is highly unlikely that the Perch survives below Cataract Dam due to the physical barrier created by the dam wall. The Silver Perch is unlikely to occur within the project area due to the presence of a physical barrier upstream. Further assessment is not required.

Three of the threatened species, including the Macquarie Perch, Australian Grayling and Sydney Hawk Dragonfly were identified as having potential habitats within the project area. An assessment of significance was prepared for each of the species likely to occur in the study area, in accordance with the FM Act and EPBC Act. The threatened species tests concluded that the Project is unlikely to disrupt a local viable population of the species, such that the species is likely to be placed at risk of extinction. A significant area of known habitat for these species would not be modified or removed, or isolated from currently interconnecting or proximate areas as a result of the Project. The Project would not have a significant impact on threatened species known to occur within the Hawkesbury-Nepean catchment.

7.5.5 Fish habitat and migration assessment

Habitat

Fish Habitat Protection Plan No.1 General and Fish Habitat Protection Plan No.3 Hawkesbury-Nepean River System apply to the Project. Both of these plans contain overlapping strategies that relate to the protection of fish and their habitats. Therefore the Project would be consistent with elements of both plans in that it will not:

- involve any dredging or reclamation activities
- involve construction or alteration of any weirs, dams, bridges, roads, culverts, causeway or reservoir that would impede the passage of fish
- involve construction of breakwaters, jetties, bridges, culverts, ramps and pontoons
- involve channelisation of streams
- affect habitat structures such as snags, boulders or rock
- involve clearing of riparian or floodplain vegetation
- affect any mangroves, seagrasses or other marine vegetation.

The aim of the *Fish Habitat Protection Plan No.3 Hawkesbury –Nepean River System* is to protect key fish habitats within the Hawkesbury-Nepean River system. The Project would be consistent with this plan in that it considers the conservation of fish habitats at all stages (planning, design, construction and operation) of the Project. The Department of Primary Industries (Fisheries) has been notified with regard to details of the Project and was consulted during the process of assessing its impacts and the design of aspects that have the potential to affect fish habitats.

Section 6.12 (Water Regulation) of Fish Habitat Protection Plan No. 3 states:

> *"Natural stream flows (both the quantity and seasonality of flows) should be retained where possible; if this is not possible, then a regime of environmental flows should be provided in consultation with NSW Fisheries."*

The Hawkesbury-Nepean River system is currently affected by the alteration of natural flows from the construction of dams and weirs, water extraction and the discharge of treated wastewater. The operation of the Project and the 2009 changes to river management committed to in the 2006 Metropolitan Water Plan would be an influencing factor affecting the flow regime.

Fish species and their habitats would be protected during the construction stage of the Project by implementing standard mitigation measures to minimise known threatening risks, such as sediment laden runoff and exposure of acid sulfate and saline soils (refer to **Chapter 8**).

Fish migration

The discharge of replacement flows via Boundary Creek has the potential to attract migrating fish away from the fishway at Penrith Weir. Although fish may be able to reproduce and survive in Boundary Creek, the attraction of the replacement flows could result in a reduction in fish migrating further up the Nepean River. Based on the limited information available in the scientific literature there are two major factors which govern fish attraction, namely flow and water temperature. Migrating fish are generally attracted to higher flows and higher water temperatures.

In relation to flow, those species that are stimulated to migrate by high flows would not be affected, as the replacement flows discharge via Boundary Creek would only contribute a relatively minor proportion of the total river flow in high flow conditions. The major potential impact of the Project would be on fish species that migrate upstream during low flow periods. Under present conditions, the very low flow (95th percentile) passing over Penrith Weir (including the fishway) is 62 ML/day, compared with about 22 ML/day from Boundary Creek. The replacement flows discharge via Boundary Creek would be of a greater volume (up to 50 ML/day) and compared to 2009 very low flow volumes over Penrith Weir (67 ML/day) would be a greater portion of total flow and therefore may potentially attract fish. However, there is no current data on the fish species using the Penrith Weir fishway and whether their migration upstream occurs during low flow periods.

In relation to temperature, the tertiary treated effluent currently discharged from Penrith STP has a relatively consistent temperature which varies slightly with the season. Based on the limited temperature data available, it is likely that the tertiary treated effluent discharge is warmer than the water flowing over Penrith Weir in colder months and cooler in warmer months. The replacement flows would have a different temperature compared to the tertiary treated effluent currently discharged as it would have travelled 8km through an underground pipe before being discharged into Boundary Creek. Additional studies are required to estimate the potential temperature range of the replacement flows discharge based upon the treatment process and transfer of the replacement flows through the pipeline.

A study would be undertaken in consultation with Department of Primary Industries (Fisheries) to determine whether the discharge of the Project would result in changes to the natural fish migration over Penrith Weir. Based on outcomes of this study appropriate design and other mitigation measures would be developed.

Some of the mitigation measures that could be incorporated into the final design of the Project include:

- a diffusion structure at the mouth of Boundary Creek to reduce the flow velocities and the attraction of the Boundary Creek discharge
- a barrier to fish migration at the mouth of Boundary Creek
- discharging a portion of the replacement flows directly into the fishway in low flow periods to increase the fishway's attraction
- cooling the replacement flows to a temperature below water overflowing Penrith Weir.

Sydney Water commissioned the University of New South Wales' Centre for Water and Waste Technology to undertake a desk-top screening-level risk assessment of the potential impact on human health of releasing highly treated recycled water into the Hawkesbury-Nepean River immediately downstream of the Penrith Weir.

7.6 Human health

7.6.1 Introduction

Sydney Water commissioned the University of New South Wales' Centre for Water and Waste Technology (UNSW-CWWT) to undertake a desk-top screening-level risk assessment of the potential impact on human health of releasing highly treated recycled water into the Hawkesbury-Nepean River immediately downstream of the Penrith Weir. The study considered the potential risks to river users from waterborne pathogens and chemicals. The river uses assessed included recreational use, drinking treated or untreated river water, being exposed to soils irrigated by river water, and eating fish caught from the river. In addition, the potential for cyanobacterial

(blue-green algal) blooms arising from the Project, under different flow regimes in the river was investigated.

The study did not consider risks arising from other pathways, e.g. stormwater, agricultural run-off and the additional effects resulting from background concentrations of microorganisms and chemicals in the river system.

The risk assessment concluded that during normal operation of the AWTP, no additional health risks were identified from either pathogenic microorganisms or from chemicals in the replacement flows for the various river uses investigated.

The risk assessment concluded that during normal operation of the AWTP, no additional health risks were identified from either pathogenic microorganisms or from chemicals in the replacement flows for the various river uses investigated.

A detailed summary of the Human Health Risk Assessment is presented in **Appendix D**.

7.6.2 Risk assessment process

In line with EnHealth guidelines on human health risk assessments (EnHealth Council 2002), the risk assessment was conducted as follows:

- issue identification
- hazard assessment (includes a literature review of human health risks arising from the Project and likely effectiveness of water treatment processes and other barriers, as well as relevant dose-response data)
- exposure assessment (includes quantification of pathogens and toxic chemicals);
- risk characterisation (includes the probabilities of infections and acute toxicity or cancer potential for chemicals, to aid decision making)
- uncertainty identification (includes uncertainties identified in the above 4 assessment steps and arising in the course of assessment. This summarises the knowledge gaps identified in each stage of the risk assessment)
- risk management (provides a range of management options based on the assessment presented in this report. The issues considered only cover issues relating to management options of Uncertainties highlighted by the assessment e.g. data gaps, limitations in the risk estimates provided).

It should be noted that the assessment did not include some components as prescribed by EnHealth. Some steps will be undertaken through separate means or subsequent work. These include 'Community Consultation', 'Management' (except in some identified priority areas) and 'Reality Checks' (other than those that were possible, based on literature or expertise based evaluation).

7.6.3 Hazard assessment

Initial concentrations of potential hazards from pathogens in sewage were estimated through a literature review and from examination of pathogen data for treated effluent from Sydney Water's STPs.

The chemical contaminants were subjected to a screening assessment to identify key hazards of potential concern. This involved comparing 95th percentile concentrations of the Schedule 10 list of chemical contaminants (Sydney Water data 2000-2004) with guideline values.

This process identified 27 chemicals possibly at or above guideline values, and for which more detailed risk assessment was undertaken.

Since toxic thresholds could not be identified for endocrine disruptors (EDCs), these chemicals could not be quantitatively assessed. Similarly disinfection by-products (DBPs) could not be quantitatively assessed due to a lack of information on the formation potential of this chemical during the treatment process. As a result, EDCs and DBPs are only discussed in **Appendix D**.

7.6.4 Exposure pathways

The exposure pathways considered were:

- consuming untreated river water as drinking water at Penrith Weir
- exposure to river water or sediment by ingestion, dermal (skin) contact (chemicals only) or inhalation of volatiles (chemicals only) during primary recreation (eg swimming)
- consuming vegetables irrigated with river water (pathogens only)
- exposure to soils irrigated with river water (chemicals only)
- consuming fish which might accumulate contaminants (pathogens only)
- consuming drinking water treated by North Richmond Water Filtration Plant (pathogens only) or not treated (chemicals only).

7.6.5 Key findings from the risk characterisation process

Pathogens

The overall risk from pathogens due to discharge of replacement flows was assessed as "Low" for each of the exposure pathways studied, when the AWTP is working normally (ie no failures at the AWTP).

The worst-case exposure pathway considered in the microbial risk assessment was drinking untreated river water (supplemented with the highly treated recycled water) downstream of Penrith Weir under low flow conditions. This was for three index pathogens Cryptosporidium (a human pathogenic protozoan), Campylobacter (a human pathogenic bacterium) and Rotavirus (a human pathogenic virus).

In this worst-case exposure pathway, assuming effective microfiltration/ reverse osmosis treatment, estimated risks were well below benchmark values of <1 µDALY and "1 in 10,000 risk of infection (more properly expressed as the probability of infection being 10-4.person-1.y-1). One µDALY is one Disability Adjusted Life Year per million people, which is used by the World Health Organisation as a measure of safe pathogen health burden. For this exposure pathway, the risk of infection would exceed the benchmark values only when a major failure of the reverse osmosis system occurs or when there is concurrent breakdown of both microfiltration and reverse osmosis membranes.

For the other exposure pathways, the risk benchmarks were exceeded for primary recreation (eg. swimming) downstream of Penrith Weir under a situation of low river flow conditions and concurrent breakdown of both microfiltration and reverse osmosis, only. The consumption of shellfish and irrigated vegetables, and in particular consumption of treated drinking water from the North Richmond reticulated supply presented risks well below the benchmark values.

Chemicals assessed

The only identified risk from chemicals (3 chemicals out of 111) was from recreational exposure to sediments in the river closest to the replacement

flow mixing zone, under conditions of poor reverse osmosis removal and low to medium river flow. The three chemicals were Aldrin, Benzo(a)pyrene and Dibenz(ah)anthracene. In this case the risk was assessed as "Low" to "Moderate", even though these three chemicals have not been detected in river water at the current limit of detection.

The initial screening stage of the chemical risk assessment of tertiary treated effluent data, without microfiltration/reverse osmosis treatment, resulted in the removal from consideration of 84 of the initial 111 Chemicals of Potential Concern (COPCs).

The risk characterisation of the remaining 27 chemicals of potential concern was undertaken in two stages. The first was the quantitative determination of residual risks associated with individual chemical contaminants identified from Schedule 10 monitoring data. This was followed by a qualitative interpretation of the overall risks based on hazard analysis.

Calculated risks for individual carcinogenic and non-carcinogenic chemicals were based on relationships and process assumptions described by the US Environmental Protection Agency for the assessment of risk associated with contaminated sites. Cancer risks and hazard quotients determined by these relationships were calculated separately for various exposure routes (i.e. oral, dermal, inhalation). The latter included consideration of partitioning (to air, water sediments and aquatic biota) for individual chemicals. Risks for the various pathways were summed to obtain a total exposure risk for each chemical under each exposure pathway.

Non-cancer chemical risks

No unsafe concentrations of non-cancer risk chemicals were identified.

No unsafe concentrations of non-cancer risk chemicals were identified.

Hazard quotients (for non-cancer risks) were calculated as a simple ratio between predicted exposure levels and exposure levels determined to be protective of human health. They were interpreted according to whether they were greater than or less than the Hazard Quotient (HQ) value of 1.0.

Based on HQs, monochloramine, hydrogen sulphide and nickel were the only non-cancer risk chemicals considered (their toxicity to humans was the risk concern because they are not considered to be carcinogenic). For each of these chemicals, calculated hazard quotients were less than 1.0 for each of the considered exposure pathways.

Cancer risks

The overall risks posed by these chemicals were assessed as 'Low' to 'Moderate'.

Risk estimations for carcinogenic chemicals were interpreted using the benchmark cancer risk (lifetime average probability) of one in a million (10^{-6}). That is, safe levels were assumed where calculated risk values were less than 10^{-6}.

Calculated risk values were less than 10^{-6} for all individual chemicals under the following exposure pathways and routes:

- oral consumption of drinking water
- recreational activities in the river (with exceptions noted below)
- exposure via irrigated soils.

A few chemicals were calculated to be equal to or slightly above the benchmark under some circumstances for the recreational exposure pathways. These were:

- Aldrin (river immediately downstream of Penrith Weir under low flow conditions and assuming poor reverse osmosis removal) (maximum exposure risk $1x10^{-6}$)
- Benzo(a)pyrene (river immediately downstream of to Penrith Weir under low or median flow conditions and assuming poor reverse osmosis removal) (maximum exposure risk 2-3 $x10^{-6}$)
- Dibenz(ah)anthracene (river immediately downstream of Penrith Weir under low or median flow conditions and rivers segments from Penrith Weir to Emu Plains under low flow conditions and poor reverse osmosis removal) (maximum exposure risk $1-5x10^{-6}$).

These risks were calculated as the sum of a number of exposure pathways. Of these the predominant influence was by dermal contact with river mud (sediment) in river segments.

It is important to note, however, that the identified chemicals may not pose a problem in reality. All three risk estimate sets, with risks exceeding the 10^{-6} risk benchmark were calculated using detection limit values rather than actual 95th percentile concentrations. None of these three compounds, Aldrin, Benzo(a)pyrene and Dibenz(ah)anthracene was detected in the 75 samples (3 analytes x 25 measurements) used in the assessment. It should also be noted that Aldrin has been banned for use in Australia.

Cyanobacterial toxins

The overall risk of the Project increasing the risk of cyanobacterial blooms is "Low" based on reduced nutrient load that would be discharged into the Hawkesbury-Nepean River. The reduction in nutrient loads is further discussed in **Section 7.4**.

7.6.6 Key inputs from the literature survey

Using the selected hazards and initial identification of exposure pathways as guides, a review of the available quantitative information, needed to estimate removal rates of the potential hazards, was undertaken. This was supplemented by available data for the Hawkesbury-Nepean River and background information for the Project (e.g. Sydney Water's hydrological model of river flow and dilution regimes). While there was no reported risk assessments of the use of highly treated recycled water for flow replacement that could be used as a model, there was sufficient information on the contaminant classes (hazards), exposure pathways and human effects to estimate risks using the EnHealth framework. Key findings were as follows:

- membranes vary appreciably in their effectiveness as barriers to pathogens and chemicals depending on nominal pore size, manufacturer, units in series, operational practice, and the contaminant type
- microfiltration/reverse osmosis treatment is expected to reduce pathogens by more than a billion-fold under normal operating conditions
- microfiltration/reverse osmosis is less effective at reducing chemicals than pathogens. Large charged organic chemicals would typically be reduced in excess of 1,000-fold, but small neutral molecules and ions may be less effectively reduced, with removals ranging from close to zero up to 1,000-fold. When considering the effectiveness of microfiltration/reverse osmosis treatment it is essential to assess each chemical species individually or on the basis of key attributes (e.g. molecule size, charge, hydrophobicity)
- phosphate concentrations should be reduced by reverse osmosis by about 25 to 63-fold

- dilution at the point of release into the river should further reduce contaminant concentrations under 20th (high) and 80th percentile (low) river flows by 80-fold and 4-fold respectively, assuming negligible background concentrations in ambient water
- once in the environment, further protection to human health would be provided by further dilution, pathogen inactivation, and chemical degradation and partitioning between air, water, and sediments, as well as additional water treatment where water is extracted for potable uses.

7.6.7 Conclusions

No additional risk from pathogens was identified for the pathways examined from the discharge of highly treated recycled water to the Hawkesbury-Nepean River during effective operation of the microfiltration/reverse osmosis treatment process. Furthermore, due to the conservative worst-case assumptions used in the study, uncertainties related to the pathogen risk assessment were considered unlikely to affect the study outcomes based on:

- direct consumption in recreation would be far less than via the raw drinking water route and thus the latter estimates would identify whether there was a major risk
- it was unclear if raw mussels are currently consumed by the public
- normal good hygiene practice requires raw vegetables to be withheld before marketing, and washed before consumption. Both would provide a large degree of additional protection not accounted for in this study.

In regard to chemicals, no additional risk was identified for the majority of chemicals investigated (108 out of 111 chemicals) from the discharge of the highly treated recycled water during effective operation of the microfiltration/reverse osmosis treatment process. A marginal risk was calculated for three of the chemicals by one exposure pathway only. This risk is likely to be overestimated, however, given the sensitivities of current detection methodologies. These chemicals were not detected in any of the samples used in the study so the minimum detection limit was used as a conservative estimate in calculations. It is recommended that endocrine disrupting chemicals and disinfection by-products be further investigated due to the uncertain nature of the risk, with the understanding that these risks can largely be managed operationally.

The impact on cyanobacterial risk levels by the implementation of the Project was seen as positive based on a reduction in nutrient loads.

The impact on cyanobacterial risk levels by the implementation of the Project was seen as positive based on a reduction in nutrient loads.

7.6.8 Recommendations

The exposure analysis process identified a number of appropriate management options whose significance would be assessed in subsequent studies as a matter of priority.

The microfiltration/reverse osmosis plant would be maintained at a high degree of functionality with any suspected malfunction triggering rapid shut down. The total risk would be very small from any such malfunctions but it is recommended that a model of failure modes, their impact, and the detection and management actions triggered should be developed to confirm and aid in the development and testing of system management protocols.

Evidence already exists that microfiltration/reverse osmosis systems are very effective under normal operating conditions. The construction of a small pilot test unit may provide further useful data on the functioning of

a full scale plant, however, it is the effect of failure of the reverse osmosis system on risk that needs further investigation. Thus testing would be more appropriate on the full-scale system with cessation of its operation when malfunctions are detected followed by close studies of such malfunctions. Such work could include:

- confirmation of predicted performance
- confirmation of capacity of failure detection systems
- challenge testing of seasoned units taken off line
- challenge testing of an operational part of the treatment train taken off-line, using safe surrogate microorganisms (e.g. bacteriophage) and chemicals (e.g. fluorescent dyes).

The efficacy of membranes in removal of chemicals under a range of conditions should be investigated at pilot scale to verify the outcomes of the risk assessment. This would assist in optimising the membranes for the full-scale plant and to determine whether any chemicals require further management. This may include specific trade waste and source control options.

Whilst chemical screening itself is limited by the number and range of chemicals that can be realistically monitored, biological endpoint testing can be included to detect potential impacts from chemicals not considered here or from cumulative impacts from chemicals that may be present at trace concentrations.

Once the Project is operational, the highly treated recyled water would be monitored to verify removal to levels based on relevant guideline values. After plant commissioning, an ongoing program of testing should be agreed with NSW Health using the guideline values, biological endpoint testing (which in time will cover emerging issues such as EDCs) and compliance with the Australian Drinking Water Guidelines at North Richmond Water Filtration Plant. Some investigation of disinfection by-product formation, removal efficiencies and fate, is recommended to further assess the risks.

The operational integrity of the reverse osmosis treatment process can be routinely monitored by standard online measurements, such as salinity and total organic carbon (TOC).

The operational integrity of the reverse osmosis treatment process can be routinely monitored by standard online measurements, such as salinity and total organic carbon (TOC). The suitability of these criteria for reverse osmosis treatment, however, may be limited by their sensitivity at the very low salinity and TOC concentrations expected for a well-performing reverse osmosis plant. The effectiveness of these (and other suitable) integrity tests should be investigated on an on-going basis. Target operational values should be carefully identified and justified. Furthermore, detailed plans should be developed for operational procedures to be undertaken when the target values are exceeded.

The risk assessment identified sediment (river mud) as a potential exposure pathway, via the dermal route, for some chemicals. This was a calculated risk based on the limit of detection concentrations; these three chemicals were not detected in the sewage samples used in the study. It is recommended to undertake a sediment survey following commissioning of the plant to refine the risk assessment outcomes.

A detailed characterisation of exposed populations and relevant uses of water from the Hawkesbury-Nepean River would better inform future risk assessment activities. For example, it would be valuable to determine:

- the actual degree of access to various reaches of the river
- the populations that extract water from the river for drinking or other purposes without treatment

- the fishing activities that are undertaken in various reaches of the river
- the nature and typical frequencies (for individuals) of various recreational activities at the river.

In addition, the assessment of consumption of aquatic biota for chemicals requires further collection of data of the amount and types of fish consumed from the river.

7.7 Recreation

7.7.1 Introduction

The Hawkesbury-Nepean River system is an important recreational resource for the local population and for tourists. More than 900 'cultural and recreational services' businesses employed 4,050 people in the Hawkesbury-Nepean catchment in 1997. Due to the population growth in the region the number of visits to the river each year is estimated to increase to 20 million in 2020, from 10 million in 1992 (HNRMF 2004).

As well as providing opportunities for water based activities the weir pools and many of the main river stretches have retained their scenic qualities, which attract visitors who come to enjoy the natural surroundings. A rough estimate of general recreation expenditure was in the order of $300 million per year (1992). In 1993 the gross revenue to caravan and ski parks alone was about $5.1 million (HNRMF 2004).

The area of the Hawkesbury Nepean River potentially affected by the Project has been separated into six distinct reaches. These reaches have been described separately and are shown in **Figure 7.1**.

Lowering the levels of total nitrogen and total phosphorous entering the river system will inhibit the growth of algae and weeds, and so, is expected to increase the appeal of the river for recreation purposes.

Aquatic plant growth is responsive to nutrient inputs. Previously blue-green algae and macrophytes, in particular exotic species, have impacted reaches of the Hawkesbury-Nepean River due to high nutrient concentrations. This has reduced the clarity and attractiveness of the river for primary contact users such as swimmers and water skiers. There are also safety implications where algae or weeds reduce visibility in the water.

Lowering the levels of total nitrogen and total phosphorous entering the river system will inhibit the growth of algae and weeds, and so, is expected to increase the appeal of the river for recreation purposes. Increased water clarity would also enhance the scenic qualities of the water resource, whilst the overall improvements in river health are likely to be beneficial to recreational fishers.

7.7.2 Warragamba River

Existing conditions

This section covers the area from the Warragamba Dam wall to the confluence with the Hawkesbury-Nepean River. This 3.5 km stretch of river has picnic facilities located within Havilland Park on the east side of the dam and at Warragamba Park at the confluence with the Nepean River. There are no boat ramps or camping facilities provided along this short stretch and the river is largely inaccessible as it flows through a gorge.

Assessment of impact

Due to the decrease in flow and potential impacts on water quality from the Wallacia STP and dam seepage water, recreational amenity of this reach of the river may decrease with the operation of the Project.

However, as noted in **Section 7.4** a strategy to ensure that water quality is maintained at an acceptable level in this reach of the river is being developed. Overall the impact of the Project upon recreational values of this river reach would be minor.

7.7.3 Wallacia Weir to Penrith Weir (Nepean River)

Existing conditions

Wallacia was a renowned holiday resort from the late 1800s to the 1940s and is still popular (*www.penrithcity.nsw.gov.au*). There are a few recreational facilities around Wallacia including Blaxlands Crossing reserve with associated caravan park, picnic area and barbecue facilities and Wallacia Golf Course. Wallacia Weir is located approximately 1.75km downstream of Wallacia. The stretch of river from the weir to the confluence with the Warragamba River includes rapids, which are navigable by canoe. Norton's Basin is a large calm pool with rocky cliffs around, and is a popular swimming area (*www.penrithcity.nsw.gov.au*).

From the junction with the Warragamba River, the Nepean River enters the Nepean Gorge. Most of this gorge is located within the Blue Mountains National Park and access is only possible by boat or walking trail. The gorge is bounded by scenic cliffs and there are a number of large exposed and submerged rocks in this area which makes navigation by some craft difficult. Euroka Creek runs through the Blue Mountains National Park and joins the Nepean around the Nepean Gorge. There are walking tracks alongside the creek and camping is available within the National Park at Euroka Clearing.

Downstream of Glenbrook Creek the river returns to floodplain. From this point onwards the river becomes wide and deep and there are high levels of public access. Tench Reserve lies on the eastern bank of the Nepean River at Regentville, commencing around the point of the confluence of Mulgoa and School House Creeks extending north beyond the Western Motorway bridge to the Cable Water Ski Park at Penrith. The reserve has a boat ramp on the north side of the bridge. The Nepean Belle paddle steamer also operates from the Tench Reserve, taking passengers on trips through the scenic Nepean Gorge. The stretch of Nepean River between the reserve and Victoria Bridge at Penrith is used as a Championship Rowing Course and rowing and kayak sprint course. This stretch used to be the region's main rowing venue, until the Sydney International Regatta Centre at Penrith Lakes opened.

There are parks on either side of the river around Victoria Bridge. Regatta Park and adjacent reserve on the western bank is mainly used for passive recreational pursuits such as picnicking, informal ball games and walking. This site is a popular spectator spot. The Weir Reserve is located on the eastern bank. This park has picnic areas, public amenities and a caravan park. It is also popular for picnicking, walking and fishing, as well as providing a scenic backdrop for wedding photographs at the pagoda overlooking the river (UTS 2002). The Nepean Rowing Club, located in the reserve, provides a boat shed and licensed club facilities.

The Cable Water Ski Park, Nepean Shores Riverside Resort and Conference Centre, playgrounds, Jamieson Golf Resort, hotels, motels and log cabins are concentrated in the area just south of Victoria Bridge.

A number of annual water based events are held at Penrith, including the following:

- Australia Day Committee bridge to bridge swimming race
- Triathlon
- Nepean River festival
- 100 mile canoe race
- Penrith Swimming Club's annual swimathon.

Assessment of impact

The Project (in conjunction with the other changes to river management) would result in greater flows in this river reach, for all but very low flows. There would be no change in water quality associated with the Project, however it should be noted that the upgrade of West Camden STP and recycled water scheme will result in improvements in water quality in the upper sections of this river reach. Overall, river health in this reach may improve with increased flows, however, this cannot be conclusively determined.

The recreational amenity of this section of the river would remain relatively unchanged and would not deteriorate as a result of the Project.

7.7.4 Penrith Weir to Yarramundi (Nepean River)

Existing conditions

The navigability of the river in this section has been decreasing due to siltation and a number of beaches and sand banks have built up around the Jackson Falls area. The area to the north of Penrith has been transformed through extensive sand and gravel extraction. This has now been restored and forms the Penrith Lakes Scheme, International Regatta Centre and Whitewater Stadium. The scheme includes a series of lakes covering 700 hectares providing facilities for rowing and canoeing, whitewater rafting and picnicking (*www.penrithlakes.com.au*).

Further north into Castlereagh, the river passes alongside the Yellow Rock Reserve and Yellow Rock Recreation Reserve. Further north, around Lynch Creek, is the Lynch Creek Reserve, River Park Christian Youth Camp and Yarrawood Teachers College Camp, all located on the western bank of the Nepean.

Yarramundi is another major zone for in-stream gravel extraction. Significant extraction occurred between 1927 and 1989 at the confluence of the Grose and Nepean Rivers. This has now been transformed into the Yarramundi Reserve. This reserve lies to the west of Agnes Banks and Yarramundi Lagoon and provides local and regional recreation opportunities such as fishing, canoeing, swimming, nature-based study, bird watching, educational activities, walking, mountain-bike riding, jogging, dog walking and horse riding (*www.hawkesbury.nsw.gov.au*).

Assessment of impact

The current discharge of approximately 22 ML/day of tertiary treated effluent from Penrith STP would be cease and instead up to 50 ML/day of highly treated recycled water would be discharged into this reach of the river as replacement flows.

The replacement flows, which have been treated through reverse osmosis to remove pathogens and nutrients, would significantly reduce the nutrient loads and pathogens discharged to the Nepean River at Penrith. Lowering the levels of total nitrogen and total phosphorous entering the river system would reduce the potential for excessive growth of algae and weeds, as

such, would be expected to increase the appeal of the river for recreational purposes. Increased water clarity would also enhance the scenic qualities of the water resource, whilst the overall improvements in river health resulting from the scheme would potentially be beneficial to recreational fishers.

7.7.5 Yarramundi to South Creek (Hawkesbury River)

Existing conditions

Recreational fishing is popular at Richmond Bridge, as well as some commercial fishing, motor boating, canoeing and raft races. There are a number of parks providing land based recreation activities and access to the riverbank between Yarramundi and Windsor. These include Hawkesbury Park, Hanna Park, Terrace Park and the Breakaway.

Tourist and recreation facilities are concentrated around Windsor, with hotels and motels present within the town and public mooring available around Windsor Bridge. There are parks on both sides of the river, including Deerubbin Park and Howe Park on the southern bank. Macquarie Park is positioned alongside Windsor Bridge and has parking, amenities, playgrounds and facilities for picnicking. The Power Boat Club, which has parking and boat ramps, is located within Governor Phillip Park alongside the confluence with South Creek. The most popular recreation activity at Windsor is picnicking, followed by speed boating, swimming and motor boating. There are only low levels of sailing, bushwalking and sightseeing (HNRMF 2004). There is a low suitability for swimming due to dense macrophytes.

Assessment of impact

There would be little change in water quality and flows in this river reach associated with the Project. There will be a reduction in nutrient loads from the South Creek inflow, although the benefits of this are more likely to be observed in the downstream river reach.

Consequently the recreational amenity and suitability of this river reach would not change as a result of the Project.

7.7.6 South Creek to Sackville (Hawkesbury River)

Existing conditions

The most popular recreation activities identified at Windsor and downstream are picnicking, speed boating, waterskiing and swimming. This stretch of river has the greatest number of riverside recreational facilities of all of the sections discussed. There are around twenty five water ski resorts, around twenty of which are associated with caravan parks. Further recreation and camping facilities are present within the surrounding areas, including Cattai National Park and Parr State Recreation Area. This area is the site of the annual bridge-to-bridge water ski classic. This is the world's longest water skiing race and is held annually from Dangar Island in Broken Bay to Windsor, drawing up to 20,000 spectators (*www.waterskinsw.com.au*).

Canoeing is also a popular activity along these reaches. The Hawkesbury Canoe Classic, an annual canoe race held at night, obtains exclusive use of the river from Windsor to Brooklyn once a year (*www.canoeclassic.asn.au*). Other recreation facilities in this stretch include the Riverside Oaks Golf Course, which is located along the river bank at Maroota South and accessed from Wisemans Ferry Road.

There are significant permanent boat moorings at Sackville and a few at Gronos Point, Ebenzer, Portland, Colo and Wisemans Ferry. A number of cruise hire companies operate out of Wisemans Ferry and there are ferry services at Sackville and at Webbs Creek.

Assessment of impact

There would be a significant reduction in the load of nutrients entering this river reach from the South Creek inflow. Lowering the levels of total nitrogen and total phosphorus entering the river system would reduce the potential for excessive growth of algae and weeds, and so it would be expected to increase the appeal and suitability of the river for recreational purposes. Increased water clarity would also enhance the scenic qualities of the water resource, whilst the overall improvements in river health resulting from the scheme would potentially be beneficial to recreational fishers.

7.7.7 South Creek and Eastern Creek

Existing conditions

Dunheved Golf course is located a short distance from St Marys STP. South Creek flows through Shanes Park and alongside Berkshire Park Racehorse Education Centre. A reserve runs alongside the western bank in the Windsor Downs area. Besides a boat ramp near the confluence with the Hawkesbury River, the waters of South Creek are not used extensively for recreation purposes.

From Quakers Hill STP, Eastern Creek flows northwards. With the exception of Knudsen Reserve there are no official parklands alongside the creek up to its junction with South Creek.

Assessment of Impact

There would be a substantial reduction in flows and loads of nutrients impacting upon these creeks with the operation of the Project. This may result in an improvement in water quality and health of aquatic ecosystems in the creeks. However, this is unlikely to affect the relatively low recreational values and uses of the creek.

7.8 Primary industries

The key primary industry uses of the Hawkesbury-Nepean River that may be impacted by the Project are agriculture, horticulture and commercial fisheries.

The economic value of agriculture and horticulture in the Hawkesbury-Nepean catchment is estimated to be approximately $1.07 billion per year, of which $600 million per year is derived from irrigated agriculture.

7.8.1 Agriculture and Horticulture

Existing conditions

In the Hawkesbury-Nepean catchment, agricultural and horticultural water extraction may be up to 100 billion litres per year. The rate of extraction is highly variable and it is only in extended dry periods that most irrigators take their full allocation of river water. In many years, irrigators may use less than 40 per cent of their allocation (HNRMF 2004).

The economic value of agriculture and horticulture in the Hawkesbury-Nepean catchment is estimated to be approximately $1.07 billion per year, of which $600 million per year is derived from irrigated agriculture.

Industries are mainly horticultural and animal production, and represents an estimated gross value of 12 per cent of all New South Wales agriculture production. Agricultural industries also provide numerous community benefits to the greater Sydney water supply region, including employment diversity, rural amenity and tourism, agri-tourism and heritage values. Agriculture in the Sydney Basin faces challenges such as increased urban development, the increasing effects of aquatic weeds, and the impact of poor water quality on the viability of irrigated horticulture in some areas (HNRMF 2004).

Primary production activities which extract water from the Hawkesbury-Nepean River system include:

- drinking water supplies for stock
- pasture (both perennial and annual) growth
- lucerne production
- turf farming
- vegetable production
- citrus and other orchard products
- nursery watering.

The volumes of water entitlements for extraction for agricultural and horticultural uses under licences issued by Department of Natural Resources in the different reaches of the river are described in detail in **Table 7.9**. The reach of the river from Yarramundi to the Colo River has the highest allocation of water for agricultural and horticultural use (36,391 ML/year). Water users in this reach extract from the freshwater tidal pool downstream of the Yarramundi. Licensed water extraction for agriculture and horticultural uses also occurs in South Creek (7997 ML/year) and between Warragamba River and Yarramundi on the Nepean River (7768 ML/year). Although water extraction for agriculture and horticultural uses occurs in other areas of the Hawkesbury-Nepean River, these areas would not be affected by the Project and are not discussed further.

Table 7.9 Current irrigation entitlements within the study area

Catchment	Number of extraction licences	Total volumetric entitlement	Main Purpose
Upper Nepean	68	2,293 ML/year	Irrigation - 2064 ML/year Stock - 38 ML/year Other- 191 ML/year
Lower Nepean to Warragamba River	271	23,782 ML/year	Irrigation - 22,506.5 ML/year Stock - 352 ML/year Other- 923 ML/year
Warragamba River to Yarramundi Bridge	106	7,769 ML/year[1]	Irrigation – 6,937 ML/year Stock – 60 ML/year Other - 772 ML/year
Yarramundi to Colo River	431	36,392 ML/year	Irrigation - 35,546 ML/year Stock - 150 ML/year Other- 696 ML/year
South Creek	200	7,997 ML/year[2]	Not available

Source: DIPNR – Draft Water Sharing in the Hawkesbury-Nepean, Summary Information for Surface Water Zones)

[1] 45% of volumetric entitlements are held by Penrith Lakes – these will be surrendered before 2015 and an alternative water harvesting arrangement for the Lakes will be implemented

[2] All of South Creek entitlements including entitlements above STP discharges locations. Below the STP discharge locations entitlements are estimated to be approximately 1,925 ML/year

Assessment of impact

At the same time the Project would become operational in 2009, other changes to river management would be implemented, namely increased environmental flow releases from the upper Nepean dams and the protection of low flows from extraction. The cumulative effects of these changes on river flows at relevant locations in the study area are discussed in detail in **Section 7.3**.

Warragamba River to Penrith Weir (Nepean River)

Apart from very low flows (>95th percentile), the volume of water in this reach of the river across all flow categories would increase compared to the existing situation primarily due to the increase in environmental flow releases from the Upper Nepean dam. For very low flows, there would be a slight decrease in flow volumes at the junction of the Nepean River with Warragamba River. Consequently, there would be no adverse impact on water availability for extraction in this river reach due to the Project.

Penrith Weir to Sackville (Hawkesbury-Nepean River)

Flow volumes downstream of Penrith Weir would increase substantially for all flows (ie very low to high flows) compared to the existing situation. This would result in a greater volume of water entering the freshwater tidal pool (ie Yarramundi to the Colo River) from the Nepean River. However, flow volumes from the South Creek inflow would be reduced. The cumulative effect of these changes would result in increased flows into the freshwater tidal pool downstream of Yarramundi, primarily due to higher environmental flow releases from the Upper Nepean dams. Consequently the volume of water available for extraction for agricultural and horticultural uses in the freshwater tidal pool would not be adversely impacted.

South and Eastern Creeks

Although water licences in the South Creek catchment allow 7997 ML/year to be extracted, most of the licensed extraction points are located upstream of the Quakers Hill and St Marys STP discharge locations – and therefore would not be impacted by the Project. However, licensed extractions downstream of the STPs (1,925 ML/year) may potentially be affected due to the significant decrease in discharge volumes from the STPs as tertiary treated effluent is diverted to the AWTP. Based on flow gauging information, it is estimated that approximately 5 ML/day (on average) and a peak demand of 9.3 ML/day, is extracted from the creeks downstream of the STPs.

Although effluent discharges from STPs are currently not recognised as a source of water by the Draft Water Sharing Plan (and therefore Sydney Water has no statutory requirement to ensure flows in the creeks are maintained for downstream water users), Sydney Water recognises that these effluent discharges are used as a source of water for agriculture and horticulture. Consequently, in developing the Project, the water requirements of extractors downstream of the STPs were considered and sufficient volumes of effluent were allocated for continuing discharge to South and Eastern Creeks. These releases are sufficient to meet both the average and peak demands for current water extraction and therefore there would be no adverse impact on agricultural and horticultural water users downstream of the STPs.

7.8.2 Fisheries

Existing Conditions

There are between 75 and 100 commercial fishing licences held for the Hawkesbury-Nepean River system. These licences are administered and regulated by the Department of Primary Industry - NSW Fisheries. The licence holders catch a diverse range of finfish, crustaceans and molluscs using a wide range of fishing methods such as meshing, hauling, trawling and trapping. It should be noted that the vast majority of commercial fishing activities are undertaken in the saline estuarine and marine reaches of the Hawkesbury River, downstream of the study area for the Project.

In 2004, the Hawkesbury-Nepean River was reported to support New South Wales' second largest commercial coastal fishery of prawns, oysters and fish with a wholesale value of $6.3m per year (HNRMF, 2004).

Assessment of impacts

The major commercial fisheries in the Hawkesbury-Nepean River system are located in the saline estuarine and marine areas downstream of the study area. These downstream areas would not be affected by the Project and so the commercial fisheries would not be directly impacted. Some of the species targeted by the commercial fisheries may spend part of their lifecycle in the freshwater reaches of the Hawkesbury-Nepean River. The impact of the Project on these reaches is described in detail for water flow (**Section 7.3**), water quality (**Section 7.4**) and aquatic ecology (**Section 7.5**). These impacts have been assessed to have a neutral impact on flows and a neutral to potentially beneficial impact on the water quality of receiving waterways, except for the Warragamba River. Mitigation measures would be implemented to maintain acceptable water quality within Warragamba River.

As there would be no significant adverse impacts on water quality, flows and aquatic ecosystems in the freshwater reaches of the Hawkesbury-Nepean River affected by the Project, commercially important fish and crustaceans which spend part of their lifecycle in the freshwater would also not be affected. Consequently there would be no indirect impacts on commercial fisheries from the Project.

7.9 Conclusion

7.9.1 Summary of impacts

Presented in **Table 7.10** is a summary of the existing conditions in the study area and the predicted impacts as a result of the Project.

7.9.2 Summary of mitigation measures

The following additional operational mitigation measures (apart from monitoring) would be implemented:

- Sydney Water would continue investigations to establish a sustainable solution to manage the effluent produced by the new Wallacia STP
- a study would be undertaken in consultation with Department of Primary Industries (Fisheries) to determine whether the discharge of the Project would result in changes to the natural fish migration over Penrith Weir. Based on outcomes of this study, appropriate design and other mitigation measures would be developed
- a suitable volume of effluent would continue to be released from the St Marys and Quakers Hill STPs to ensure that current irrigation users downstream of these plants are not disadvantaged by the operation of the Project
- management of the concentrate, including the AWTP and storages, would ensure there is no discharge of concentrate to the Hawkesbury-Nepean River including South Creek catchment, unless there is a significant incident or emergency or as otherwise agreed with DEC. Management of the concentrate would also ensure that there is no increase in overflow frequencies from the NSOOS.

Table 7.10 Summary of impacts due to the operation of the Replacement Flows Project

Environmental Aspect		Warragamba River	Wallacia Weir to Penrith Weir	Penrith Weir to Yarramundi	Yarramundi to South Creek	South Creek to Sackville	South Creek & Eastern Creek
Water Quantity	Existing Conditions	Interim flow releases of 43 ML/day (although only 22 ML/day currently due to drought)	For very low flow conditions 0 ML/day over Wallacia Weir and 62 ML/day over Penrith Weir	For very low flow conditions 84 ML/day downstream of Penrith Weir	Freshwater tidal pool	Freshwater tidal pool	Approximately 69 ML/day of effluent discharges into creeks Dry weather flows < 1 ML/day
	Predicted Impact	Cessation of all flow releases (ie 0 ML/day) Flow releases from Warragamba Dam to be reviewed in 2009	For very low flow conditions 39 ML/day over Wallacia Weir and 67 ML/day over Penrith Weir. Flows near Warragamba River inflow 4 ML/day lower for very low flows. Flows increase for all other flow conditions	For very low flow conditions 117 ML/day downstream of Penrith Weir Flows increase for all other flow conditions	Flows into the freshwater tidal pool from upstream would increase while inflows from South Creek would decrease	Flows into the freshwater tidal pool from upstream would increase while inflows from South Creek would decrease	Effluent discharges would decrease to around 20 ML/day in 2009
Water Quality	Existing Conditions	Complies with relevant water quality guidelines	Wallacia Weir affected by West Camden STP discharges Penrith Weir complies with relevant water quality guidelines	Impacted by discharges from Winmalee and Penrith STPs Nitrogen levels are elevated and higher than relevant water quality guidelines	Impacted by upstream and South Creek inflows Nitrogen levels are elevated and higher than relevant water quality guidelines	Impacted by South Creek inflows Nitrogen and chlorophyll-a levels are elevated and higher than relevant water quality guidelines	Existing discharges from Quakers Hill and St Marys STP dominate water quality downstream of discharge locations
	Predicted Impact	Deterioration in water quality due to the cessation of Warragamba Dam releases. Note: strategy to be developed to maintain water quality to acceptable level	Improved water quality at Wallacia Weir due to upgrade of West Camden STP No change at Penrith Weir	Improved water quality due to reduced load of nitrogen and phosphorus and increased flows	Some improvement water quality due to reduced load of nitrogen	Decrease in nitrogen concentrations due to reduced loads in inflow from South Creek	Minor increase in phosphorus and decrease in nitrogen
Macroinvertebrates	Existing Conditions	Moderate to poor quality	Moderate quality	Moderate to poor quality	Moderate to poor quality	Moderate to poor quality	Poor quality, highly impacted ecosystem
	Predicted Impact	No significant change expected	No significant change expected	No significant change expected	No significant change expected	No significant change expected	No significant change expected
Fish	Existing Conditions	Native and exotic species present	Native and exotic species present	Native and exotic species present	Native and exotic species present	Native and exotic species present	Exotic species dominant
	Predicted Impact	No significant change expected	No significant change expected	Potential for fish attraction due to increased flows from Boundary Creek	No significant change expected	No significant change expected	No significant change expected

Table 7.10 Summary of impacts due to the operation of the Replacement Flows Project *(cont'd)*

Environmental Aspect		Warragamba River	Wallacia Weir to Penrith Weir	Penrith Weir to Yarramundi	Yarramundi to South Creek	South Creek to Sackville	South Creek & Eastern Creek
Macrophytes	Existing Conditions	Some Salvinia present	Egeria densa - dense growth particularly out of the gorge country (bank to bank). Patches of Salvinia just below Wallacia Weir	Egeria densa very dense growth downstream of Penrith. Pockets of Salvinia washed downstream	Egeria densa present. Surface macrophytes present	Thin bands of Egeria densa along the edges. Surface macrophytes present in very low flow conditions (Salvinia)	Limited to immediately downstream of the STPs as water is too turbid in other areas of the creek
	Predicted Impact	Potential for increased growth due to higher nutrient levels	No significant change expected	Reduced nutrients and increased flows may improve habitat for native species	No significant change expected	No significant change expected	No significant change expected
Phytoplankton (Algae)	Existing Conditions	Moderate level of phytoplankton	Moderate level of phytoplankton	Low level of phytoplankton	Moderate levels of phytoplankton, increasing towards South Creek	Algal blooms from South Creek to Sackville	Phytoplankton growth is limited due to velocity and light penetration
	Predicted Impact	Potential for increased growth due to higher nutrient levels	No significant change expected	No significant change expected	No significant change expected	Potential improvements expected due to major reduction in nutrient loads	No significant change
Primary Industries	Existing Conditions	No water extracted for irrigation	Only small volumes of water extracted for irrigation	Only small volumes of water extracted for irrigation	Large volumes of water extracted for irrigation	Large volumes of water extracted for irrigation	Approximately 5ML/day extracted for irrigation
	Predicted Impact	No impact	No impact as sufficient water will be available	No impact as sufficient water will be available	No impact as sufficient water will be available	No impact as sufficient water will be available	No impact as sufficient water will be available
Recreational and Aesthetics	Existing Conditions	Not used for recreation	Moderately suitable for canoeing. Low suitability for water-skiing and swimming. Attached plant growth a nuisance to swimming. Suitable for fishing	Boating and fishing at limited locations. Low suitability for swimming due to dense macrophyte growth. Low value for boating	Suitable for boating and fishing. Low suitability for swimming due to dense macrophytes	Suitable for boating and fishing. Low suitability for swimming	Not suitable for recreational activities
	Predicted Impact	No significant change expected	No significant change expected	Recreational opportunities and access may improve slightly with reduced macrophytes.	No significant change expected	Some aesthetic improvement due to reduced algal blooms	No significant change expected
Human Health	Existing Conditions	No information available	No information available	No information available	Suitable for raw drinking water	No information available	No information available
	Predicted Impact	No significant change expected	No significant change expected	No significant change expected	Remains suitable as source of raw water for drinking	No significant change expected	No significant change expected

7.9.3 Monitoring

This section describes the monitoring framework for the Project. In summary, the framework would be based on:

- establishing the monitoring objectives for construction, impact verification and operational program components
- identification of key monitoring parameters
- ensuring congruence with existing programs and overarching strategic initiatives such as the Hawkesbury-Nepean Integrated Water Monitoring Framework.

Where possible, data from relevant existing monitoring programs would be used under this framework to assist in the verification of impacts. This would be used in conjunction with the outcomes of specific investigations, including short-term monitoring programs to validate the predicted impacts of the Project, as identified in the Environmental Assessment.

Monitoring objectives

The principal objective of the Project monitoring program is to identify and quantify potential impacts that may result from the operation of an AWTP situated at St Marys STP and the subsequent discharge of treated recycled water into Boundary Creek, which in turn discharges into the Hawkesbury-Nepean River below Penrith Weir.

The monitoring program would focus on potential impacts relating to:

- River ecological health (as assessed through receiving water quality, aquatic ecology and toxicity monitoring)
- human health impacts (as assessed through the measurement of pathogens and chemicals)
- construction related impacts, including noise, and fauna disturbance.

Information developed as part of the monitoring program would be used to update existing Hawkesbury-Nepean River water quality models.

Before-after and construction impact monitoring

Monitoring of recycled water discharge impacts would be conducted in two phases: a baseline phase to quantify the existing water quality and structure of the aquatic environment; and a post-commissioning phase in which the results would be compared with data from the baseline phase. Samples would be collected from sites at which changes are expected after commissioning of the AWTP are expected ("impact" sites) and from some sites at which changes are not expected after commissioning ("control" or "reference" sites). Comparisons of the water quality and ecological parameters would then be made before and after commissioning of the AWTP at control and impact sites.

In addition, monitoring during the construction and commissioning phases would be undertaken to confirm impact predictions in relation to these activities.

A discharge monitoring component would be developed and implemented to characterise and quantify the types, concentrations and loads of constituents being discharged to the environment; determine the area of impact for the discharge, including hydrological changes; and quantify changes in the quality (including toxicity) of waters surrounding the discharge location. This would involve monitoring potential changes in phytoplankton, aquatic vegetation, macroinvertebrates, fish, nutrients, other physico-chemical parameters and pathogens.

In relation to construction phase monitoring, the following monitoring activities will be implemented:

- noise monitoring at locations where noisy construction activities are scheduled
- a complaints management system for the Project to monitor and manage social impacts of the Project
- monitoring of open trenches to rescue fauna that may have penetrated exclusion fencing and have entered open trenches.

Existing monitoring programs

Where possible, data would be drawn from existing sources and monitoring programs to develop a functional description of baseline water quality. Such sources include, for instance, Sydney Water's operational licence compliance data, as collected under the Sewage Treatment System Licensing Program.

To support this data from existing monitoring programs, in the form of licence effluent quality, toxicity, receiving and source water quality for North Richmond Water Filtration Plant, the Bubble Licence for St Marys, Quakers and Riverstone STPs, Penrith STP and North Head STP would be incorporated into the Replacement Flows Project monitoring program as part of baseline and performance monitoring.

Hawkesbury-Nepean Integrated Water Monitoring Framework

The *2006 Metropolitan Water Plan* (MWP) identified the development of an integrated monitoring program for the Hawkesbury Nepean River that will provide information on the river health, the outcomes of environmental flows and recycling initiatives. In response to this initiative, a Hawkesbury-Nepean River Integrated Water Monitoring Framework (IWMF) has been established. It will provide a coordinated framework for the planning of studies, the management of collective data and the development of an ongoing synopsis of whole-of-river ecological health. A draft large-scale monitoring program has been developed under this framework, which will involve the collection of ecological, physical and chemical water characteristics with respect to hydrological conditions. The draft monitoring program includes existing Sydney Water, SCA and DNR monitoring locations and sampling parameters collected at these locations.

Additional information will also be collected and analysed under this framework. This information comprises the outcomes of targeted studies undertaken as part of the environmental flow releases program under the MWP and investigations into macrophyte abundance, community structure and nutrient source.

Therefore, the extent of the operational aspects of the Project on the river system would be monitored as part of this program. The sampling locations and sampling parameters outlined within the draft IWMF that relate to the Project are presented in **Table 7.11**.

Table 7.11 Sampling locations and details for IWMF monitoring program relevant to the Replacement Flows Project

	Water Quality	Hydrology	Macro-invertebrates	Fish	Floating Macrophytes	Submerged Macrophytes
Warragamba River (N641)	✔		✔			
Nepean River at Penrith Weir (N57)	✔	✔	✔	✔	✔	✔
Nepean River downstream of Penrith STP (N53)	✔		✔	✔	✔	✔
Nepean River at Smith Road (N48)	✔		✔			
Nepean River at Yarramundi Bridge (N44)	✔	✔	✔	✔	✔	✔
Hawkesbury River at North Richmond (N42)	✔	✔	✔	✔	✔	✔
Hawkesbury River at Freemans Reach (N39)	✔			✔	✔	✔
Hawkesbury River at Windsor Bridge (N38)	✔		✔	✔	✔	✔
Hawkesbury River at Wilberforce (N35)	✔	✔	✔	✔	✔	✔
Hawkesbury River at Sackville Ferry (N26)	✔		✔			
Downstream of Quakers Hill STP (NS087)	✔		✔	✔	✔	✔
Downstream of St Marys STP (NS23)	✔		✔	✔	✔	✔



Management of other key issues

This chapter provides an assessment of the key issues of terrestrial ecology, noise and vibration and waste management. Other environmental issues were considered using a risk framework assessment. Potential impacts are identified and mitigation measures to manage any risk are outlined.

8.1 Overview

The residual impacts likely to occur following mitigation are considered to be minimal as they would be avoided where possible through careful design or would be appropriately managed during construction and operation.

Chapter 7 addressed the key issues of water quality and water cycle management, aquatic ecology and human health. The other issues, identified in the Environmental Assessment requirements as potentially key issues, were terrestrial ecology (flora and fauna), waste management, noise and vibration.

Other environmental issues considered for assessment were:

- geology, soils and construction water management
- hazardous materials
- heritage
- land use and tenure
- visual amenity
- air quality
- traffic.

For each environmental issue considered, an analysis was undertaken to identify potential environmental impacts associated with the Project, proposed mitigation measures and any residual environmental impacts after the application of the proposed mitigation measures.

The residual impacts likely to occur following mitigation are considered to be minimal as they would be avoided where possible through careful design or would be appropriately managed during construction and operation.

8.2 Flora and fauna

A detailed terrestrial flora and fauna study was undertaken for the Project (refer to **Appendix E**). The following section provides a summary of this assessment.

Field surveys of the proposed pipeline routes, Advanced Water Treatment Plant (AWTP) site, concentrate storage pond and ancillary infrastructure areas were conducted on 24-25 July and 8-11 August 2006. The extent and quality of native vegetation, fauna habitats and species diversity were recorded, targeting threatened species and endangered ecological communities previously recorded in the region.

The assessments were undertaken in accordance with the *Draft 3A Guidelines for Threatened Species Assessment* (July 2005) prepared by DEC. The assessments also considered the *Guidelines for Developments Adjoining Department of Environment and Conservation Land* (DEC 2006a).

8.2.1 Flora

Of the 53 threatened flora species known to occur in the greater Sydney area, at least 20 may occur in the study area, on the basis of potential habitats being present. Further assessment of threatened species considered likely to occur was undertaken to determine the potential impact of the Project on the viability of these species within the local area (see **Appendix E**).

The vegetation communities identified in the general area are typical of those documented for the Cumberland Plain Region and are primarily linked to local geology and associated shale, gravel and alluvial soils.

Natural vegetation present within close proximity to the pipeline routes generally comprises remnant or regrowth Grey Box (*Eucalyptus molucanna*) and Forest Red Gum (*E. tereticornis*) communities in more elevated areas, and riparian vegetation dominated by Swamp Oak (*Casuarina glauca*) along creek lines and low depressions. A large freshwater wetland adjoins the northern and eastern boundaries of the Penrith Sewage Treatment Plant (STP). At the eastern end of the study area, in proximity to the proposed concentrate pipeline link to the NSOOS at Vineyards Creek, patches of disturbed remnant vegetation are present. These are dominated by Sydney Blue Gum (*E.saligna*) and Blackbutt (*E.pilularis*).

Three Endangered Ecological Communities (listed under the *Threatened Species Conservation Act 1995* (TSC Act) were recorded during the site assessment. These were Cumberland Plain Woodland, River-flat Eucalypt Forest and Freshwater Wetlands (refer to **Figure 8.1a,b and d**). Cumberland Plain Woodland is also listed as an Endangered Ecological Community under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Three remnants of Cumberland Plain Woodland were identified within the pipeline routes to the east of Penrith STP and on both sides of the Westlink M7 Motorway. River-flat Eucalypt Forest was identified in association with alluvial soils adjacent to creeklines and, as stated above, a Freshwater Wetland was identified adjacent to Penrith STP.

Juniper-leaved Grevilleas (*Grevillea juniperina subsp juniperina*), listed as Vulnerable under Schedule 2 of the TSC Act, were recorded in vegetation on the south western side of Bells Creek, to the south of Marsden Park (refer to **Figure 8.1b**). No other threatened flora species were identified during the site assessments.

Figure 8.1a High value conservation areas



Figure 8.1b High value conservation areas



Figure 8.1c High value conservation areas



Figure 8.1d High value conservation areas



Most areas of the remnant vegetation have been highly modified, with areas of native understorey vegetation restricted to a few small patches where threatened flora and ecological communities were recorded.

8.2.2 Fauna

A total of 35 threatened fauna species have previously been recorded in the study area. An assessment of the potential for these species to occur was conducted, indicating that 13 of these species have suitable habitat elements present within the study area. Further assessment of threatened species considered likely to occur was undertaken to determine the potential impact of the Project on the viability of these species within the local area (see **Appendix E**).

Habitat for fauna along the works corridor consists of cleared and modified habitats that include open grass, road verges and fragmented shrubs and small trees in adjoining residential areas.

Habitat for fauna along the works corridor consists of cleared and modified habitats that include open grass, road verges and fragmented shrubs and small trees in adjoining residential areas.

Evidence of the threatened Cumberland Land Snail (*Meridolum corneovirens*) (listed as Vulnerable under Schedule 2 of the TSC Act) was recorded in isolated areas in the section between Richmond Road and Quakers Hill STP. These sightings were recorded on the edge of large expansive areas of woodland habitat associated with the Marsden Park area, suggesting that similar habitat is well represented throughout the wider locality.

Insectivorous bats (microchiropterans) were recorded at St Marys and Penrith STPs, including the Chocolate Wattled Bat (*Chalinolobus morio*), Large Bentwing-bat (*Miniopterus schreibersii oceanensis*), Eastern Freetail Bat (*Mormopterus* sp.), Gould's Wattled Bat (*Chalinolobus gouldii*) and a Long-eared Bat (*Nyctophilus* sp.). Several additional bat species are expected to occur.

Several individuals of the Common Eastern Froglet (*Crinia signifera*) and Striped Marsh Frog (*Limnodynastes peronii*) were identified within the project area by call recognition. The Green and Golden Bell Frog (*Litoria aurea*) (listed as Vulnerable on the EPBC Act and Endangered on the TSC Act) has previously been recorded within the vicinity of St Marys, generally in the area around South Creek. The Green and Golden Bell Frog typically inhabits lentic (slow moving or standing water) water bodies such as swamps and marshes and is considered unlikely to be affected by a change in flow volume in South Creek, which is characterised by lotic (moving) water.

Fauna habitats were generally very limited within all works areas. A small number of trees with hollow-cavities, important for many threatened species for shelter and nesting, were noted within the site for the proposed concentrate storage pond at Quakers Hill and at the rear of residences at Hassall Grove.

8.2.3 Construction impacts and mitigation measures

Impacts

The significance of any impact associated with vegetation removal would depend on the sensitivity of the vegetation / habitats to be cleared and the extent of clearance required.

Minor impacts on vegetation may result from clearing for construction of the AWTP, concentrate storage pond and linking pipelines. This would be

The proposed infrastructure and pipeline routes have been located to minimise impacts on remnant vegetation, in particular endangered ecological communities including Cumberland Plain Woodland and River-flat Eucalypt Forest that are considered to have high conservation value.

limited to impacts on isolated trees or small stands or regrowth within predominantly cleared easements. The proposed infrastructure and pipeline routes have been located to minimise impacts on remnant vegetation, in particular endangered ecological communities including Cumberland Plain Woodland and River-flat Eucalypt Forest that are considered to have high conservation value. Implementation of the mitigation measures described below would ensure the proposed development is unlikely to impose a 'significant impact' on local populations of threatened species, endangered communities or their habitats as listed under the EPBC Act and TSC Act. The proposed development would not reduce the area of land currently occupied by Endangered Ecological Communities and threatened species in the western Sydney region.

The assessment of flora and fauna meets each of the key thresholds, set out in Step 5 of the *Draft 3A Guidelines for Threatened Species Assessment*. That is:

- the proposal would include actions to avoid or mitigate impacts through selection of the sites or routes to avoid any sensitive ecological areas and use of mitigation measures such as boring beneath creeks and important habitat sites to ensure that biodiversity values are maintained or improved
- the proposal would not accelerate the extinction of the species, population or ecological community or place any of these at risk of extinction
- no critical habitat would be adversely affected.

In addressing the *Guidelines for Developments Adjoining Department of Environment and Conservation Land* (DEC 2006a) a series of mitigation measures would be implemented to prevent impact on the following issues:

- erosion and sediment control – mitigation measures would be implemented in accordance with Managing Urban Stormwater guidelines (Landcom 2005) and DEC's *A Resource Guide for Local Councils: Erosion and Sediment Control* (DEC 2006b)
- stormwater runoff to DEC land would be prevented through implementation of the controls noted above
- management implications, pets, weeds, edge effects – construction activities would be managed in accordance with Sydney Water's standard management practices to avoid introduction of weeds. No edge effects or issues associated with pets entering the site would occur as a result of construction
- fire and location of asset protection zones - construction activities would be managed in accordance with Sydney Water's standard management practices to minimise the potential for fire and impacts on asset protection zones
- visual, odour, noise, air quality and amenity – construction activities would be managed in accordance with Sydney Water's standard management practices to minimise visual, noise or air quality impacts.

Mitigation measures

Any intact areas of remnant vegetation adjoining the works area would be identified and protected during construction activities to avoid incidental damage.

The detailed design of the pipeline route would avoid areas of remnant vegetation, threatened species habitat and Endangered Ecological Communities, where practicable. The infrastructure has been located within highly modified and degraded landscapes. Any intact areas of remnant vegetation adjoining the works area would be identified and

protected during construction works to avoid incidental damage. Following completion of construction, the area would be revegetated using endemic species similar to adjacent areas, to offset any potential small losses associated with the removal of individual specimens.

Protected species and habitats along the route would be avoided through avoidance or the use of boring techniques to avoid the need for surface trenching.

Protected species and habitats along the route would be avoided or by-passed using boring techniques rather than surface trenching. Specific areas to be avoided include the River-flat Eucalypt Forest along South Creek and the *Grevillea juniperina* subsp *juniperina* areas on the western side of Bells Creek. Works would also ensure that the hollow bearing trees identified at Quakers Hill and at the rear of residential properties would be protected.

Mitigation measures implemented to minimise the impact of construction activities on flora and fauna would comprise:

- retention of vegetation by minimising the extent of construction areas and retaining and protecting vegetation adjacent to construction areas
- stabilisation and revegetation of bare earth areas as soon as practicable following completion of construction, to limit the potential for erosion which could affect adjacent vegetation communities and watercourses
- protection of large, hollow bearing trees where possible
- underground boring techniques to avoid potential impacts on sensitive habitats, including riparian vegetation (as shown on **Figure 8.1a,b,c and d)**
- positioning of construction compounds, access tracks, stockpiles, storage and depot sites in cleared areas away from watercourses
- weed control throughout the construction areas to minimise their spread to adjacent areas in accordance with the *Noxious Weeds Act 1993*
- all revegetation works to be undertaken with species that are locally native including those representative of the Cumberland Plain Woodland. Regeneration would be monitored and further management undertaken if required.

Additional mitigation measures to be implemented to minimise the impacts in the regional park area (shown in **Figure 8.1a)** would comprise:

- fallen logs encountered within the works corridor would be pushed aside and retained in their natural state
- timber felled for clearing would be retained, where practicable, to provide ground cover for terrestrial fauna
- trenches would be dug with shallow sloping ends to allow natural fauna escape and would be inspected each morning and checked for captured fauna. Fauna captured would be removed and released into the adjacent natural habitat. Where appropriate injured fauna would be captured and taken to the local Wildlife Information and Rescue Service centre or vet.

8.2.4 Operation impacts and mitigation measures

Impacts

The pipeline route and disturbed ground at the AWTP site would be revegetated with a variety of local native species following construction completion.

The pipeline route and disturbed ground at the AWTP site would be revegetated with a variety of local native species following the completion of construction. Providing the vegetation and associated habitats are maintained during operation, the potential impacts on native fauna would be negligible.

There is the potential for some impact on flora and fauna during routine maintenance inspections where vegetation is removed or damaged or where maintenance activities have the potential to disturb fauna.

The assessment of flora and fauna meets each of the key thresholds set out in Step 5 of the *Draft 3A Guidelines for Threatened Species Assessment*. That is, the infrastructure would be placed within existing STP sites and pipeline routes located below the ground surface. This would avoid any reduction in the long-term viability of local populations of species or ecological communities.

In addressing the *Guidelines for Developments Adjoining Department of Environment and Conservation Land* (DEC 2006a), a series of mitigation measures would be implemented to prevent impact on the following issues:

- stormwater runoff – the pipeline routes would be revegetated and no stormwater treatment measures would be required
- management implication– no significant long term impacts on the management of the Regional Park zone would occur, as the pipelines are to be placed within cleared bushfire protection zones
- fire – maintenance activities would be managed in accordance with Sydney Water's standard management practices to minimise the potential for fire
- boundary encroachments – the proposal would have no impact in terms of the DEC boundaries
- visual, odour, noise, air quality impacts and amenity – pipelines would be placed beneath the ground surface and the site regenerated, thus avoiding visual impacts. No noise, air quality or associated amenity impacts would occur
- threats to ecological connectivity – the pipelines would be placed within cleared areas which are maintained for fire protection purposes. As such the Project would have no significant long term impact on movement corridors.

Mitigation measures

Vegetation would be restored on completion of any maintenance activities and operations would be undertaken in accordance with Sydney Water's standard management practices.

8.2.5 Summary

From an ecological perspective the project can be justified on the basis that there is no requirement to clear remnant or intact areas of significant vegetation (eg Cumberland Plain Woodland or River-flat Eucalypt Forest), threatened flora species or critical habitat of threatened fauna species.

The measures detailed in **Table 8.1** would be implemented to minimise the potential impacts on flora and fauna.

An assessment under Section 5 of the EP&A Act (**see Appendix E**) for all identified and potentially occurring threatened species indicates that the project is unlikely to significantly impact these species, even if they were present. An assessment of listings under the EPBC Act similarly concluded that the proposal is unlikely to significantly impact upon any listed species or communities (see **Appendix E**).

Limited impacts on vegetation may result from the clearing for construction of the AWTP, concentrate storage pond, pipelines and associated infrastructure (see **Appendix E**). From an ecological perspective the project can be justified on the basis that there is no requirement to clear remnant or intact areas of significant vegetation (eg Cumberland Plain Woodland or River-flat Eucalypt Forest), threatened flora species or critical habitat of

threatened fauna species. A range of mitigation measures, as described above, would be implemented to ensure that there is no reduction in the extent of areas of conservation value and the Project would not accelerate the risk of extinction for an endangered ecological community or threatened species occurring in the Western Sydney region.

Table 8.1 Terrestrial flora and fauna summary

Aspect	Impact	Mitigation measures
Construction		
Regional Park	Damage or disturbance to wildlife habitats Injury or death of fauna, in particular emu, kangaroos, reptiles and amphibians	• fallen logs encountered within the works corridor would be pushed aside and retained in their natural state • timber felled for clearing would be retained as ground cover for terrestrial fauna • trenches would be dug with shallow sloping ends to allow natural fauna to escape and would be inspected each morning and checked for captured fauna. Any fauna captured would be removed and released into adjacent natural habitat. • Any injured fauna would be captured, where appropriate, and taken to the local Wildlife Information and Rescue Service centre or vet.
Retention of vegetation / habitat creation	Loss of Ecologically Endangered Communities (EECs), riparian vegetation, remnant trees and fauna habitats.	• minimise construction area and fence off areas of vegetation to be retained • all revegetation works would be undertaken with species that are locally native, including those representative of the Cumberland Plain Woodland. Regeneration would be monitored and further management undertaken if required • boring beneath creeks or in areas of dense vegetation.
Management	Damage / disturbance to wildlife habitats	• locate construction compounds, access tracks, stockpiles and storage areas on cleared sites away from watercourses.
Noxious weeds	Introduction or spread of noxious weeds.	• management procedures would be implemented to prevent spread of noxious weeds.
Operation		
Habitat	Vegetation loss and soil erosion. Spread of noxious weeds on maintenance vehicles.	• revegetation where vegetation removal has occurred revegetation would be undertaken using species that are locally native, including those representative of the Cumberland Plain Woodland. Regeneration would be monitored and further management undertaken if required • prevent the spread of weeds in accordance with the *Noxious Weeds Act 1993* and Sydney Water's standard management procedures.

8.3 Waste management

8.3.1 Liquid wastes

Construction

Water may enter excavations after rainfall or through groundwater infiltration. When this occurs, trenches and other excavations would need to be dewatered to allow work to continue. The condition (quality) of the water would need to be considered before discharge.

Bentonite slurry would be used to lubricate cutting heads and drilling equipment during boring beneath sensitive environmental areas, creeks or roads, as detailed in **Section 3.8**. The bentonite slurry would be reused in the drilling process, although small quantities of this liquid waste may be produced and would require disposal.

No significant volumes of liquid wastes, including oils or fuels, would be generated on site during construction.

Operation

The AWTP would generate approximately 8 ML/day of concentrate, the content of which is described in **Chapter 3**. Approximately 7 ML/day of backwash water would also be produced from the pre-treatment process, which would be fed back to the head of works at St Marys STP. Biocides would also be added to the reverse osmosis membranes if they were to be shut down for two or more days. Wastes would also be produced from periodic cleaning of the reverse osmosis membranes. The cleaning process would typically use caustic soda, citric acid, sodium hypochlorite and the waste stream produced would be discharged with the concentrate. This concentrate would be pumped to the NSOOS and discharged via the deep ocean outfall off North Head.

8.3.2 Solid wastes

Construction

The vast majority of solid waste generated by the Project would be produced during the construction phase. The waste would predominantly be spoil from excavation of pipelines, site works for the AWTP and from the storage pond. The estimated volumes of spoil and the numbers of trucks required to remove the spoil are provided in **Table 8.2**.

Spoil would be reused on site, wherever possible. Unused spoil would be disposed of at landfill sites or on other projects requiring clean fill.

Other wastes produced during construction would include:

- packaging waste
- off-cuts and disused construction materials
- general waste from construction workers
- demolition waste including asbestos from a disused building requiring demolition at St Marys STP site
- vegetation from clearance activities.

Table 8.2 Estimated spoil volumes

Project component	Construction method	Spoil volume (cubic metres- loose)	Total truckloads
Pipelines between Penrith, St Marys and Quakers Hill STPs	Trenching Boring	40,000[1]	1,800
Concentrate pipeline from Seven Hills to Dundas	Trenching Boring	24,000[2]	1,090
AWTP site	Excavation	10,000[3]	450
Concentrate storage pond at Quakers Hill site	Excavation	40,000[4]	1,800

Assumptions:

1 20 km pipeline, $2m^3$ (loose) spoil per metre as surplus

2 12 km pipeline, $2m^3$ (loose) spoil per metre as surplus

3 removal of spoil to one metre over an area of about $7000m^2$ ($10,000m^3$ loose)

4 25ML pond will yield $25,000m^3$ of spoil ($40,000m^3$ loose)

5 each truck carries about $22m^3$ spoil (loose)

Operation

The reverse osmosis membranes would be replaced every 3-7 years, with spent membranes disposed of at an appropriate landfill.

Other operational wastes would comprise general wastes generated from maintenance and management of the project sites.

8.3.3 Construction impacts and mitigation measures

Impacts

Water from dewatering activities may contain high levels of suspended solids that could have an impact on surface water quality if discharged without treatment. Bentonite slurry wastes, although non-toxic, could also impact on surface water quality if inappropriately managed.

Inappropriate material handling or poor management of solid wastes would result in excessive waste production, overuse of natural resources and premature filling of local landfill sites.

Hazardous waste created through the demolition of a building constructed with asbestos sheeting at St Marys STP would need to be sent to a suitably licensed facility. There is the potential for health impacts if this waste were inappropriately managed and environmental impacts may result if it is not disposed of at a suitably licensed facility.

Mitigation measures

The source and lifecycle of construction materials would be considered when making purchasing decisions.

Appropriate waste management strategies would be implemented in accordance with the *Waste Avoidance and Resource Recovery Act 2001*. This would include investigation of opportunities for the reuse of potential wastes, such as spoil or disused construction materials. Waste production would be minimised through the accurate ordering of materials to avoid wastage and the preferential purchase of materials that have minimal packaging. The source and lifecycle of construction materials would be considered when making purchasing decisions.

Organic wastes produced through vegetation removal or generated from construction workers would be minimised where possible and opportunities for mulching and composting would be investigated.

The discharge of water from excavations would need to be managed in accordance with the *Protection of the Environment Operations Act 1997* (POEO Act). Liquid and non liquid wastes would be classified and managed in accordance with the DEC *Environmental Guidelines: Assessment, Classification and Management of Liquid and Non-liquid Wastes* (1999).

All hazardous waste produced would be handled by appropriately licensed contractors.

8.3.4 Operation impacts and mitigation measures

Impact

The downstream effects of the discharge of the concentrate to the NSOOS were addressed in detail in **Chapter 7** and it was concluded that, overall, the management and discharge of concentrate would have a negligible impact on the environment. Solid wastes generated at the AWTP and other sites would, if unable to be reused or recycled, be disposed of at a suitably licensed landfill.

Mitigation measures

The operation of the AWTP would be managed to minimise both solid and liquid waste produced during operation.

8.3.5 Summary

Table 8.3 summarises the measures that would be implemented to manage waste.

Table 8.3 Waste summary

Aspect	Impact	Mitigation measures
Construction		
Liquid waste	Dirty water from the dewatering of excavations impacting on the local environment.	Dewatering to be managed in accordance with the requirements of the POEO Act.
Solid waste	Solid waste production resulting in high costs and premature filling of local landfill sites. Organic wastes Packaging waste Disposal of disused construction materials.	• waste to be managed in accordance with the *Waste Avoidance and Resource Recovery Act 2001* and EPA 1999 guidelines • spoil reuse opportunities to be investigated • vegetation clearing to be kept to a minimum. Composting or mulching options to be investigated • preferential purchase of materials with minimal packaging/higher recycled content • accurate ordering and careful handling to minimise breakage/ wastage.
Hazardous waste	Inappropriate handling and disposal of asbestos containing materials.	Asbestos containing materials to be handled and removed by a suitably licensed contractor and disposed of in accordance with DEC guidelines.

Aspect	Impact	Mitigation measures
Operation		
Liquid waste	Waste cleaning fluids produced during periodic cleaning and maintenance will require disposal. About 8 ML/day of concentrate would require disposal.	Management and maintenance to be undertaken in a manner that ensures wastes production is minimised To be disposed of through the NSOOS and to be managed in accordance with Sydney Water's standard management practices.
Solid waste	Disposal of chemical containers and spent reverse osmosis membranes.	Maintenance to be undertaken in a manner that ensures waste production is minimised.

8.4 Noise and vibration

A noise impact assessment for the operation of the Project was undertaken in accordance with DEC's *Industrial Noise Policy* (INP) **(see Appendix F).** Construction noise was assessed according to *Construction Site Noise Guidelines* issued by DEC.

Existing environment

The nearest privately owned residential dwellings to the St Marys site are located on Forrester Road, (Ropes Crossing) about 1600 m to the south east of the site.

At Penrith STP the nearest receivers are industrial/commercial premises located in Dean Street. The area to the east of the site is predominantly residential, mixed with some open space, sporting grounds and bushland. The nearest residential receivers to the Penrith STP site are located in Panorama Road approximately 900 m from the STP boundary.

The nearest receivers to the St Marys site are residential premises in Trigg Street. These are owned by Sydney Water and are adjacent to the STP site boundary. Despite Sydney Water ownership of these premises, they were included in the assessment of noise impacts. The nearest privately owned residential dwellings to the St Marys site are located on Forrester Road (Ropes Crossing), about 1600 m to the south east of the site. Commercial buildings are located more than 50 m away on Links Road. The existing land use in the area is predominantly industrial, with mainly local road traffic.

The Quakers Hill STP is located on Quakers Road, with the nearest residential receivers being located approximately 150 m to the south of the proposed works in Jasmine Avenue. The existing land use in the area is mostly residential, with some open parkland to the south east of the site. To the west of the site is Quakers Hill Parkway, which is a significant source of road traffic connecting to Richmond Road.

There is a range of sensitive receivers along the pipeline routes that may potentially be affected by noise during construction of the Project. These include:

- residential dwellings
- recreational areas
- educational centres
- hospitals and nursing homes.

Background noise level

Measurements of the noise environment were undertaken at locations near the STP boundaries and at nearby residential locations to determine the influences of existing noise sources. A summary of the locations and descriptions of the noise sources are presented in **Table 8.4**, with the attended monitoring results given in **Table 8.5.**

Table 8.4 Monitoring locations and description of noise sources

STP site	Monitoring location	Description of noise environment
Penrith	1 STP Site Boundary	At the boundary of the STP the existing noise sources include some road traffic noise. The dominant noise source is the Crane Enfield Metals Facility in Castlereagh Road. Operations from within the STP are largely inaudible against the background noise.
	2 Panorama Avenue (Residential)	Constant industrial noise of non specific origin comes from the direction of the STP, with occasional load noise ("Crash" and "Bang"). The majority of the noise generated is believed to come from the Crane Enfield Metals site.
St Marys	3 Triggs Road (Residential) STP Site Boundary	Constant noise from within the STP plant and possibly from water flows. No other identifiable road traffic or industrial noise sources in the area.
	4 Forrester Road (Residential)	Road traffic is dominant source of noise. No other industrial type noise is present.
Quakers Hill	5 Jasmine Street (Residential)	Traffic on Quakers Road and Quakers Hill Parkway are the dominant noise source. Frogs and crickets are audible from the drainage channel between the STP and Jasmine Ave. The STP is not audible from the residences over the background noise levels.

Table 8.5 Summary of attended noise surveys

Location	Time	Noise Level Descriptors - dB(A)			
		L_{A10}	L_{Aeq}	L_{A90}	$L_{A\ Min}$
2	11:11 pm	50	48	46	44
3	10:42 pm	48	47	47	46
5	10:00 pm	51	50	47	45

dB(A) - Unit used to measure 'A-weighted' sound pressure levels. A-weighting is an adjustment made to sound-level measurement to approximate the response of the human ear.

L_{A10} - The $L_{A(XX)}$ refers to statistical indicators that represent the percentage of time that a noise level is exceeded. These levels are commonly the L_{A1}, L_{A10}, and the L_{A90}, and are graphed to show how these levels change over the course of a 24 hour period.

L_{Aeq} - Although the L_{Aeq} is not a statistical indicator, it is probably one of the most important of the noise descriptors. It represents the equivalent continuous A-weighted noise level for the measurement period. This is the level of noise energy averaged over the measurement period.

L_{A90} - Is an important statistical indicator that represents the A-weighted sound pressure level that is exceeded for 90% of the time over which the noise is measured. This is often termed the background noise.

$L_{A\ Min}$ - The lowest noise level during a specified time period or during a specified number of events expressed as the absolute minimum value of the root-mean-square (r.m.s.) sound pressure level using time weighting 'F'

Construction noise goals

The noise goals adopted for construction (see **Appendix F**) are those contained in the construction guidelines *Construction Site Noise* (previously Chapter 171 of the *Environmental Noise Control Manual* (ENCM) (NSW DEC 1994).

The noise assessment for the construction phase was based on the equipment likely to be used and the proximity of sensitive receivers. The construction equipment that has potential to contribute to the acoustic environment include:

- excavator operations and earthmoving equipment
- boring rigs
- general construction noise
- truck movements.

Night-work may be required for construction of the pipelines where they cross major roads or intersections, to minimise disruption of local and through traffic.

Operation noise goals

The DEC's *Industrial Noise Policy* recommends that for a residence located in a rural area, an acceptable amenity criteria would be an LA_{eq} of 60, 55 and 45 dB(A) for day, evening and night periods respectively (see **Appendix F**)

There would be several sources of noise at the proposed AWTP at St Marys that may potentially cause an impact at nearby residential receivers. The main source of noise emission would be the pumps, balance tanks with submersible pumps and the electrical substation.

At Penrith STP the proposed pumps are not expected to create noise emissions as they would be submersible. The proposed additional infrastructure at the Quakers Hill site includes a storage tank and a number of pumps, which would be submersible and sized similarly to the pumps considered for Penrith. For this reason they are not expected to produce significant noise emissions.

The operational noise assessment has been made based on attended monitoring results from site visits to the various STPs during the early part of the night time period. This level of assessment is considered appropriate, considering the pre-existing noise environment surrounding the STPs and the low level risk of impact associated with the proposed works.

At Penrith and St Marys the project specific noise goals are designed to account for the cumulative noise impacts and are conservatively estimated to be L_{aeq} 47dB(A)$_{period}$ and 35 dB(A)$_{period}$ respectively where the L_{aeq} value is taken over the night time (8hr) period. These values are derived from the application of the modified amenity criteria (se **Appendix F**), based on the influence of industrial noise on the existing environment.

As an estimate of the background noise level in the vicinity of the Quakers Hill STP during the early hours of the morning, background noise levels may reduce to LA90 35 dB(A), producing an intrusive noise criterion for the Project of 40dB(A)$_{15\ Min}$ at the nearest residential boundary.

Project specific noise goals for noise and vibration sensitive receivers against operational scenarios are ideally set against the most stringent assessment criterion. The LA_{eq} noise level resulting from the proposed works during the night time period is assumed to be the most stringent at the nearest affected residence.

8.4.1 Construction impacts and mitigation measures

Impacts

Construction activities and particularly the pipelines would impact on the local acoustic environment and would present a short-term nuisance to adjoining residents and users of public reserves. The construction activities would be continually moving, advancing at a rate of about 16 m per day, and are unlikely to be adjacent to any residence for a period of more than a few weeks at a time.

There is the potential for vibration impacts on properties under which boring would take place. Vibration may impact on properties alongside the pipeline route, particularly within the densely populated areas along the proposed concentrate pipeline. The effects of vibration in buildings can be divided into three main categories:

- where occupants or users of the building are disturbed or inconvenienced

- those in which the building contents may be affected
- circumstances in which the integrity of the building or the structure itself may be prejudiced.

Mitigation measures

The continual movement of construction works associated with the pipeline would limit the impacts on properties.

The continual movement of construction works associated with the pipeline would limit the impacts on properties. The following noise goals would be adopted for construction as detailed in the noise control guidelines *Construction Site Noise* (previously Chapter 171 of the *Environmental Noise Control Manual* (ENCM) (NSW DEC 1994):

- for construction periods of four weeks or less, the LA10 (noise level 10 per cent of the time) should not exceed the background (LA90) level by more than 20dBA
- for periods of greater than four weeks but less than 26 weeks, the LA10 should not exceed the background (LA90) level by more than 10dBA.

Monitoring would be undertaken during the initial stages of construction to assess compliance with the ENCM goals. Where noise would be audible at residential properties construction would be limited to the hours of 7am to 6pm Monday to Friday and 8am to 1pm on Saturday, unless otherwise approved by DEC. Night works, if required, would be carefully controlled to minimise the potential impacts on neighbouring residences.

Noise management measures would be implemented to minimise construction noise impacts. Construction activities would be undertaken in accordance with Australian Standard AS 2436-1981 *Guide to Noise Control on Construction, Maintenance and Demolition Sites*. Management measures for construction noise would include the following:

- the selection of equipment to minimise noise levels
- the maintenance of equipment in good working order (including mufflers, enclosures and bearings) to ensure unnecessary noise emissions are eliminated
- use of residential class mufflers and where applicable, engine shrouds (acoustic lining)
- appropriate use of plant and equipment, including adoption of 'reasonable' working practices with no extended periods of 'revving' , idling, or 'warming up' within close proximity to residential receivers. Any excessively loud activities would be scheduled during periods of the day when high ambient noise levels also occur
- all equipment to be used on site would need to demonstrate compliance with noise levels recommended within AS2436-1981.

Management practices would be implemented to ensure that daytime construction noise during installation of the pipeline within 100 m of a receiver is minimised.

Management practices would be implemented to ensure that daytime construction noise during installation of the pipeline within 100 m of a receiver is minimised, although they may exceed the guideline levels in the short term. The impacts on sensitive receivers in each location would be considered and amelioration measures adopted where necessary.

Residents in the vicinity of the pipeline route and STP sites would be advised prior to the commencement of construction activities. Contact details would be provided and an outline given of the construction methods, duration and timing of the works. A log of complaints would be maintained and a complaints management procedure would be formulated and adhered to.

Where vibration may impact on residents, construction activities would be managed in accordance with the British Standard BS 6472 (1984 to 1992), the International Standard ISO 2631:2-1989 and the Australian Standard AS 2670.2-1990. The impact of vibration on buildings cannot be accurately predicted as it depends on the building type and foundations. Where vibration may impact on nearby structures, activities would be managed in accordance with British Standard 7385:Part1-1993 *Evaluation and Measurement for Vibration in Buildings*. For historic buildings, which have a higher sensitivity to vibration, the more conservative guidelines within the German Standard DIN 4150:Part3 – 1986 would be adhered to.

Where the potential for vibration impacts has been identified, an assessment of the likelihood of damage would be carried out. If it is considered that damage is possible, a pre-construction dilapidation survey would be conducted on potentially affected properties and monitoring undertaken through construction to confirm any potential impacts.

8.4.2 Operation impacts and mitigation measures

Impacts

The main components of the Project that would generate noise during operation would be the AWTP and effluent, concentrate and recycled water pumping stations.

A review of equipment to be included in the proposed works for each of the sites was used to estimate operational noise levels (see **Appendix F**). These were applied to a SoundPLAN noise model and noise level predictions were preferred for the nearest residential receivers.

The predicted noise level resulting from the AWTP at the St Marys site would exceed the Modified Amenity Criteria at the nearest residential locations owned by Sydney Water in Trigg Street by approximately 10 dB(A). These levels are based on the AWTP being fabricated from sheet steel with the pumps enclosed in a masonry enclosure. However, the operational noise criteria would not be exceeded at the nearest private properties located along Forrester Road.

The AWTP would operate within a building structure, located on the existing St Marys STP site. The building will be designed to ensure the operation of the plant meets the noise criteria outlined in the *NSW Industrial Noise Policy* (NSW EPA 2000).

Mitigation measures

The AWTP would operate within a building structure, located on the existing St Marys STP site. The building would be designed to ensure the operation of the plant meets the noise criteria outlined in the *NSW Industrial Noise Policy* (NSW EPA 2000). The pumping stations would be enclosed to aid in noise attenuation.

There is the potential to reduce the predicted noise levels from the AWTP by several dB(A) at the nearby Sydney Water owned residences by using a more substantial construction for the main building, as well as the appropriate location of equipment within the building. External pumps and other noise sources would also require additional attenuation. If considered necessary, noise impacts identified for Trigg Street residences could be mitigated to achieve the DEC INP criterion. The decision to apply these attenuation measures and/or the addition of any noise mitigation measures on the affected properties would be considered following consultation between Sydney Water and its tenants. It should be noted that the nearest private residences to the AWTP at Forresters Road would not be affected by the noise generated at the AWTP.

Periodic maintenance and inspections would typically not result in significant noise generation and would be managed through Sydney Water's standard management procedures.

8.4.3 Summary

The measures described in **Table 8.6** would be implemented to minimise noise and vibration impacts.

Table 8.6 Noise and vibration summary

Aspect	Impact	Mitigation measures
Construction		
Noise	Disturbance to neighbouring residences, commercial areas and users of recreational facilities. Sleep disturbance through night works.	Construction activities to be undertaken in accordance with AS2346-1981. Monitoring to be undertaken to assess compliance with noise control guidelines *Construction Site Noise* (previously Chapter 171 of the *Environmental Noise Control Manual* (NSW DEC 1994). Standard noise controls would be implemented including: • generally limiting construction works where noise is audible at residential premises to between 7am to 6pm Monday to Friday and 8am to 1pm on Saturday unless otherwise approved by DEC. Night-work may also be required for construction of the pipelines, where they cross major roads or intersections, to minimise disruption of local and through traffic • minimising the noise generated by construction activities through construction planning and plant selection, use of mufflers, shrouds and appropriate maintenance • adoption of suitable mitigation measures where necessary, for works within 100 m of sensitive receivers • staff to be trained in work practices which minimise noise generation • notification of adjacent residents prior to commencement of construction works • implementation of a complaints management system to ensure that issues associated with excessive noise generation can be identified and resolved.
Vibration	Damage to specific buildings and heritage listed structures. Impact on residents	• construction activities to be managed in accordance with British Standard 7385:Part 2 – 1993 Evaluation and Measurement of Vibration in Buildings, and for heritage buildings German Standard DIN 4150:Part 3-1986 • where the potential for vibration impacts have been identified, an assessment of the likelihood of damage would be carried out. If it is considered that damage is possible, a pre-construction dilapidation survey would be conducted on potentially affected properties and monitoring undertaken through construction to confirm any potential impacts • construction activities to be managed in accordance with BS6742 (1984 and 1992), ISO 2631.2-1989 and AS 2670.2-1990.

Operation		
Noise	Potential noise impacts from the AWTP site. Pumping stations at the STP sites.	• the AWTP building will be designed to ensure the operation of the plant meets the noise criteria outlined in the NSW INP (NSW EPA 2000). • the pumping stations would be enclosed to aid in noise attenuation.
Maintenance activities	Maintenance vehicles and workers.	To be managed in accordance with Sydney Water's standard management practices.

8.5 Geology, soils and construction water management

8.5.1 Geology and soils

The geology of the area consists primarily of the Middle Triassic Wianamatta Group shales and sandstones.

The north western and western areas of Sydney lie on the Cumberland Plain and are characterised by low lying, gently undulating plains and low hills. The geology of the area consists primarily of the Middle Triassic Wianamatta Group shales and sandstones. The Blacktown soil landscape predominates, along with Berkshire Park and Richmond fluvial soil landscapes. South Creek soils dominate along major creeks.

The salinity potential in the study area is considered to be moderate, with high salinity potential generally confined to areas along the creeks and drainage lines (DIPNR 2002).

The erodability of the soils in the study area generally ranges from moderate to high, presenting a moderate to high erosion hazard. The soils between the three STP sites generally exhibit moderate erodability. Luddenham soils and South Creek soils around South and Ropes Creeks have high erodability.

For the concentrate pipeline, the soils around Vineyard Creek generally have low erodability. The Blacktown soils to the west have moderate erodability and the soils associated with the South Creek landscape around Pendle, Greystanes and Toongabbie Creeks are highly erodable.

8.5.2 Soil contamination

Some minor surface soil contamination in the form of total petroleum hydrocarbon constituents exists at the Penrith STP site but there is no evidence of wide scale contamination of fill or natural materials on site as a result of site activities.

Sludge, grit, screenings and other waste, including asbestos, have in the past been buried on-site at Quakers Hill STP. There is no evidence of this disposal in the areas likely to be disturbed for the Project and there is no contamination above National Environment Protection Council (1999) commercial / industrial land use criteria recorded in soils at the site.

No soil contamination is expected at St Marys STP. Along the pipeline corridor some soil contamination may exist at the International Peace Park, Seven Hills, which is built over a former municipal tip.

8.5.3 Construction water management

Groundwater quality results for the area indicate that there are elevated concentrations of heavy metals beneath the three STP sites. These elevated levels are thought to reflect background concentrations in the regional aquifer.

Analysis of groundwater samples at Quakers Hill STP identified elevated levels of total nitrogen, ammonia, phosphorus and bacteria. No information is available on the quality of water entering the site. As such the source of this potential contamination could not be confirmed.

There are several creeks in the study area that would either be crossed, or are located in close proximity to the proposed works. These are:

- creeks near Penrith, St Marys and Quakers Hill STPs and associated pipelines, comprising Breakfast Creek, Eastern Creek, Bells Creek, South Creek, Ropes Creek and Boundary Creek
- creeks near the concentrate pipeline from Seven Hills to the NSOOS near Vineyard Creek, comprising Blacktown Creek, Greystanes Creek, Quarry Branch Creek, Toongabbie Creek and the Parramatta River.

8.5.4 Construction impacts and mitigation measures

Potential impacts

The potential exists for materials excavated for the installation of infrastructure around the STP sites and pipeline routes to be contaminated, specifically at Quakers Hill STP and along the pipeline route at the International Peace Park. The disturbance of any contamination present at these locations may affect a range of sensitive receivers such as local residents, groundwater, flora and fauna and construction workers.

The construction phase also has the potential to contaminate soil, ground and surface water through the spillage of liquids such as oils or other materials required for construction, and through erosion of soils, particularly where vegetation has been cleared or where stockpiling occurs.

Depending on the groundwater levels within the study area and rainfall during the construction phase, dewatering of pipeline trenches and other excavations may be required. Inappropriate disposal of this material has the potential to impact on soils or surface waters.

Mitigation measures

Any construction materials and fuels stored and used on site would be managed to minimise the risk of soil or water contamination.

Contaminated land identified during construction would be managed in accordance with the requirements of the *Contaminated Land Management Act 1997* and necessary remediation undertaken in accordance with *State Environmental Planning Policy 55 – Remediation of Land* (SEPP 55).

Contaminated soil identified on site would be classified and managed in accordance with the DEC *Environmental Guidelines: Assessment, Classification and Management of Liquid and Non-liquid Wastes* (1999). All hazardous waste produced would be handled by appropriately licensed contractors and would be transported and disposed of in accordance with the *Protection of the Environment Operations (Waste) Regulation 2005*.

Any construction materials and fuels stored and used on site would be managed to minimise the risk of soil or water contamination. Dewatering activities would be managed and erosion and sedimentation controls would be installed and maintained in accordance with *Managing Urban Stormwater* guidelines (Landcom 2005).

8.5.5 Operational impacts and mitigation measures

Potential impacts

The potential for contamination exists from the spillage of chemicals at the STP sites and from leakage or accidental release of chemical from

the STP sites or associated pipelines. The operation of the AWTP and associated infrastructure would not significantly increase the risk of surface or groundwater pollution.

Mitigation measures

The potential for contamination of soils or groundwater during operation is considered minimal. Maintenance of the infrastructure would be undertaken in accordance with Sydney Water's standard management practices. Chemical storages would be designed to meet appropriate guidelines as detailed in **Section 8.6** and operational procedures implemented to minimise the risk of accidental spillage. Storage ponds would be lined to prevent infiltration.

8.5.6 Summary

The measures described in **Table 8.7** would be implemented to minimise soil, ground and surface water contamination risks.

Table 8.7 Geology, soils and construction water management summary

Aspect	Impact	Mitigation measures
Construction		
Contaminated land	Potential for runoff from contaminated spoil at STP sites and from pipeline routes	Managed in accordance with the *Contaminated Land Management Act 1997* and remediation in accordance with SEPP 55. Contaminated soil identified on site would be classified and managed in accordance with the DEC Environmental Guidelines. Contaminated waste and asbestos to be transported in accordance with POEO (Waste) Regulation. On identification of visual or olfactory evidence of contamination, construction is to cease and further investigations to be undertaken to identify management or disposal requirements.
Accidental releases	Spillage of potentially polluting liquids/ materials during construction	Appropriate handling of construction materials including avoiding storage of potentially contaminating liquids on site unless within bunded facilities away from water courses Maintenance of spill kit on site.
Water pollution	Erosion and sedimentation. Water pollution due to dewatering of excavations. Infiltration of contaminated groundwater.	Dewatering, installation and maintenance of erosion and sedimentation controls to be undertaken in accordance with *Managing Urban Stormwater Guidelines* (Landcom 2005) Containment and treatment of liquids resulting from dewatering in line with provisions of the POEO Act Contaminated water to be removed and disposed of at an appropriate waste management facility.
Operation		
Accidental releases	Spillage, leakage, accidental release of liquids during operation.	Facilities to be managed and maintained in accordance with Sydney Water's standard management practices.

8.6 Hazardous materials

State Environmental Planning Policy 33 - Hazardous and Offensive Development (SEPP 33) defines potential hazardous and offensive developments and specifies requirements for the assessment of hazards and the granting of development applications. SEPP 33 normally only applies to developments requiring development consent under Part 4 of the *Environmental Planning and Assessment Act 1979*. As the Project is to be undertaken under Part 3A of the *Environmental Planning and Assessment Act 1979*, the requirements of SEPP 33 would not apply.

Although SEPP 33 would not apply to the Project, the assessment procedures included in SEPP 33 were used to examine the potential hazards relating to the current proposal and the assessment is consistent with this policy and with the guideline *Multi-Level Risk Assessment* (DUAP 1997).

The STP sites currently store a number of chemicals commonly used in water treatment plants including sodium hypochlorite, ferrous chloride, sodium bisulfite solution, methanol and caustic soda. All existing storage areas conform to relevant standards and codes, primarily AS1940 – 2004 *The Storage and Handling of Flammable and Combustible Liquids* and Dangerous Goods Storage codes. The transportation of these goods and unloading of the goods at the STP sites also conforms to the *Road and Rail Transport (Dangerous Goods) (Road) Regulation 1998*.

The hazardous materials and the quantities and classes of these materials, which are to be utilised as part of the Project, were identified and compared with screening thresholds set out in 'Applying SEPP 33: Hazardous and Offensive Development Application Guidelines - DUAP, 1994' (**Table 8.8**).

The potential for fire or explosion exists during construction due to the presence of class 3 flammable liquids associated with fuels required for construction vehicles, chainsaws and other construction equipment. The quantity of these substances on site would be only that contained within vehicles, construction equipment and mini-tankers and as such, these fuels do not represent a significant hazard.

With the Project, storage volumes of class 8 (corrosive) sodium hypochlorite stored at Quakers Hill and Penrith STPs would increase above existing storage volumes by 77% and 43%, respectively. Sodium hypochlorite storage at St Marys would increase from 5 kilolitres to 79 kilolitres. There would also be increased storage and delivery of class 8 chemicals (sodium bisulfite and caustic soda) at St Marys and the storage and delivery of additional class 8 substances not currently kept on site, including ammonia, antiscalent and hydrochloric acid.

8.6.1 Construction impacts and mitigation measures

Impacts

The potential for fire or explosion would exist during construction due to the presence of class 3 flammable liquids associated with fuels required for construction vehicles, chainsaws and other construction equipment. The quantity of these substances on site would be only that contained within vehicles, construction equipment and mini-tankers and as such, these fuels would not represent a significant hazard.

Mitigation measures

The storage of fuels on or around the site would generally be avoided and vehicles and equipment would be refuelled off site. Where off-site refuelling is unavoidable mini-tankers would be used. Minitankers would be required to follow standard procedures to minimise the risk of explosion or fire.

Table 8.8 Hazardous materials summary

Dangerous goods class	Hazardous material	Current quantity stored	Proposed quantity stored	Screening threshold	Screening threshold exceeded	Delivery quantity and frequency	Transported threshold	Transport threshold exceeded
St Marys STP								
3	Methanol (underground) - 3PGII	30kL	30kL (6KL)[1]	3PGII 8 metres from site boundary	No	24t (6 loads per year)	Class 3PGII 3t (>750 loads/year)	No
	Methanol (above ground) - 3PGII	0.2kL	0.2kL	Class 3PGII < 2 m^3 N/A	No	0	N/A	No
8	Sodium bisulfite solution (40%) - 8PGIII	15kL	20kL	Class 8PGII 25kL	Yes	Approximately 8.2t (16 loads per year)	Class 8 2t (>500 loads/year)	No
	Ferrous chloride - 8PGIII	165kL	165kL			40t (8 loads per year)		
	Sodium hypochlorite - 8PGIII	5kL	79kL			Approximately 20.7t (91 loads per year)		
	Caustic soda - 8PGII	50kL	81kL			Approximately 19.3t (20 loads per year)		
	Ammonia - 8PGIII	0kL	8kL			6t (12 loads per year)		
	Antiscalent[2] - 8PGIII	0kL	7kL			6t (12 loads per year)		
	Hydrochloric acid - 8PGII	0kL	55kL			20t (36 loads per year)		
Penrith STP								
8	Ferrous chloride - 8PGIII	100kL	100kL	Class 8PGIII 50kL	Yes	25t (52 loads per year)	Class 8 2t (>500 loads/year)	No
	Sodium bisulfite solution (40%) - 8PGIII	10kL	10kL			6t (10 loads per year)		
	Sodium hypochlorite - 8PGIII	30kL	43kL			Approximately 11.9t (39 loads per year)		
Quakers Hill STP								
C1	Diesel - C1	4.5kL	4.5kL	N/A	No	N/A	N/A	No
3	Petrol - 3PGII	0.12kL	0.12kL	Class 3PGII < 2 m^3 N/A	No	N/A	Class 3PGII 3t (>750 loads/year)	No
8	Ferrous chloride - 8PGIII	150kL	150kL	Class 8 PGIII 50kL	Yes	N/A	Class 8 - 2t (>500 loads/year)	No
	Sodium bisulfite solution (40%) - 8PGIII	10kL	10kL			11t (10 loads per year)		
	Sodium hypochlorite 8PGIII	31kL	55kL			Approximately 20.9t (38 loads per year)		
Northern Suburbs Ocean Outfall Sewer								
8	Sodium hydroxide - 8PGII	0kL	44kL	Class 8 PGII 25kL	Yes	20t (10 loads per year)	Class 8 - 2t (>500 loads/year)	No

1 For class 3 materials stored underground, the capacity of the tank should be divided by five prior to assessing it against the screening threshold (DUAP, 1994)..

2 MSDS for Osmoflo Osmotreat used to classify antiscalent as it contained the highest hazard alert and most information of reverse osmosis antiscalants on Chemwatch (2006).

8.6.2 Operation impacts and mitigation measures

Impacts

The Project is not potentially hazardous and is therefore not likely to pose a risk to the community, workers or the environment providing that appropriate storage, delivery, unloading and handling procedures are implemented and the relevant standards and codes are adhered to.

The operation of the Project would lead to an increase in the quantity of potentially hazardous substances delivered to and stored at each STP site, particularly Class 8 substances. The additional volumes of Class 8 substances at Penrith, Quakers Hill and St Marys STPs would exceed screening threshold levels and a risk assessment was undertaken. The potential risk to surrounding land uses of these increased volumes of Class 8 substances is considered negligible, as the only pathway for impact from thee substances is direct contact. Transportation of these substances to site would be via major roads and highways, rather than suburban streets and the vehicle movement transport thresholds specified in SEPP 33 would not be exceeded.

The Project is not potentially hazardous and is therefore not likely to pose a risk to the community, workers or the environment, providing that appropriate storage, delivery, unloading and handling procedures are implemented and the relevant standards and codes are adhered to.

Mitigation measures

All Class 8 storage areas would be maintained within bunded facilities which conform with relevant standards and codes, primarily AS1940: *The Storage and Handling of Combustible and Flammable Liquids* and Dangerous Goods Storage Codes. Separate bunded areas would be constructed for each type of chemical and would drain to a sump, not to stormwater drains.

Any new chemical unloading areas would be capable of collecting and containing spills and all drains in the unloading area would be directed to a sump and not to stormwater. Appropriate handling procedures would be implemented.

8.6.3 Summary

A summary of the measures to be implemented to minimise risks associated with hazardous material storage on and delivery to the STP sites is produced in **Table 8.9**.

Table 8.9 Hazardous materials summary

Aspect	Impact	Mitigation measures
Construction		
Storage of class 3 flammable liquids	Potential for fire or explosion risk associated with fuels required for construction vehicles, chainsaws etc.	storage of fuels on or around the site to be minimised vehicles and equipment to be refuelled off site where possible. Where unavoidable mini-tanks to be used for refuelling.
Operation		
Class 8 Handling	Potential for spillage during delivery, unloading or use and potential for direct contact with workers and assets.	workforce trained in appropriate handling procedures unloading only within designated bunded areas drainage to sump to be maintained spill kit maintained adjacent to unloading facilities.
Class 8 Storage	Potential for direct contact in event of spillage.	storage of materials separately in bunded facilities storage in accordance with AS1940 maintain drainage to sump.

8.7 Heritage

8.7.1 Aboriginal heritage

A preliminary assessment of indigenous heritage items was undertaken for the Project by Navin Officer. This included a search of the Department of Environment and Conservation's (DEC) *Aboriginal Heritage Information Management System* which identified 50 previously recorded Aboriginal sites within 500m of the proposal (**Figures 8.2a - 8.2d**). Of the 50 previously recorded sites, only two sites (isolated finds) occur along the alignment of the proposed pipeline.

Aboriginal consultation is being undertaken in accordance with the *Interim Aboriginal Community Consultation Guidelines* (DEC 2004) and the *Draft 3A Guidelines for Aboriginal Cultural Heritage Impact Assessment and Community Consultation* (DEC 2005).

An archaeological field investigation was undertaken as part of the preliminary assessment at the three STP sites and along the pipeline routes. The following items or sites were identified:

- two artefact scatters (each scatter contained two silcrete flakes)
- three isolated finds (either volcanic or silcrete flakes)
- five potential archaeological deposits (PADs) located in the vicinity of creeks.

The two previously recorded isolated finds could not be located during the field survey.

The preliminary assessment identified the presence of Aboriginal cultural heritage values which may be affected by the Project (see **Figures 8.3a - 8.3d**). Consultation with local Aborigineal communities is being undertaken in accordance with the *Interim Aboriginal Community Consultation Guidelines* (DEC 2004) and the *Draft 3A Guidelines for Aboriginal Cultural Heritage Impact Assessment and Community Consultation* (DEC 2005). Consultation activities are ongoing and include the following:

- briefing meetings with leaders from the Darug Tribal Aboriginal Corporation, Darug Custodian Aboriginal Corporation and the Darug Tribal Cultural Heritage Corporation. These groups were provided with a copy of the preliminary assessment for comment
- letters have been sent to the following providing details of the Project:
  - Local Aboriginal Land Council
  - Native Title Services
  - Blacktown, Parramatta, Penrith and Baulkham Hills councils
  - Department of Environment and Conservation.
- placement of a media advertisement in local and metropolitan papers and the Koori Mail during September 2006, inviting Aboriginal groups and individuals with an interest in the cultural and heritage values of the area to be consulted
- Aboriginal groups registering their interest as a result of the advertisement were invited for a briefing and provided with a copy of the preliminary assessment for comment
- all groups have been asked to identify areas of cultural significance in the study area
- written confirmation of areas of cultural heritage significance has been requested
- site visits have been offered to all Aboriginal groups that have registered an interest in the Project

Figure 8.2a Location of Aboriginal sites within 500m of the study area and historical Heritage listings



Figure 8.2b Location of Aboriginal sites within 500m of the study area and historical Heritage listings

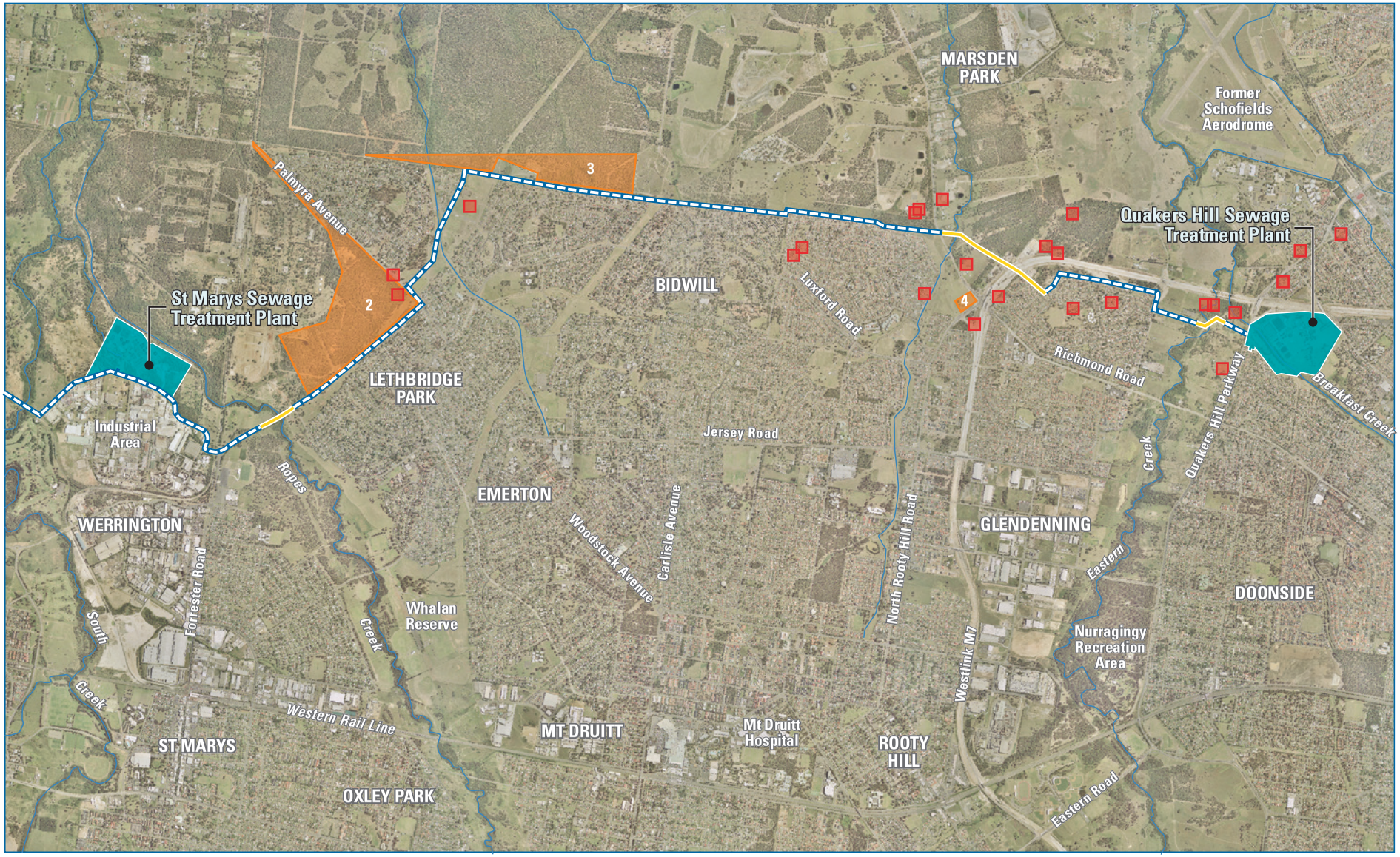


Figure 8.2c Location of Aboriginal sites within 500m of the study area and historical Heritage listings



Figure 8.2d Location of Aboriginal sites within 500m of the study area and historical Heritage listings



- comments and information provided as a result of the consultation process would be considered during detailed design.

8.7.2 European heritage

Navin Officer also assessed the potential impact of the Project on non-indigenous or European heritage. Initially the following heritage registers and schedules were searched:

- the National Heritage List (Australian Heritage Council)
- the Commonwealth Heritage List (Australian Heritage Council)
- the Register of National Estate (Australian Heritage Council)
- the State Heritage Register (NSW Heritage Office)
- the State Heritage Inventory (NSW Heritage Office)
- Heritage Schedule(s) from Blacktown, Parramatta, Baulkham Hills and Penrith Local Environmental Plans
- Parramatta Local Environmental Plan 1996 (Heritage and Conservation)
- section 170 Heritage and Conservation Register (compiled by Sydney Water).

From the database search, 27 items of heritage interest were identified within the study area (see **Figures 8.2a - 8.2d**). Three of these sites (shown in **Table 8.10**) are located along the alignment of the proposed pipeline.

Table 8.10 European heritage sites

Item	Details
Parramatta Archaeological Management Unit (AMU) 2898	The AMU includes a sports field (Ritchie Benaud Oval), a single-storey amenities building and surrounding open space and trees. This AMU was reserved for recreation in the 1870s and has remained a reserve and sports ground since that time. This is categorised as a Reserve and is considered to have high archaeological potential.
Parramatta Archaeological Management Unit 3167	This AMU includes the Old Salesyards Reserve. A stock salesyard was well established in this area by the 1950s. Since then the salesyards and house have been demolished and the area is now the Old Salesyards Reserve. It is considered to have little archaeological potential.
Parramatta Gaol	The Parramatta Correctional Centre is the oldest gaol in original use in Australia and is the most intact of the pre-1850s gaols of Australia. The gaol is a sandstone structure of several wings enclosed in high sandstone walls topped with observation towers. Constructed between 1835 and 1842 it has undergone a number of modifications since that time. It is considered to be of heritage significance.

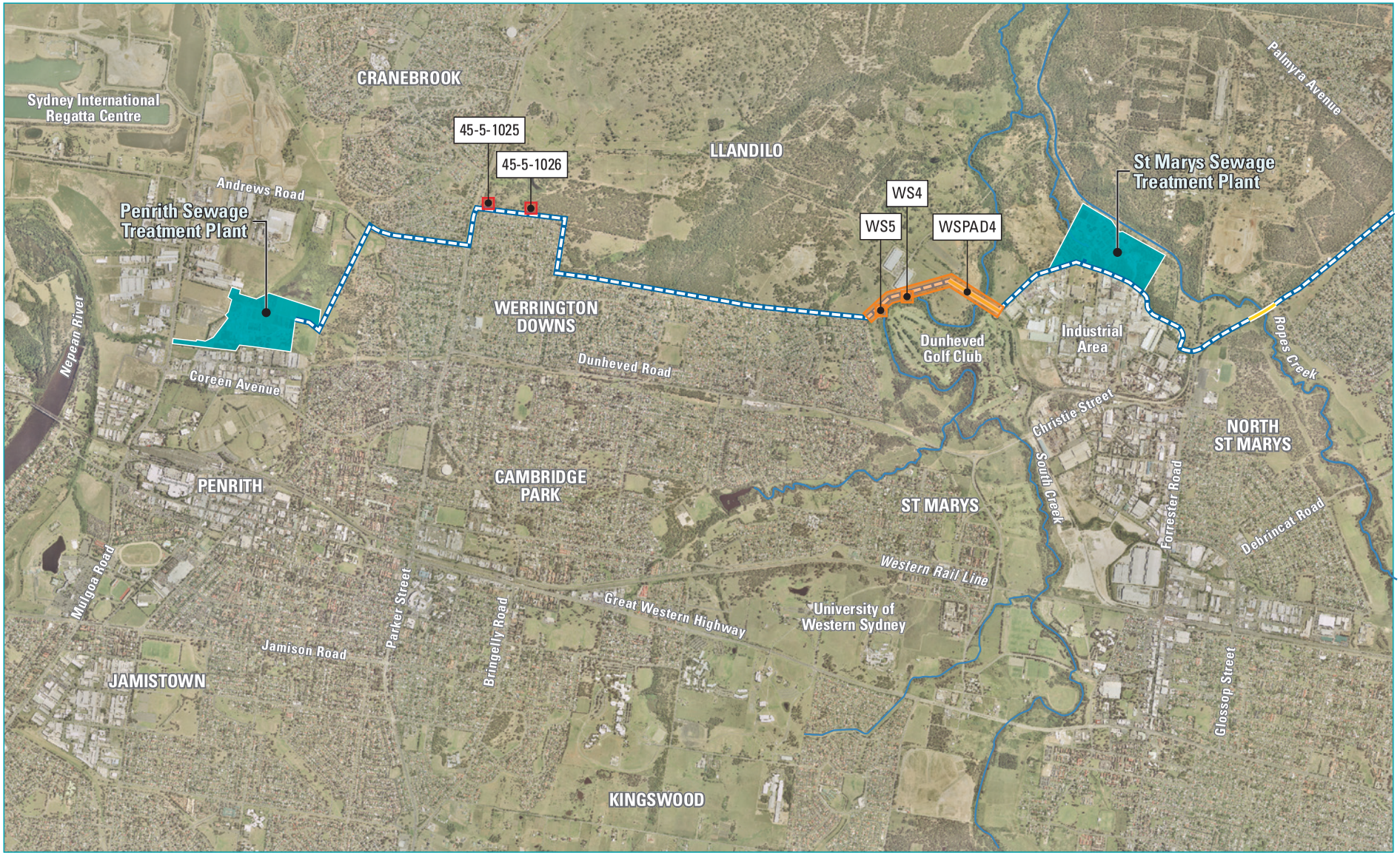
8.7.3 Construction impacts and mitigation measures

Impacts

Construction of the proposed pipelines would potentially disturb one site containing several indigenous stone flakes and five areas containing PADs (see **Figures 8.3a - 8.3d**).

Construction of the pipeline would also potentially disturb two Archaeological Management Units, both of which comprise parkland/open space (see **Figures 8.3a - 8.3d**).

Figure 8.3a Location of sites that would be directly impacted by the Project



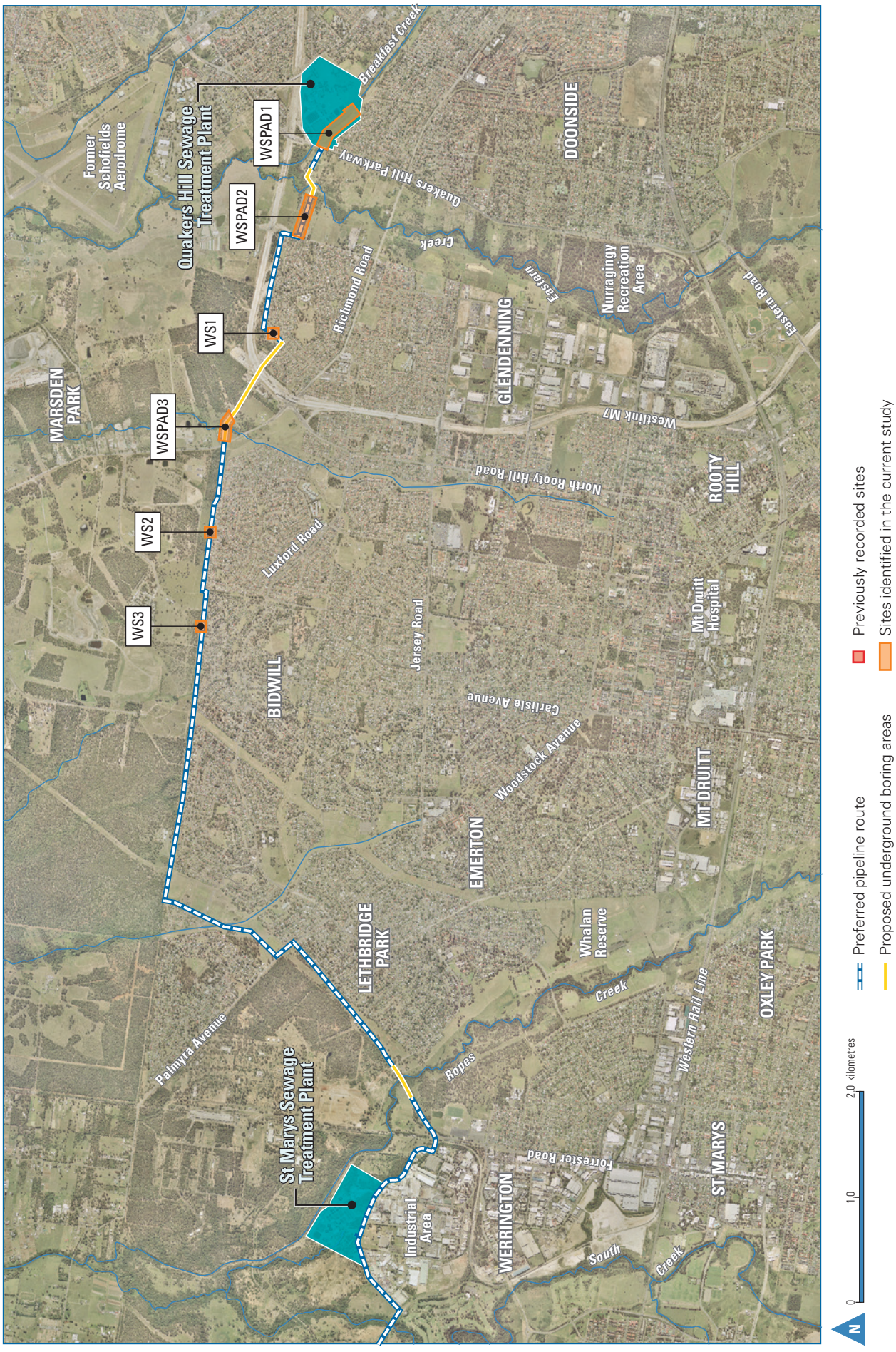


Figure 8.3b Location of sites that would be directly impacted by the Project

Figure 8.3c Location of sites that would be directly impacted by the Project

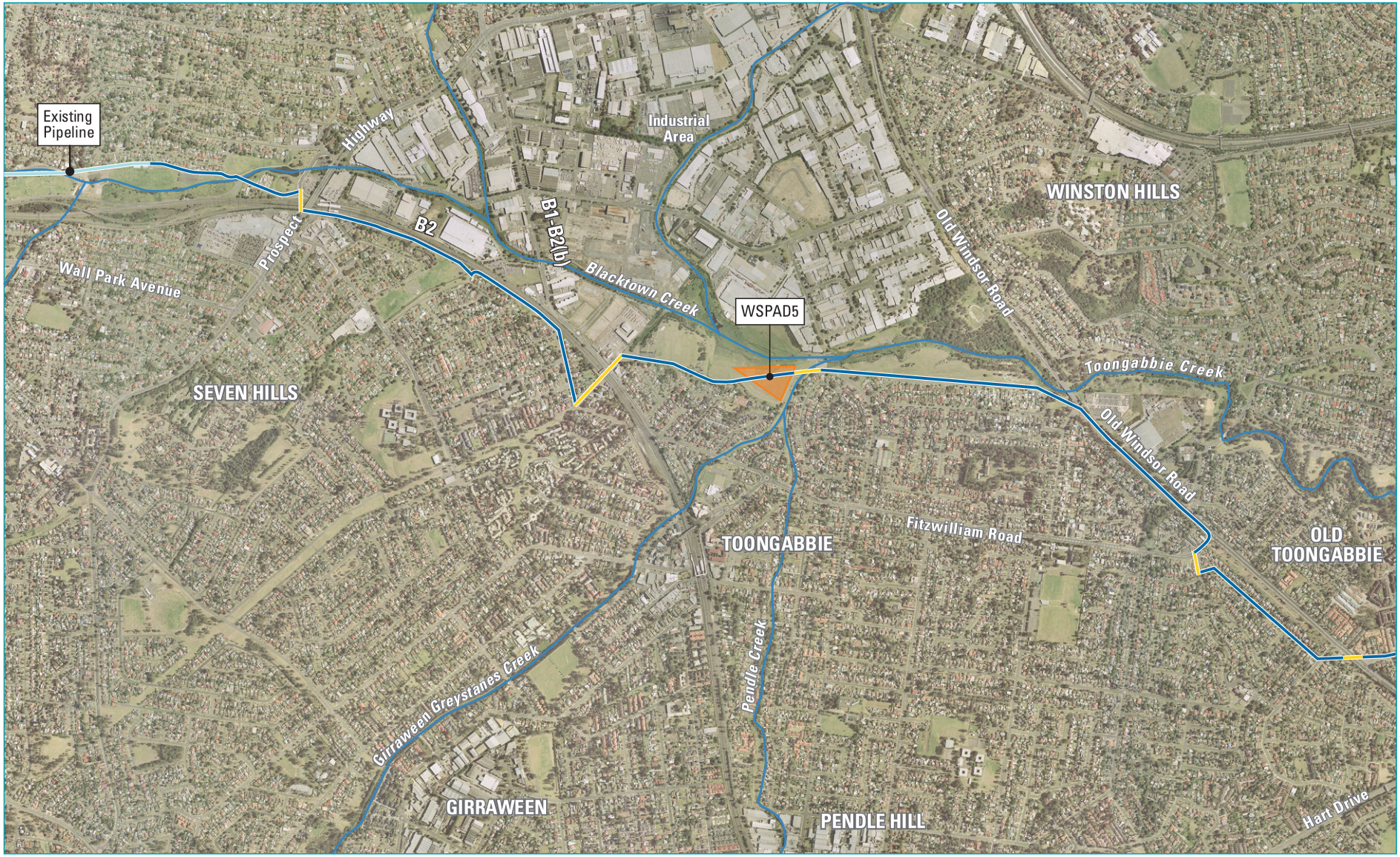
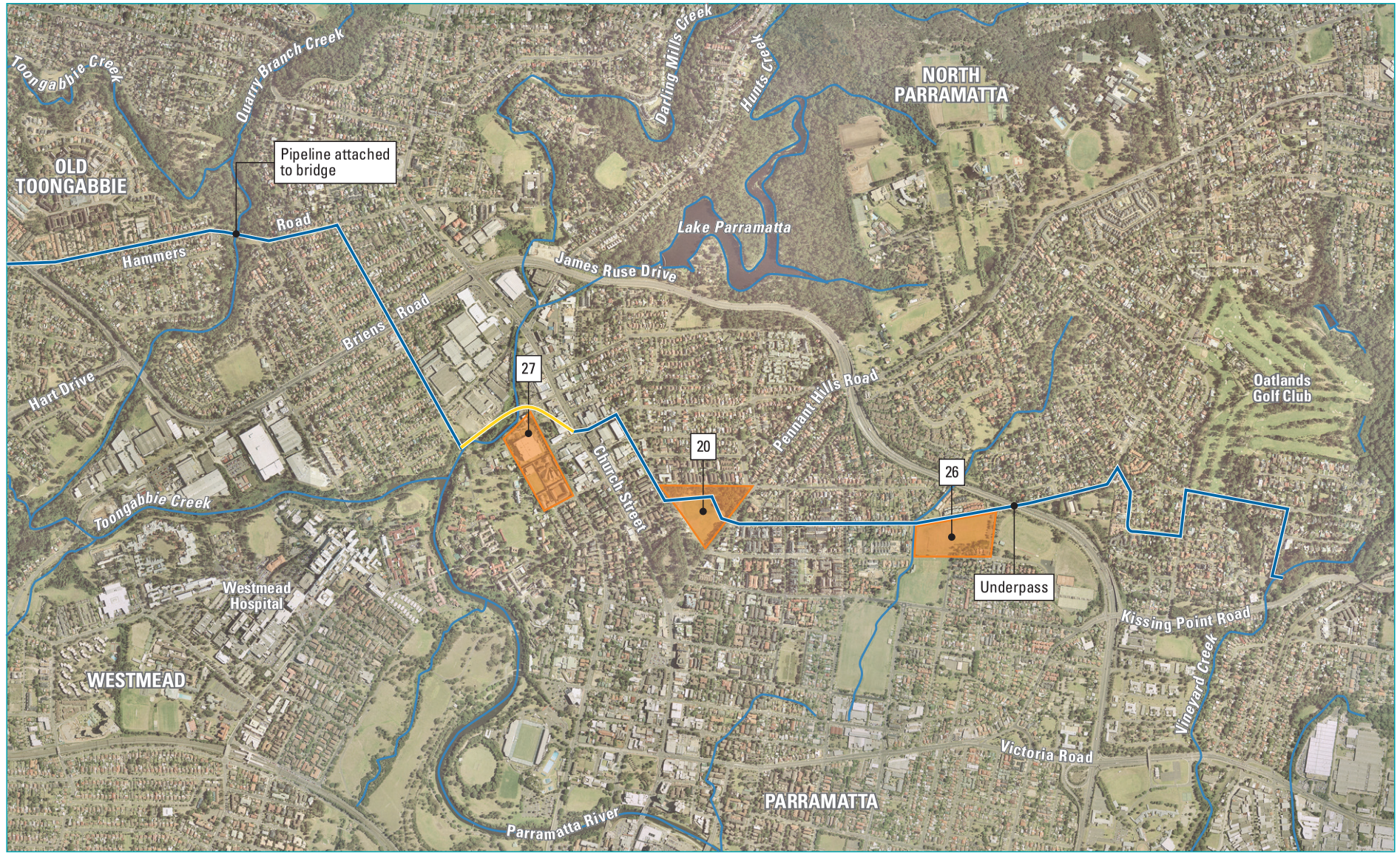


Figure 8.3d Location of sites that would be directly impacted by the Project



There is also the potential for impact the heritage listed Parramatta Gaol area through vibration during boring activities. The proposed pipeline would be bored beneath a perimeter wall associated with the linen service. Mitigation options are proposed to minimise these impacts.

Mitigation measures

Many of the areas containing PADs are adjacent to creeks, where boring of pipelines would be undertaken. One of the PADs is located adjacent to Toongabbie Creek, where the pipeline would be attached to a bridge, to avoid disturbing the PAD. Where boring is not possible in a PAD area, a program of archaeological subsurface investigation would be undertaken to determine the presence, nature, extent and integrity of any archaeological deposits that may be present. If archaeological investigation is required prior to consent being granted under Part 3A of the *Environmental Planning & Assessment Act 1979*, then a permit would be obtained under Part 87 of the *National Parks and Wildlife Act 1974*.

Where boring is not possible in a PAD area a program of archaeological subsurface investigation would be undertaken to determine the presence, nature, extent and integrity of any archaeological deposits that may be present.

Management options for the site containing stone flakes identified along the pipeline route are the subject of ongoing consultation with local Aboriginal Groups. Options under consideration include the removal of these items prior to construction commencement and their replacement in situ on completion, or relocation to a museum or other display or storage location.

If previously unidentified Aboriginal objects are discovered during construction, all work likely to affect the object(s) would cease and the DEC would be informed. Further investigation by a suitably qualified archaeologist would be required before work recommences to identify measures to be implemented to reduce the impact on the objects discovered.

Construction works through the AMU sites would be subject to review by a qualified archaeologist. If any potential heritage items are found along the route, construction would cease and further archaeological advice would be sought.

An alternative route around Parramatta Gaol would be investigated to avoid impacts. If this alternative was not practical, boring beneath the perimeter wall associated with Parramatta Gaol would be undertaken at a depth to minimise potential vibration impacts on the perimeter wall. Monitoring would be undertaken prior to, during and after boring to identify any impacts resulting from the boring activities. In the unlikely event of damage, a program of repair would be undertaken in consultation with the Heritage Office.

8.7.4 Operation impacts and mitigation measures

No impacts on European or Aboriginal heritage would occur during operation.

8.7.5 Summary

Table 8.11 summarises the measures which would be implemented to minimise the potential impacts on Indigenous and European heritage items.

Table 8.11 Indigenous and European heritage summary

Aspect	Impact	Mitigation measures
Construction		
Aboriginal heritage	Potential impacts on sites containing stone flakes identified as isolated finds or artefact scatters along pipeline routes. Potential impacts on five potential archaeological areas (PADs) around creeks. Identification of Aboriginal heritage items during construction.	Ongoing consultation with Aboriginal groups to determine management options for these artefacts. Boring beneath the PADs. If this is not feasible an archaeological investigation may be undertaken by an appropriately qualified archaeologist prior to works commencing. Construction to cease and advice to be sought from Archaeologist.
European heritage	Impact on AMU 2898 and AMU 3167. Impact on perimeter wall associated with Parramatta Gaol Discovery of European heritage items during construction.	For the two AMUs, monitoring by an appropriately qualified archaeologist during construction. Alternative route chosen or boring to be undertaken beneath the wall at a suitable depth to avoid impact. Monitoring to be undertaken. Construction to cease and advice to be sought from Archaeologist.

8.8 Land use and tenure

The AWTP site and other infrastructure apart from the pipelines are located within land owned by Sydney Water. The preferred pipeline route has been positioned within cleared areas, including roads and other easements where possible, to minimise the impact on private properties. Where possible, Sydney Water would seek easements for the pipelines. Further details of land ownership and property is provided in **Chapter 3** and detailed in **Appendix A**.

8.8.1 Construction impacts and mitigation measures

Impact

Access to private properties would be maintained during construction and as construction activities would be undertaken progressively, the duration of potential land use impacts would be minimised. Once installation of the pipelines has been completed, the land would be returned to its former use.

Services and utilities in the area may be affected if they occur along the alignment of the proposed pipeline.

Mitigation measures

Measures to maintain access to properties would be developed in consultation with affected land owners. Any buried services that may be impacted would be identified and necessary consultation with the service providers would be undertaken. Boring would be undertaken where significant land use impacts would occur (e.g. major road crossings) and the land would be rehabilitated to its former use on completion.

8.8.2 Operation impacts and mitigation measures

Impact

The creation of easements for the pipelines would only result in minor constraints to future and existing land uses.

Occasional maintenance or repair of the pipelines may cause limited, short-term constraints to activities. As the proposed pipelines would be buried, they would not prevent current land uses from continuing.

Mitigation measures

Sydney Water's standard management procedures would be implemented to avoid negative impacts on land use and property associated with repair or maintenance. Appropriate compensation would be provided to landowners where easements for pipelines are created.

8.8.3 Summary

Table 8.12 summarises measures that would be implemented to minimise the potential impacts on land use, property and services.

Table 8.12 Land use and property summary

Aspect	Impact	Mitigation measures
Construction		
Property	Disruption. Access restrictions.	Consultation with affected property owners prior to works commencing. Maintain access to private properties.
Services and utilities	Potential damage to underground services during construction. Potential disruption to rail services associated with rail crossings.	All services to be located prior to works. Notification of service providers of proposed works. Ongoing consultation with RailCorp to determine construction requirements for railway crossing.
Land use	Change of land use	Rehabilitation of the land to former use on completion.
Operation		
Land use	Land use change	The infrastructure would be managed in accordance with Sydney Water's standard management procedures.
Property	Potential disruption maintenance and repairs. Easement compensation.	Infrastructure to be managed in accordance with Sydney Water's standard management procedures.

8.9 Visual amenity

The visual environment at the three STP sites typically comprises sewage treatment infrastructure, with areas of open space and pockets of vegetation.

The nearest residential properties to Quakers Hill STP are located to the south west beyond Breakfast Creek and are at least 150 m from the site boundary. The view to the site from these properties is obscured by vegetation. An open field is located adjacent to the proposed works at Penrith STP and some residential properties exist adjacent to St Marys STP,

where the new infrastructure is to be constructed. Both Penrith and St Marys STPs are located in close proximity to industrial areas.

The pipeline routes pass through areas with both urban and rural visual components. The concentrate pipeline, in particular, passes through densely populated residential and commercial areas, with the pipeline positioned for the most part within the existing road corridors. The pipelines connecting the three STPs generally pass on the outskirts of urban areas, outside suburban fences with only small sections occurring within residential streets. The pipeline route has been positioned, where possible, within cleared land and along existing service corridors or bushfire protection zones. The visual environment along these routes ranges from small-scale closed landscapes with isolated pockets of vegetation, to cleared flat open parkland and open pasture.

8.9.1 Construction impacts and mitigation measures

Impacts

During construction of the pipelines, trenches would be dug and the pipelines laid in sections along the proposed routes. Construction equipment would be visible to residences where construction work is proposed on roadways. In other areas, visibility would vary depending on the extent of distance, residential vegetation and fences. Some sporting fields and reserves also exist along the proposed pipeline routes. The presence and operation of construction equipment in these areas would affect the visual amenity, although use of these areas by the public is generally limited to weekends and outside of work hours, when construction work would be limited. Additionally, the construction period in the vicinity of any one house, field or reserve would be short and as such, the anticipated visual impacts would be minimal.

A work depot would need to be established in the vicinity of each pipeline route. Each depot is not expected to occupy a large area and would only be required during the pipeline construction phase. The anticipated visual impact from work sheds would therefore be minimal.

The location of the proposed infrastructure at the STPs presents a high level of integration with the existing land use at each site. The view to Quakers Hill STP is obscured from the view of the closest residents to the south west by the riparian vegetation of Breakfast Creek. No residential properties have direct views to the construction area at Penrith STP, although construction would be visible from the adjacent reserve. As such, a moderate visual impact is expected during construction.

Some visual impacts are likely during construction of the balance tank, pumping station and AWTP and associated infrastructure at St Marys STP. These structures are to be built in the south western corner of the plant, adjacent to several residential properties which are owned by Sydney Water. Although the proposed works would be consistent with the current STP site use and the majority of land use in the adjacent Dunheved industrial estate, a moderate impact on visual amenity is expected due to the close proximity of these properties to the construction site.

Mitigation measures

The construction of pipelines would progress quickly, resulting in short temporary impacts on visual amenity in the vicinity of any one home, park or reserve. Progressive rehabilitation of the pipeline route would also occur following the laying of pipes and backfilling of trenches.

The depots would be established in cleared areas where the presence of construction equipment and operations would not contrast significantly with the current land use to ensure no significant impacts to the visual amenity of the area. Hoardings or temporary screening would be erected to form a visual barrier in locations where views are likely from sensitive receivers. Good housekeeping practices would be employed on-site to minimise visual impacts.

The construction period at the STPs would be relatively short and fencing or vegetation along the fence line would be used to obscure construction works from view and further reduce the visual impact of construction.

8.9.2 Operation impacts and mitigation measures

Impacts

The majority of proposed pipelines would be constructed underground and as such would have no visual impact during operation.

The operation of the proposed infrastructure at the STPs would be consistent with the current environment at each site. Views to the proposed structures at the Quakers Hill STP would be obscured by vegetation and distance. No residential properties have direct views of the proposed infrastructure at Penrith STP, although these structures would be visible from the adjacent reserve. The visual impact of the STP as a whole would not be altered by the operation of the proposed infrastructure.

The balance tank, pumping station, AWTP and associated infrastructure at the St Marys STP site does not contrast with the existing visual environment at the site or surrounding areas. The proposed infrastructure is, however, in close proximity to several residential properties on the south western border of the site. The visual impact of this infrastructure would be moderate on these properties if mitigation measures were not implemented. **Figure 8.4** provides a visual representation of the view to the proposed AWTP site at St Marys from the nearest public area (Trigg Street).

Mitigation measures

Existing vegetation would be maintained and where appropriate the planting of additional vegetation would be undertaken along site boundaries and to obscure views of the proposed infrastructure from sensitive receivers.

8.9.3 Summary

The measures described in **Table 8.13** would be implemented to minimise impacts to visual amenity.

Table 8.13 Visual amenity summary

Aspect	Impact	Mitigation measures
Construction		
Visual amenity	Disturbance to residents	• pipeline construction period within the vicinity of any one home is short • existing vegetation screening along STP boundaries • progressive rehabilitation of pipeline route will be undertaken • work depots will be enclosed.
Visual amenity	Disruption to users of fields and reserves	• construction works limited on weekends and outside of normal work hours • storage of major construction equipment away from open areas • short pipeline construction period within the vicinity of any one field or reserve.
Visual amenity	View to STP sites	• vegetation screening along boundaries where views of construction are available to sensitive receptors.
Operation		
Visual amenity	View to STP sites	• vegetation screening along boundaries where views of new infrastructure are available to sensitive receptors.

Figure 8.4 Views of the AWTP



View of the AWTP from Links Road



View of the AWTP from the entrance to St Marys STP

8.10 Air quality

The existing air quality around the project area is influenced by surrounding rural residential and residential land uses, vehicular traffic movements and emissions, surface disturbance and exposure of soil associated with construction works and industrial land uses.

8.10.1 Construction impacts and mitigation measures

Impacts

Construction of the pipelines would require only minimal surface disturbance at any one time, as the excavation works and site rehabilitation works would be completed progressively. Topsoil and subsoil material would be stripped and temporarily stockpiled immediately adjacent to the construction area for backfilling and compaction of the trench.

Construction of the AWTP at St Marys STP and the concentrate storage pond at Quakers Hill STP would require the levelling and minor amounts of clearing of up to 4 hectares at St Marys and up to 2 hectares at Quakers Hill, including demolition of a derelict building containing asbestos sheeting at St Marys STP. Both sites are relatively flat and should not require major earthworks. Construction of the storages and pumping stations at the STP sites would only require minor disturbance and exposure of the soils. Other sources of dust during construction which would include vehicle movements and demolition activities.

Mitigation measures

Appropriate dust management measures would be implemented throughout the duration of the construction activities, including watering of exposed soils when necessary, water sprays for dust generating excavation and demolition activities, covering of trucks removing spoil, progressive restoration of disturbed areas, and maintenance of stockpiles at a height of less than 1.5 metres. These standard measures would ensure that the impacts from dust generation are minimised.

Demolition of the derelict building would be undertaken by a suitably licensed contractor to minimise the potential for asbestos fibres to become airborne.

The combustion of fuels by construction equipment and vehicular movements would also contribute to emissions within the local environment. However, provided equipment and vehicles are maintained, emissions would not cause a significant impact and would be temporary in nature.

8.10.2 Operation impacts and mitigation measures

Impacts

The operation of the AWTP and pipelines would not result in any dust or combustion emissions. Emissions from maintenance vehicles (dust or combustion emissions) are not considered significant.

Odour generation would be negligible, as tertiary treated effluent used as feed-water to the AWTP has a low organic load and is largely odourless. The concentrate generated would also be largely odourless and would be contained within the proposed pipeline system. The concentrate storage pond at Quakers Hill STP would only be used for short periods of time when discharge to the NSOOS is not permitted and there is little opportunity for the concentrate to be exposed to the air for sufficient time

to become odorous. Existing buffer zones around the STP also ensure that sensitive receivers are distant from potential odour sources.

Mitigation measures

During pilot testing of the Project, the potential for anoxic conditions and subsequent odour generation to occur during periods of temporary concentrate storage in the pond would be determined. If odour generation is identified as a potential issue, mitigation measures such as water aerators would be installed to maintain aerobic conditions.

Maintenance and management of the AWTP, concentrate storage ponds and other infrastructure would be undertaken according to Sydney Water's standard management practices to minimise the potential for odour and dust.

8.10.3 Summary

The measures described in **Table 8.14** would be implemented to minimise air quality impacts.

Table 8.14 Air quality summary

Aspect	Impact	Mitigation measures
Construction		
Dust	Dust from construction impacting on local residences/properties.	Appropriate dust control measures would be implemented including: • limiting area of cleared land • revegetation on completion • damping down exposed surfaces • limiting height of stockpiles • covering spoil truck loads.
Asbestos particles	Health impacts for construction workers and local residents	Demolition of buildings containing asbestos sheeting to be undertaken by a suitably licensed contractor.
Vehicle emissions	Release of particulates and greenhouse gases	Maintenance of vehicles and construction equipment.
Operation		
Dust	Vehicular traffic and maintenance activities	To be managed in accordance with Sydney Water's standard management practices.
Vehicle emissions	Release of particulates	Maintenance vehicles to be appropriately maintained.
Odour	Odour from concentrate storage pond	To be managed in accordance with Sydney Water's standard management practices.

8.11 Traffic

Penrith, St Marys and Quakers Hill STPs are accessible via Castlereagh Road, Links Road and Quakers Road, respectively.

The proposed pipeline routes would be located within the road reserve of the following roads (or would cross these roads):

- Westlink M7 Motorway
- Andrews Road
- The Northern Road
- Links Road
- Forrester Road

- Palmyra Road
- Richmond Road
- Quakers Hill Parkway.

Source:
St Marys Transport Assessment SKM October 2005 (SKM 2005)

Surveys of traffic volumes were undertaken at the Links Road/Forrester Road intersection during the morning and afternoon peak periods (e.g. 7:00 to 9:00 and 4:00 to 6:00 respectively) on Thursday 13th October 2005. On Forresters Road, a total of 1,486 vehicles were surveyed to the south of Links Road during the morning peak period (as shown in **Table 8.15**).

Table 8.15 Traffic volume at Links Road / Forresters Road

Road	Movement	AM			PM		
		Light	Heavy	Total	Light	Heavy	Total
Forresters Road (South of Links Road)	Northbound	791	78	869	653	58	711
	Southbound	558	59	617	911	47	958
	TOTAL	**1349**	**137**	**1486**	**1564**	**105**	**1669**
Forresters Road (North of Links Road)	Northbound	576	44	620	707	48	755
	Southbound	609	25	634	649	20	669
	TOTAL	**1185**	**69**	**1254**	**1356**	**68**	**1424**
Links Road (West of Forresters Road)	Eastbound	1	5	6	10	6	16
	Westbound	329	47	386	122	25	147
	TOTAL	**330**	**52**	**392**	**132**	**31**	**163**

Analysis of the surveyed traffic volumes was carried out using Sidra Intersection Modelling software. The output showed that the intersection is operating at an acceptable level of service during both the morning and afternoon peak periods, with average delays at the intersection of 11 and 12 seconds respectively. Level of Service Criteria for the year 2016 is defined by the NSW RTA, based on the average delay per vehicle (RTA 2002).

Existing traffic generated by St Marys STP is minimal and is primarily associated with the removal of waste products (eg dewatered sludge) and delivery of chemicals generating between 4-6 heavy vehicle movements per day. The number of staff at the STP site is small and the light traffic generated would be less than 20 traffic movements per day. Around St Marys STP, Forrester Road is a major connecting road between St Marys and the surrounding areas and Links Road is the main access road for the Dunheved Industrial area. Forrester Road carries high volumes of traffic, including a high number of heavy vehicle movements servicing the predominantly industrial areas of St Marys. Existing access to the STP site is via Werrington, Christie and Links Road.

The construction phase is expected to last for approximately 12-15 months. During this period, construction workforce numbers would vary, depending on the construction activities being undertaken, but would peak at approximately 130 personnel.

The volumes of traffic generated by Penrith and Quakers Hill STPs would be similar to those generated by St Marys STP. The main link road in the vicinity of the Penrith STP is the Great Western Highway and access to Penrith STP is from Castlereagh Road. The main link road in the vicinity of Quakers Hill STP is Richmond Road. The STP site itself is accessible from Quakers Road off Quakers Hill Parkway.

The construction phase is expected to last for approximately 12-15 months. During this period, construction workforce numbers would vary, depending on the construction activities being undertaken, but would peak at approximately 130 personnel. Spoil generated from construction of the AWTP facilities and storage ponds at Quakers Hill would generate approximately 450 and 1,800 truckloads respectively. Spoil generated from installation of the pipelines between the three STPs and the concentrate

pipeline would generate 1,800 and 1,090 truckloads respectively. The 1,800 truckloads (over a 2-3 month period) would equate to about 40 truckloads (80 movements to and from the site) per day.

8.11.1 Construction impacts and mitigation measures

Impacts

Construction of the pipelines has the potential to cause localised traffic delays and diversions, due to:

- additional vehicles movements associated with the transport of construction workers, raw materials, waste, equipment and machinery to and from the development site
- short-term closure of sections of road reserve and traffic lanes, to allow the safe installation of pipelines within existing road easements
- restricted or modified access to adjacent properties.

The road verge and one lane of traffic would be closed during trenching and installation of the pipelines in or adjacent to roads (for the minimum section necessary at any one time), to allow safe access and operation of construction equipment.

Approximately 4.5 km of the proposed 20 km pipelines between the three STP sites would be located in or adjacent to roads. The majority of the proposed 12 km pipeline from Seven Hills to the NSOOS near Vineyard Creek would be located in or adjacent to roads.

It is anticipated that road works in or adjacent to roads would be undertaken progressively over a period of 4 months, with any one area being disturbed for approximately 3 weeks.

The construction traffic, including trucks and construction worker vehicles, would result in an increase in traffic volumes on roads surrounding the study area and could result in increased competition for roadside parking spaces. The impact on local roads and intersections are not considered significant as the roads in the vicinity of the works area generally have sufficient capacity to absorb the construction traffic volumes proposed.

Mitigation measures

Underground boring techniques would be used to minimise the damage or disruption to roads, particularly where pipelines would cross major roads. Consultation would be undertaken with the RTA and local government regarding works that may impact on roads. Traffic and public transport service providers would also be notified of potential route changes or delays associated with the construction works. Access would be maintained to private properties and all property owners notified in advance of works.

Qualified traffic controllers would undertake all road diversions and traffic management activities, in accordance with Sydney Water's standard operating procedures.

Construction works would generally be undertaken between 7am to 6pm Monday to Friday and 8am to 1pm on Saturday, unless otherwise approved by DEC. Night-work may also be required for construction of the pipelines, where they cross major roads or intersections, to minimise traffic impacts.

Construction traffic impacts would be minimised by:

- the provision of construction worker parking within the STP sites to prevent parking problems on surrounding roads

- the construction contractor to consider providing group transport to the construction sites or encouraging car shares
- trucks avoiding residential streets where possible
- the timing of truck movements to avoid peak periods to minimise local traffic congestion
- clearly defining routes to disposal/reuse facilities, with consideration of road capacity and current traffic volumes.

8.11.2 Operation impacts and mitigation measures

Impacts

The operation of the new infrastructure and processes required as part of the Project would lead to an increase in the quantity of potentially hazardous substances delivered to and stored at each STP site. The estimated number of deliveries of sodium hypochlorite to Quakers Hill STP would increase from 12 loads to approximately 38 loads per year and at Penrith STP there would be an increase from 11 loads per year to 39 loads. Sodium hypochlorite volumes delivered to St Marys STP would increase to approximately 91 loads per year, which would be delivered to the site along Links Road. Several additional class 8 potentially hazardous substances, ammonia, antiscalent and hydrochloric acid, would also be delivered to and stored on the St Marys site at the AWTP. Due to the additional infrastructure at the three STPs there would also be additional maintenance traffic visiting these facilities.

The increase in truck deliveries to the new AWTP site at St Mary's would not be significant as the traffic using Links Road and Forrester Road is predominantly vehicles visiting Dunheved industrial area.

Mitigation measures

The potential impacts from increased traffic associated with maintenance and deliveries is not considered to be significant and would be managed in accordance with Sydney Water's standard management procedures.

8.11.3 Summary

The measures to be implemented to minimise traffic impacts are summarised in **Table 8.16**.

Table 8.16 Traffic summary

Aspect	Impact	Mitigation measures
Construction		
General traffic management	Road closures and traffic diversions	Consultation with RTA, local government and public transport service providers regarding works that may impact roads or traffic. Consultation with impacted property owners to maintain access during construction and notification of activities prior to commencement. Construction activities to be restricted to 7am to 6pm Monday to Friday and 8am to 1pm on Saturday, unless otherwise approved by DEC. Night-work may be undertaken for the construction of the pipelines, where they cross major roads or intersections, to minimise traffic impacts Construction traffic management for the Project to include: • provision of construction worker parking within the STP sites to prevent parking problems on surrounding roads • construction contractor to consider providing group transport to the construction sites or encouraging car shares • trucks avoiding residential streets where possible • timing of truck movements to avoid peak periods to minimise local traffic congestion
		• routes to disposal/reuse facilities to be clearly defined with consideration of road capacity and current traffic volumes • road diversions and traffic management activities would be undertaken by qualified traffic controllers.
Major roads	Significant traffic disruption and intersection delays.	For pipeline crossings of major roads (eg Westlink M7 Motorway, Northern Road) and major intersections, underground boring techniques would be used to minimise any damage or disruption to roads.
Operation		
Deliveries	Disruption to local traffic movements	Deliveries to be timed to minimise impacts on local traffic. Managed in accordance with Sydney Water's standard management practices.
Maintenance vehicles	Disruption to local traffic movements/ access restrictions.	Maintenance to be undertaken in accordance with Sydney Water's standard management practices.

8.12 Risk Assessment

An environmental risk analysis was undertaken for the Project to identify issues which warrant a detailed assessment and further discussion in this EA. The issues addressed in **Chapter 7** were not included in this risk assessment, as they were identified as key issues during the preliminary environmental assessment.

The methodology used for this process follows the general principles outlined in Australian Standard AS/NZS 4360:1999 Risk Management and Environmental Risk Management – Principles and Process (Standards Australia, 2000). The results of the risk assessment are included in **Appendix F**.

The method used for the Environmental Risk Analysis encompasses the following key steps:

1. establishment of the context for the risk analysis process
2. identification of environmental risks
3. analysis of risks.

These steps are discussed further in **Appendix F.**



Stakeholder engagement and consultation

Sydney Water has engaged with key statutory and public authority stakeholders during the preparation of this Environmental Assessment. Exhibition of the Environmental Assessment will present an opportunity for stakeholders and the community to input ideas, raise issues and provide feedback.

9.1 Consultation during Environmental Assessment preparation

9.1.1 Stakeholder consultation

Commonwealth Department of Environment and Heritage (DEH) was consulted regarding potential impacts on matters of National Environmental Significance: The consultation involved:

- a pre-referral briefing with DEH and Sydney Water on September 2006
- a referral in accordance with the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act) with DEH in September 2006

On 10 October 2006 the Commonwealth Minister for Environment and Heritage advised that the Project is not likely to have a significant impact on any matters protected under the EPBC Act and is therefore not a controlled action.

On 10 October 2006 the Commonwealth Minister for Environment and Heritage advised that the Project is not likely to have a significant impact on any matters protected under the EPBC Act and is therefore not a controlled action.

In accordance with the Environmental Assessment requirements of the Director-General of the Department of Planning (DoP), the following NSW government agencies were consulted during the preparation of the Environmental Assessment:

- Department of Environment and Conservation (DEC) – regarding potential impacts on water, noise, heritage and aquatic ecology:
  - DEC attended the Planning Focus Meeting. DEC advised the Director-General of Planning of air, water, noise and aquatic ecology issues to be considered in the Environmental Assessment through the Planning Focus Meeting process
  - DoP consolidated these issues in the Environmental Assessment requirements
  - DEC is a member of the Western Sydney Recycled Water Initiative

Project Control Group and is represented on the Metropolitan Water CEOs group.

- Department of Primary Industry (DPI) – regarding potential impacts on fisheries and primary industries:
  - DPI attended the Planning Focus Meeting. DPI advised the Director-General of Planning of issues to be considered in the Environmental Assessment through the Planning Focus Meeting process
  - DoP consolidated these issues in the Environmental Assessment requirements
  - an additional meeting was held in September 2006 with DPI to discuss the Project.
- NSW Department of Health – regarding potential health impacts:
  - Department of Health attended the Planning Focus Meeting. The Department advised the Director-General of Planning of water health issues to be considered in the Environmental Assessment through the Planning Focus Meeting process
  - DoP consolidated these issues in the Environmental Assessment requirements
  - Sydney Water has worked in conjunction with the Department of Heath in the development of the Human Health Risk Assessment. Sydney Water commissioned the study from the University of New South Wales
  - human health issues are addressed in **Chapter 7** and **Appendix D**.
- NSW Department of Natural Resources (DNR) – regarding potential impacts on the river health and riparian zones:
  - DNR attended the Planning Focus Meeting. It advised the Director-General of Planning of issues to be considered in the Environmental Assessment through the Planning Focus Meeting process
  - DoP consolidated these issues in the Environmental Assessment requirements
  - DNR is a member of the Western Sydney Recycled Water Initiative Project Control Group.
- Hawkesbury-Nepean Catchment Management Authority- regarding potential impacts on management of the catchment:
  - Hawkesbury-Nepean Catchment Management Authority attended the Planning Focus Meeting. The Authority notified the Director-General of Planning of issues to be considered in the Environmental Assessment through the Planning Focus Meeting process
  - DoP consolidated these issues in the Environmental Assessment requirements
  - Sydney Water met with the Hawkesbury Nepean Catchment Management Authority in Goulburn to present the Replacement Flows Project in the context of the *2006 Metropolitan Water Plan* and discuss in detail the catchment impacts of the proposal.
- The Sydney Catchment Authority (SCA) – regarding potential impacts on management of the catchment:
  - SCA attended the Planning Focus Meeting. SCA advised the Director-General of Planning of issues to be considered in the Environmental Assessment through the Planning Focus Meeting process

  - DoP consolidated these issues in the Environmental Assessment requirements
  - SCA is a represented on the Metropolitan Water CEOs group.
- Relevant local councils:
  - Hawkesbury and Penrith City Councils attended the Planning Focus Meeting. Both Councils advised the Director-General of Planning of issues to be considered in the Environmental Assessment. DoP consolidated these issues in the Environmental Assessment requirements
  - Sydney Water held meetings with the following local councils during the preparation of the Environmental Assessment to provide them with an awareness of the Project, specific details of potential impacts within their LGA and the strategic context of the Project:
    - Parramatta City Council
    - Penrith City Council
    - Hawkesbury City Council
    - Baulkham Hills Shire Council
    - Blacktown City Council.

  Issues discussed in the meetings included river health (water quality and quantity), waste disposal, construction impacts and notification of construction works to communities. These issues are addressed in **Chapters 7 and 8** of the Environmental Assessment.
- Key Project stakeholders:
  - Sydney Water identified and grouped stakeholders according to their information requirements. A number of stakeholders, generally local councils and affected landowners, were identified as requiring information about the Project in advance of the Environmental Assessment exhibition period. Sydney Water wrote to these groups and offered to make a detailed presentation about the Project. A number of stakeholders accepted the offer and meetings were held with the following groups:
    - Department of Energy Utilities and Sustainability – presentation of the Replacement Flows Project in the context of the *2006 Metropolitan Water Plan*
    - Western Sydney Regional Organisation of Councils - regarding an awareness of the Project and the path of the preferred route through the local council areas
    - RailCorp - regarding an awareness of the Project and the path of the preferred pipeline route across the rail corridor at two points near Seven Hills train station
    - Growth Centre Commission – regarding an awareness of the Project and the timing of the Project relevant to the development of the North and South West Growth Centres
    - Roads and Traffic Authority (RTA) – regarding the impact of the preferred route utilising RTA corridors and easements and impact on RTA roads
    - Transgrid - regarding the impact of the preferred route utilising Transgrid corridors and easements
    - Department of Housing - presentation of the Replacement Flows Project in the context of the *2006 Metropolitan Water Plan.*

Issues discussed at these meetings included access to land for construction, pipeline alternatives and construction impacts. These issues are discussed in **Chapters 3, 4 and 8** of the Environmental Assessment.

- Delfin Lend Lease – regarding the path of the preferred route around the border of the former ADI site at St Marys
- ADI Residents Action Group – as an awareness of the Project prior to advising residents of survey work to be undertaken on and around the former ADI site and with regard to the potential impacts on flora and fauna on the former ADI site during construction.

Issues discussed at these meetings included consultation timeframes, protection of heritage and culturally significant sites, construction impacts, river health (water quality and quantity) and future servicing of growth areas. These issues are addressed in **Chapters 7 and 8** and the strategic context of servicing western Sydney is covered in **Chapter 2.**

- in addition to the meetings held, letters were sent to the DPI, Integral Energy, AGL and Department of Corrective Services
- where new stakeholder groups are identified during the Environmental Assessment exhibition period, Sydney Water will offer a presentation/ meeting to provide further information about the Project and answer questions.

- Local Aboriginal Communities:
  - in accordance with DEC requirements, Sydney Water is undertaking consultation with identified local Aboriginal community groups and individuals.
  - meetings have been held with:
    - Darug Custodians Aboriginal Corporation - regarding the preferred route and potential impacts on indigenous heritage
    - Darug Aboriginal Cultural Heritage Assessments - regarding the preferred route and potential impacts on indigenous heritage
    - Darug Tribal Aboriginal Corporation - regarding the preferred route and potential impacts on indigenous heritage
    - NSW Aboriginal Land Council – on consultation and engagement processes
    - a presentation was given to twenty members of an Aboriginal and Torres Strait Islander local council network, regarding Project overview and areas of cultural significance.

  Issues discussed at these meetings included consultation timeframes, protection of heritage and cultural significant sites, construction impacts and river health (water quality and quantity). These issues are addressed in **Chapters 7 and 8**.

Stakeholder consultation is summarised in **Table 9.1**.

Table 9.1 Stakeholder consultation

Stakeholder	Date of meeting/s	Issues raised relevant to the Replacement Flows Project	How responded to in Environmental Assessment
Department of Environment and Conservation	27/7/06 (PFM) Draft copy of EA sent on 13/09/06 28/09/06	Comments received in writing on 21/09/06 Monitoring Statement of commitments	Chapters 7 and 11
Department of Primary Industries	27/7/06 (PFM) Draft copy of EA sent on 13/09/06 22/09/06	Fish migration issues and fishways Statement of commitments for additional study on fish migration	Chapters 7 and 11
NSW Department of Health	27/7/06 (PFM)	Health risk assessment Exposure pathways	Chapter 7 and Appendix D
NSW Department of Natural Resources	27/7/06 (PFM) 12/10/06	River health (water quantity and quality) and riparian zones salinity impacts of recycled water used in gardens (WSRWI)	Chapter 7 and Appendix C
Hawkesbury-Nepean Catchment Management Authority	27/7/06 (PFM) 11/9/06	River health (water quantity and quality)	Chapter 7 and Appendix C
Sydney Catchment Authority	27/7/06 (PFM) Declined further meetings	River health (water quantity and quality)	Chapter 7 and Appendix C
Hawkesbury City Council	21/7/06 27/7/06 (PFM)	River health (water quantity and quality) supply of water for irrigation Use of high quality effluent by agriculture Community	Chapters 7, 8 & Appendix C
Penrith City Council	20/7/06 27/7/06 (PFM)	River health (water quantity and quality) Construction impacts	Chapters 7, 8 & Appendix C
Parramatta City Council	25/8/06	Construction impacts, notification of constructions works to communities Traffic management issues	Chapters 7, 8 & Appendix C
Blacktown City Council	8/9/06 11/10/06	River health (water quantity and quality) South Creek volumes construction impacts, notification of constructions works to communities. Community consultation WSRWI and other local projects	Chapters 2, 7, 8 & Appendix C

Stakeholder	Date of meeting/s	Issues raised relevant to the Replacement Flows Project	How responded to in Environmental Assessment
Baulkham Hills Shire Council	18/8/06	River health (water quantity and quality), construction impacts, salinity impacts of recycled water used in outdoor areas	Chapters 7, 8 & Appendix C
Western Sydney Regional Organisation of Councils	28/8/06	River health (water quantity and quality)	Chapters 3, 4 & 8
RailCorp	30/08/06	Preferred pipeline route (across rail corridor at Seven Hills Train Station) Sufficient time for investigation of rail crossings	Chapters 3, 4 & 8
Growth Centres Commission	25/8/06	Project timeframe servicing strategy	Chapters 3, 4 & 8
RTA	13/9/06	Preferred pipeline route impact on RTA corridors, easements and roads Traffic management during construction	Chapters 3, 4 & 8
Transgrid	19/9/06	Preferred pipeline route impact on Transgrid corridors and easements Design considerations	Chapters 3, 4 & 8
Department of Energy, Utilities & Sustainability	15/8/06	Synergy with increased flows from the Nepean Ensuring irrigators needs are met River health	Chapters 7, 8 & Appendix C
Department of Housing	18/9/06	Preferred pipeline route Potential land use loss due to easements	Chapters 3, 4 & 8
Delfin Lend Lease	28/8/06	Preferred pipeline route traversing the former ADI site Strategic context of WSRWI	Chapters 2, 7 & 8
ADI Residents Action Group	2/9/06	Flora and fauna impacts on the former ADI site Impacts on South Creek Strategic context of WSRWI Development of the ADI site	Chapters 2, 7 & 8
Darug Custodians Aboriginal Corporation	4/9/06	Preferred pipeline route and potential impacts on indigenous heritage river health (water quantity and quality) consultation methodology Future surveying works	Chapters 7, 8 & Appendix C

Stakeholder	Date of meeting/s	Issues raised relevant to the Replacement Flows Project	How responded to in Environmental Assessment
Darug Aboriginal Cultural Heritage Assessments	30/8/06	Preferred pipeline route and potential impacts on indigenous heritage river health (water quantity and quality) Future surveying works	Chapters 7, 8 & Appendix C
Darug Tribal Aboriginal Corporation	30/8/06	Preferred pipeline route and potential impacts on indigenous heritage river health (water quantity and quality) Future surveying works	Chapters 7, 8 & Appendix C
NSW Aboriginal Land Council	26/9/06	Consultation requirements	Chapter 8
Parramatta Council - Aboriginal and Torres Strait Islander local council network	26/10/06	Preferred pipeline route and potential impacts on indigenous heritage river health (water quantity and quality) Consultation methodology	Chapters 7, 8 & Appendix C

Advertisements were placed in local and metropolitan papers and the Koori Mail during September 2006, inviting Aboriginal groups and individuals with an interest in the cultural and heritage values of the area to be consulted on the proposed Project path and impacts.

9.1.2 Aboriginal consultation

Aboriginal consultation is being undertaken in accordance with the *Interim Aboriginal Community Consultation Guidelines* (December 2004) and the *Draft Guidelines for Aboriginal Cultural Heritage Impact Assessment and Community Consultation* (July 2005) prepared by DEC. Advertisements were placed in local and metropolitan papers and the Koori Mail during September 2006, inviting Aboriginal groups and individuals with an interest in the cultural and heritage values of the area to be consulted on the proposed Project path and impacts. As a response to the advertisement, five submissions have been received. Consultation is ongoing and comments received from this consultation process will be incorporated into the final heritage report.

9.1.3 Community information

The community has been informed about the Replacement Flows Project in the context of the Metropolitan Water Plan through the following channels:

- Release of the *2006 Metropolitan Water Plan* in April 2006
- The *Water for Life* advertising campaign which involved raising awareness of recycled projects in western Sydney and other 2006 *Metropolitan Water Plan* initiatives through the *Water For Life* website as well as TV, radio and press promotions.

- Sydney Water undertook the following initiatives, specifically for community, information about the Replacement Flows Project:
  - a Replacement Flows Project information page was established on the Sydney Water website, www.sydneywater.com.au, in September 2006. This web page provides details about the Project, maps of the project area and diagrams and descriptions of the treatment processes. Visitors to the site can use the email link to ask questions about the Project. It provides links to the Metropolitan Water Plan and other Sydney Water recycling projects

- a range of fact sheets is available for the information of stakeholders and to download from the Sydney Water website
- a free-call number [1800 685 833] is available for general telephone enquiries about the Replacement Flows Project.

9.2 Environmental Assessment consultation

During the exhibition the public are able to review the document, attend public displays, engage with the Replacement Flows Project team and forward submissions to the DoP for consideration in its assessment of the Project.

The Environmental Assessment, including Sydney Water's draft Statement of Commitments, will be publicly exhibited by the DoP for at least 30 days, from late October 2006. During the exhibition the public are able to review the document, attend public displays, engage with the Replacement Flows Project team and forward submissions to the DoP for consideration in its assessment of the Project.

During the exhibition period, Sydney Water will provide opportunities for the community to discuss the Environmental Assessment with key members of the Replacement Flows Project team and to provide comments. Information booths will be displayed at shopping centres in areas potentially impacted upon by the proposed pipeline route, and at shopping centres in the Penrith and Blacktown local government areas. In addition, a display will also be located at Seven Hills train station to inform commuters of the Project and its potential impact on parking during pipeline construction.

At each of these displays an animated video model will provide key information, including an overview of the Project, the preferred pipeline route and key outcomes and benefits in an engaging, easy to understand format.

The dates and venues of these engagement opportunities will be advertised in local and mainstream press. In addition, the community in potentially affected areas and residents of greater Sydney will have the opportunity to comment on the Environmental Assessment via the Sydney Water website www.sydneywater.com.au

The Sydney Water website will provide opportunity for the community to ask questions, provide comment and learn more about the Project via the fact sheets and maps displayed. It will build on the preliminary website established for the Project prior to the exhibition period. In addition to further fact sheets that will be added for the exhibition period, the website will feature a link to the DoP website where visitors can make a submission on the Environmental Assessment and access the animated video model.

The DoP will evaluate the Environmental Assessment, taking into account the views of relevant Government agencies, councils and other stakeholders.

The 1800 telephone number will continue to be staffed by Replacement Flows Project team members. The website will be updated as appropriate during the exhibition period. During the exhibition period, Sydney Water will continue to work closely with the local councils to identify appropriate community events, where information about the Project can be made available.

All written comments received by the DoP will be forwarded to assist Sydney Water, the Department and the other appropriate agencies in assessing the Project and the Minister for Planning in making a determination. Sydney Water will be required to respond to relevant issues raised by the community and where appropriate, take community concerns into account to reduce impacts on the environment. The Director-General may require Sydney Water to prepare a Preferred Project Report (PPR) that outlines any proposed changes to the Project to minimise its environmental impact and any revised Statement of Commitments. If the Director-General

considers that significant changes are proposed to the nature of the project, the PPR may be made available to the public.

The DoP will evaluate the Environmental Assessment, taking into account the views of relevant Government agencies, councils and other stakeholders. The Director-General will prepare an assessment report. The recommended conditions of approval in the Director-General's assessment report will refer to the draft Statement of Commitments and may modify them and/or include additional provisions. The assessment report will be submitted to the Minister for Planning for determination of the project. The Minister's determination and the Director-General's report will be published on the DoP website within 14 days of the determination being made.

9.3 Pre-construction consultation

Opportunities would be provided for potentially affected communities to identify local issues and concerns prior to the commencement of construction to ensure that appropriate measures are put in place to mitigate local impacts. These measures would address issues such as access, local amenity, safety, traffic management and protection of local flora and fauna.

9.4 Consultation during construction

Following the commencement of construction and for the duration of the Project, Sydney Water is committed to ensuring:

- the community and stakeholders have a high level of awareness of all processes and activities associated with the Project
- provision of timely, accurate and acce ssible information
- a high level of responsiveness to issues and concerns raised by the community.

Communications processes will be developed and implemented throughout delivery of the Project. These will include:

- opportunities for the community to provide input on mitigation measures for construction or operations
- methods to inform the community of the progress and performance of the Project and issues of interest to the community
- notification of construction activities to potentially affected local residents and businesses
- processes to receive and manage complaints in accordance with the Sydney Water customer contract
- consultation with affected property owners
- induction and training of construction personnel in communication requirements
- protocols to notify stakeholders of relevant activities and any incidents should they occur.



Conclusion and justification

This chapter provides an overall summary of the impacts and benefits of the Replacement Flows Project (the Project) and provides a justification for undertaking the Project in the manner described.

10.1 Background

The Western Sydney Recycled Water Initiative is a key component of the *2006 Metropolitan Water Plan*, and the implementation of this initiative will contribute to maximising the beneficial use of recycled water for residential, industrial agricultural and environmental purposes. The Replacement Flows Project (the Project) is a major component of the Western Sydney Recycled Water Initiative and will involve the beneficial use of recycled water for environmental purposes, primarily using it to maintain flows and for the health of the Hawkesbury-Nepean River system.

The Project, in combination with other planned river management changes, has been developed and designed to ensure that the substitution of Warragamba Dam releases with highly treated recycled water would deliver an equivalent or higher level of environmental benefit to the river and would not significantly impact upon water users and the community.

The Project would operate in conjunction with other river management measures detailed in the *2006 Metropolitan Water Plan* namely, increasing environmental flow releases from the Upper Nepean Dams (Avon, Cordeaux, Cataract, Nepean), modification of the weirs in the Upper Nepean River to allow these flows to pass through the system and a limit on timing and volumes of extractions from the river by water users.

The Project, in combination with other planned river management changes, has been developed and designed to ensure that the substitution of Warragamba Dam releases with highly treated recycled water would deliver an equivalent or higher level of environmental benefit to the river and would not significantly impact upon water users and the community.

The following sections present a summary of the benefits and impacts of the Project and justification of the Project in consideration of the *2006 Metropolitan Water Plan*.

10.2 Impacts of the Project

10.2.1 Warragamba River

The new Wallacia Sewage Treatment Plant (STP) is designed to discharge 1.35 ML/day of tertiary treated effluent into the Warragamba River immediately downstream of the existing release point of flows from Warragamba Dam. With the cessation of the flow releases from Warragamba Dam, the discharge from the STP would no longer be diluted and there is the potential for nutrient accumulation and resulting eutrophication in the section of the river downstream of the STP discharge. Additional mitigation measures would be required to ensure that this section of the river is not adversely impacted upon by the combined effects of the cessation of flow release from Warragamba Dam and the STP discharge. Sydney Water has commissioned additional studies to develop options to mitigate impacts of the discharge of Wallacia STP to acceptable levels. The environmental assessment of any options developed in relation to Wallacia STP would be undertaken through a separate planning and approvals process.

10.2.2 Hawkesbury-Nepean River

Due to the combined effects of the increased flow releases from the Upper Nepean Dams, proposed weir modifications, protection of dry weather flows from extraction and the Project, there would be changes in flows in the Hawkesbury-Nepean River. In the majority of locations and for most flow conditions, flow volumes would increase.

However, the reach of the Hawkesbury-Nepean River between the Warragamba River inflow and Penrith Weir would experience a minor decrease in flow volumes during very low flows. During these conditions (>95th percentile flow) in 2009 there would be a slight decrease in flows (38.7 ML/day) in the Hawkesbury-Nepean River near the confluence with Warragamba River, compared with the non-drought baseline condition (43 ML/day). However, towards Penrith Weir very low flows in 2009 (67 ML/day) would be slightly higher than the baseline condition (62 ML/day) due to the reduction in irrigation extractions. Overall, the change in very low flows in this section of the Hawkesbury-Nepean River is minor and would not result in any changes to the riparian zone, water quality and aquatic ecology.

The level of treatment for the recycled water prior to discharge to the Hawkesbury-Nepean River at Penrith would ensure no increase in risk to public health from pathogens and chemicals.

The level of treatment for the recycled water prior to discharge to the Hawkesbury-Nepean River at Penrith would ensure no increase in risk to public health from pathogens and chemicals.

South Creek flows into the Hawkesbury-Nepean River downstream of Penrith Weir where it contributes to a freshwater tidal pool. A reduction in flows in South Creek as a result of the Project would cause a decrease in the volume of water flowing into the freshwater tidal pool from South Creek in dry weather. However, the freshwater tidal pool is not dependent on dry weather flows to maintain water levels. The vast majority of water in the freshwater tidal pool is from large wet weather inflows which are trapped behind the saline estuarine water, rather than from dry weather catchment flows and STP discharges. Any reduction in flows into the freshwater tidal pool from South Creek would be compensated for by the increased flows from the Nepean River upstream of Yarramundi.

10.2.3 South and Eastern Creeks

Tertiary treated effluent would be diverted from Quakers Hill and St Marys STP as a result of the Project, reducing flows in 2009 in the creeks from 64 to 19 ML/day, returning it to a more natural flow regime. Nonetheless, STP discharges would still dominate low flow conditions. Despite reductions in flow, no change in aquatic ecosystems is expected below St Marys (South Creek) and Quakers Hill (Eastern Creek) STPs.

The reduced STP discharges would result in an increase in phosphorus concentrations in South and Eastern Creek. Catchment runoff contributes considerable loads of phosphorus to the creeks upstream of the STPs. The reduced STP discharges would no longer have the same diluting effect on phosphorus concentrations in the creeks and consequently the concentration of phosphorus would increase slightly.

10.2.4 Construction Impacts

The construction of the Project may result in both minor and temporary impacts upon the environment and community, although the locations of the works, especially the pipeline routes, were selected to minimise these impacts.

The Project may cause temporary effects on the local amenity including noise, dust and access impacts. These impacts would be minimised using appropriate mitigation measures and procedures.

Some minor clearing of vegetation would be required at the Advanced Water Treatment Plant (AWTP) site and at some locations along the pipeline routes. This vegetation is not considered of conservation significance and therefore the impact would be negligible. Disturbance of any significant or threatened vegetation would be avoided through boring under remnant vegetation (eg at creek crossings) or modifying the design to avoid this vegetation.

Some minor clearing of vegetation would be required at the Advanced Water Treatment Plant (AWTP) site and at some locations along the pipeline routes. This vegetation is not considered of conservation significance and therefore the impact would be negligible.

A number of indigenous and European heritage sites may be potentially affected by the construction of the pipelines. In these locations, after additional consultation with relevant stakeholders, construction methodologies or the detailed design may be modified to avoid impacts, or appropriate approvals sought to move or destroy heritage items (if they are not significant).

Other mitigation measures to minimise construction impacts on the environment (eg sediment and erosion control) would also be implemented.

Overall, the impacts of the construction on the environment and community would be minor or negligible and would be managed using standard measures.

10.3 Benefits of the Project

The Project would have greatest potential effect on water quality in reaches of the Hawkesbury-Nepean River downstream of Penrith Weir. The concentrations and loads of nitrogen species in the Hawkesbury-Nepean River and the loads of nutrients entering South and Eastern Creeks would be reduced. Total nitrogen loads discharged downstream of Penrith Weir would decrease by 14 per cent and total phosphorus loads would decrease by about 75 per cent, compared with the current levels. In combination with increased water flows this decrease in loads would also result in water quality concentrations of key nutrients decreasing substantially.

The Project would have a long reaching beneficial effect on water quality, particularly with respect to nitrogen species, with improvements in water quality persisting downstream of South Creek and continuing to Sackville. Phosphorus concentrations would be largely unaffected by the Project in the majority of river reaches.

The improved water quality would lead to a reduction in the potential for excessive water weed growth and algal blooms in the Hawkesbury Nepean River from Penrith to Yarramundi and from the South Creek junction to Sackville and beyond. This would, in turn, improve recreational opportunities in those parts of the river.

The Project, in conjunction with the Upper Nepean Dam releases, would generally increase the variability of flows in the river system. The improvements in water quality and quantity may also lead to improved conditions for native fish, macroinvertebrates and native aquatic flora.

The overall outcomes of the Project and Upper Nepean Dam releases are predicted to be:

- in normal conditions (non drought), greater flows in all stretches of the Hawkesbury-Nepean River upstream of the South Creek junction
- in normal conditions (non drought), an increase in the proportion of catchment derived flows throughout the Hawkesbury-Nepean system
- significant reduction in nutrient loads discharged to the Nepean River at Penrith due to the improved water quality of replacement flows compared with tertiary treated effluent
- significant reductions in the nutrient loads discharged into South Creek due to reduced discharge of effluent from STPs.

10.4 Justification for the Project

The Environmental Assessment has confirmed that the Replacement Flows Project, in combination with other planned river management changes, would ensure that the substitution of Warragamba Dam releases would deliver an equivalent or higher level of environmental benefit to the river and retain up to an additional 50ML/day (18 billion litres per year) in Warragamba Dam.

This outcome is in accordance with the Project objectives, which are to:

- save up to 18 billion litres per year of current Warragamba Dam discharges by providing high quality recycled water to the Nepean River as a replacement for existing Warragamba Dam releases
- reduce the discharge of nutrients from Penrith, Quakers Hill and St Marys STPs into the Hawkesbury-Nepean River and South Creek
- maintain appropriate flows for irrigation
- ensure environmental values are maintained – including aquatic ecosystems, primary industries, recreation and aesthetics and drinking water.

Minimising costs to the community and environment were key criteria that determined how the Warragamba Dam releases would be substituted by replacement flows to enable the additional drinking water to be retained in Warragamba Dam.

The Project would contribute to achieving the objectives of the *2006 Metropolitan Water Plan* which are to provide a secure supply of water that can meet the long term needs of Sydney, ensure that water supplies are adequate during drought, and minimise costs to the community and the environment. Minimising costs to the community and environment were key criteria that determined how the Warragamba Dam releases would be substituted by replacement flows to enable the additional drinking water to be retained in Warragamba Dam.

The project concept and details of project components were selected to contribute to providing a secure supply of water in the long term, whilst ensuring that existing environmental (and social) values would not be affected by the project.

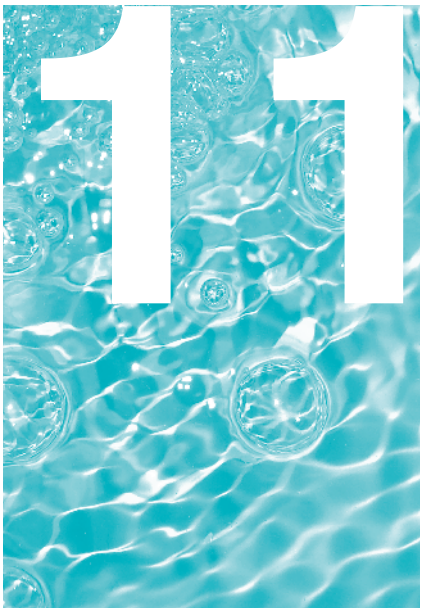
The implementation of the Project, in conjunction with the other strategies outlined in the *2006 Metropolitan Water Plan*, would further alleviate current demand pressures placed on Sydney's domestic water supply to meet the long term water needs of Sydney.

10.5 Conclusion

The replacement of environmental flows from Warragamba Dam with highly treated recycled water released downstream of Penrith Weir has been shown to be feasible and to provide a generally neutral or beneficial effect on river health. The implementation of the Project will contribute to achieving the *2006 Metropolitan Water Plan objectives*.

The Project can proceed with minimal environmental and social impact if the detailed mitigation measures proposed are implemented.

Practical measures would be implemented to mitigate any potential effects. The Project can proceed with minimal environmental and social impact if the detailed mitigation measures proposed are implemented. The Project would be carried out in accordance with the draft Statement of Commitments, which provides the environmental management framework for the project.



Draft statement of commitments

In accordance with Part 3A of the *Environmental Planning and Assessment Act 1979,* this chapter provides the draft Statement of Commitments for the Replacement Flows Project (the Project).

11.1 Overview

Following project approval, Sydney Water and its contractors will be required to deliver and operate the Project in accordance with these commitments.

The Environmental Assessment of the Project has identified measures to manage any potential impacts associated with the Project. These have been identified in **Chapters 7** and **8** and have been developed as commitments that would avoid or reduce potential effects of the Replacement Flows Project. This Chapter provides the draft Statement of Commitments for the Project. The draft will be finalised in response to stakeholder and community input during the display of the Environmental Assessment. Following project approval, Sydney Water and its contractors will be required to deliver and operate the Project in accordance with these commitments.

11.2 Draft commitments

The draft Statement of Commitments, including commitments relating to key issues and other issues, are provided in **Table 11.1** and **Table 11.2.**

The Statement of Commitments includes:

- commitment topic
- commitment statement
- relevant project phase.

Table 11.1 Draft statement of commitments: key issues

Water quality and water cycle management		Project phase
1.	A monitoring program to assess the impacts of the Project on river health (including water quality and flow) would be undertaken in conjunction with the new NSW State Government integrated water monitoring framework for the Hawkesbury-Nepean.	Operation
2.	Management of the concentrate, including the advanced water treatment plant (AWTP) and storages, would ensure there is no discharge of concentrate to the Hawkesbury-Nepean River including South Creek catchment, unless there is a significant incident or emergency or as otherwise agreed with DEC and to ensure that there is no increase in overflow frequencies from the NSOOS.	Operation
3.	Existing monitoring programs at North Head Sewage Treatment Plant (STP), as part of licence requirements, would continue over the life of the Project. Any changes in pollutant levels attributable to the AWTP concentrate would be detectable and appropriately addressed.	Operation
4.	Sydney Water would enhance predictive modelling of impacts associated with the Project to assist in the adaptive management of the river. Negotiation with relevant agencies in relation to an overall model for the Hawkesbury-Nepean River would be undertaken to identify appropriate roles and ownership.	Operation
5.	Sydney Water would continue investigations to establish a sustainable solution to maintain acceptable water quality in the Warragamba River.	Operation
6.	A suitable volume of effluent would continue to be released from the St Marys and Quakers Hill STPs to ensure that current irrigation users downstream of these plants are not disadvantaged by the operation of the Project.	Operation
Ecology		Project phase
7.	A monitoring program to assess the impacts of the Project on aquatic ecology, as outlined in Chapter 7, would be undertaken in conjunction with the new NSW State Government integrated water monitoring framework for the Hawkesbury-Nepean.	Operation
8.	An ecotoxicological study will be undertaken as part of the pilot testing program, to assess the impacts of replacement flows on aquatic species.	Operation
9.	A study would be undertaken in consultation with Department of Primary Industries (Fisheries) to determine whether the discharge of the Replacement Flows Project would result in changes to the natural fish migration upstream across Penrith Weir. Based on outcomes of this study appropriate design and other mitigation measures would be developed.	Pre-design
10.	No degradation of bed or bank stability would occur within Boundary stream downstream of Penrith STP as a result of the Project	Design, Construction & Operation
11.	All feasible and reasonable measures would be undertaken to minimise the impact of construction on vegetation. Vegetation clearance would be kept to a minimum. Infrastructure would be designed to avoid significant flora species and communities.	Construction
12.	All feasible and reasonable measures would be undertaken to minimise the impact of construction on fauna. Disturbance to native fauna would be kept to a minimum. Infrastructure would be designed to avoid significant fauna habitat areas.	Construction

13.	A range of mitigation measures would be implemented, including: • construction compounds, access tracks, stockpiles and storage areas to be located on previously cleared areas, away from watercourses • management procedures to be implemented to prevent the spread of noxious weeds • the construction area to be minimised and areas of vegetation fenced off to avoid incidental disturbance • all revegetation works to be undertaken with locally native species.	Construction & operation
Human health		Project phase
14	The reverse osmosis membranes would be monitored at pilot scale to determine the efficacy of the membranes to remove chemicals.	
15.	Sydney Water's existing monitoring program would continue to assess the quality of drinking water against the National Health and Medical Research Council guidelines.	Operation
16.	On-going refinement of the risk assessment would be undertaken, based on long-term performance data of the full-scale plant, combined with detailed studies of river water users.	Operation
17.	Further studies arising from the Health Risk Assessment would be implemented in consultation with the NSW Health.	Operation
Noise and vibration		Project phase
18.	All feasible and reasonable measures would be undertaken to minimise the impact of construction noise on sensitive receivers.	Construction
19.	All feasible and reasonable measures would be undertaken to minimise the impact of vibration on sensitive receivers.	Construction
20	Mitigation measures would be implemented, including: • generally limiting construction works where noise is audible at residential premises to between 7am to 6pm Monday to Friday and 8am to 1pm on Saturday unless otherwise approved by DEC. Night-work may also be required for construction of the pipelines, where they cross major roads or intersections, to minimise disruption of local and through traffic • minimising the noise generated by construction activities through construction planning and plant selection, use of mufflers, shrouds and appropriate maintenance • notification of adjacent residents prior to commencement of construction works • implementation of complaints management system so issues associated with excessive noise generation can be identified and resolved • designing the AWTP building to ensure the operation of the plant meets the noise criteria outlined in the NSW INP (NSW EPA 2000). • enclosing the pumping stations to aid in noise attenuation	Construction & operation
Waste generation		Project phase
21.	Wastes would be minimised. Reuse and recycling would be optimised. Wastes would be disposed of in accordance with appropriate guidelines.	Construction & operation

22	A range of mitigation measures would be implemented including: • waste to be managed in accordance with the Waste Avoidance and Resource Recovery Act 2001and EPA 1999 guidelines • spoil reuse opportunities to be investigated • vegetation clearing to be kept to a minimum. Composting or mulching options to be investigated • preferential purchase of materials with minimal packaging/ higher recycled content • accurate ordering and careful handling to minimise breakage/ wastage • asbestos containing materials to be handled and removed by a suitably licensed contractor and disposed of in accordance with DEC guidelines	Construction & operation

Table 11.2 Draft statement of commitments: other issues

Soils and surface water		Project phase
23.	Appropriate sediment and erosion control measures would be developed, implemented and maintained so the exposure of soils is not expected to have a significant effect on downstream water quality or the aquatic environment.	Construction
24.	Boring techniques would be used, where practicable, to cross under creeks.	Construction
25.	Any areas identified as affected by soil salinity would be appropriately managed and potential impacts mitigated.	Construction
26.	Soils would be appropriately classified and disposed of in accordance with appropriate DEC guidelines.	Construction
27	A range of mitigation measures would be implemented including: • contaminated soil identified on site to be classified and managed in accordance with the DEC Environmental Guidelines • contaminated waste and asbestos to be transported in accordance with POEO (Waste) Regulation • maintenance of spill kit on site • dewatering, installation and maintenance of erosion and sedimentation controls to be undertaken in accordance with Managing Urban Stormwater Guidelines (Landcom 2005) • containment and treatment of liquids resulting from dewatering in line with provisions of the POEO Act • contaminated water to be removed and disposed of to appropriate waste management facility	Construction
Hazards		Project phase
28.	Chemicals would be used and stored in accordance with appropriate guidelines.	Construction and Operation
29	A range of mitigation measures would be implemented including: • vehicles and equipment to be refuelled off site where possible. Where unavoidable mini-tanks to be used for refuelling • workforce trained in appropriate handling procedures • unloading of Class 8 substances only within designated bunded areas • spill kit maintained adjacent to unloading facilities • storage in accordance with AS1940	Construction and Operation

Heritage		Project phase
30.	Indigenous and non-indigenous cultural heritage values would be protected along infrastructure routes and at temporary construction sites. Known significant sites will be avoided where appropriate.	Construction
31	A range of mitigation measures to be implemented including: • ongoing consultation with Aboriginal groups to determine management options for artefacts • boring beneath the PADs. If this is not feasible an archaeological investigation may be undertaken by an appropriately qualified archaeologist prior to works commencing • for the two AMUs, monitoring by appropriately qualified archaeologist during construction	Construction
Land use and property		**Project phase**
32	All feasible and reasonable measures would be undertaken to minimise impacts on land use, services and utilities and private property..	Construction
33	A range of mitigation measures to be implemented including: • consultation with affected property owners prior to works commencing • all services to be located prior to commencement of works. Notification of service providers of proposed works • rehabilitation of the land to former use on completion	Construction and operation
Visual amenity		**Project phase**
34	Construction work sites would be rehabilitated progressively	Construction
35	A range of mitigation measures would be implemented including: • maintenance of existing vegetation screening along STP boundaries • progressive rehabilitation of pipeline route • construction works limited on weekends and outside of normal work hours • storage of major construction equipment away from open areas	Construction and operation
Air quality		
36.	All feasible and reasonable measures would be undertaken to minimise the impact of dust on sensitive receivers.	Construction
37	Concentrate odour generation potential would be evaluated as part of the pilot testing program, in relation to the potential for odour impacts from the concentrate storage pond at Quakers Hill STP.	Operation
38	A range of mitigation measures to be implemented including: • appropriate dust control measures comprising: - limiting area of cleared land - revegetation on completion - damping down exposed surfaces - limiting height of stockpiles - covering spoil truck loads. • demolition of buildings containing asbestos sheeting to be undertaken by a suitably licensed contractor • maintenance of vehicles and construction equipment	Construction and operation

Traffic		Project phase
39.	Disturbances to traffic and access would be minimised whenever and wherever practical.	Construction
40	A range of mitigation measures would be implemented including: • consultation with RTA, local government and public transport service providers regarding works that may impact roads or traffic • consultation with impacted property owners to maintain access during construction and notification of activities prior to commencement • construction activities to be restricted to 7am to 6pm Monday to Friday and 8am to 1pm on Saturday, unless otherwise approved by DEC • night-work may be undertaken for construction of the pipelines, where they cross major roads or intersections, to minimise traffic impacts • construction traffic management for the Project to include: - Provision of construction worker parking within the STP sites to prevent parking problems on surrounding roads - trucks avoiding residential streets where possible - timing of truck movements to avoid peak periods to minimise local traffic congestion where possible - routes to disposal/reuse facilities to be clearly defined with consideration of road capacity and current traffic volumes - road diversions and traffic management activities would be undertaken by qualified traffic controllers.	



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Appendix A

Land tenure and zoning



Appendix A –Land Tenure and Zoning

Refer to Figures A1a-d and A2a-d of this Appendix for property identification numbers. Land zoning is shown in Figures A3a-d and A4a-d.

Table 1 – Effluent Transfer Pipeline (Penrith STP to Quakers Hill STP)

Property Identification Number	Lot	DP	Parish	County	Owner	Local Government Area
1	110	774782	Castlereagh	Cumberland	Water Board	Penrith
2	2	785029	Castlereagh	Cumberland	The Council of the City of Penrith	Penrith
3	2	1036562	Castlereagh	Cumberland	Roads and Traffic Authority of New South Wales	Penrith
4	1673	811688	Castlereagh	Cumberland	The Council of the City of Penrith	Penrith
5	1	262235	Castlereagh	Cumberland	The Council of the City of Penrith	Penrith
6	5	262235	Castlereagh	Cumberland	The Council of the City of Penrith	Penrith
7	Andrews Road					Penrith
8	The Northern Road					Penrith
9	1	1079444	Londonderry, Rooty Hill	Cumberland	St Marys Land Limited	Penrith, Blacktown
10	Links Road					Penrith, Blacktown
11	1	223888	Rooty Hill	Cumberland	The Metropolitan Water Sewerage and Drainage Board	Penrith, Blacktown
12	1	31910	Rooty Hill	Cumberland	The Metropolitan Water Sewerage and Drainage Board	Penrith, Blacktown
13	Links Road					Penrith, Blacktown
14	Forrester Road					Blacktown

Property Identification Number	Lot	DP	Parish	County	Owner	Local Government Area
15	Palmyra Avenue					Blacktown
16	177	246359	Rooty Hill	Cumberland	Minister Administering the Environmental Planning and Assessment Act 1979	Blacktown
17	459	246355	Rooty Hill	Cumberland	Minister Administering the Environmental Planning and Assessment Act 1979	Blacktown
18	1	249166	Rooty Hill	Cumberland	The Housing Commission of New South Wales	Blacktown
19	49	262886	Rooty Hill	Cumberland	Roads and Traffic Authority	Blacktown
20	Hammerli Road					Blacktown
21	Tout Road					Blacktown
22	481	634363	Rooty Hill	Cumberland	Roads and Traffic Authority	Blacktown
23	1	792478	Rooty Hill	Cumberland	Minister Administering the Environmental Planning and Assessment Act 1979	Blacktown
24	Richmond Road					Blacktown
25	4	976148	Gidley	Cumberland	Roads and Traffic Authority of New South Wales	Blacktown
26	3	976148	Gidley	Cumberland	Roads and Traffic Authority of New South Wales	Blacktown
27	20	594358	Gidley	Cumberland	Roads and Traffic Authority of New South Wales	Blacktown
28	11	1048332	Gidley	Cumberland	Roads and Traffic Authority of New South Wales	Blacktown
29	41	606811	Gidley	Cumberland	The Commissioner for Main Roads	Blacktown
30	A	416811	Gidley	Cumberland	Roads and Traffic Authority of New South Wales	Blacktown
31	B	416811	Gidley	Cumberland	Roads and Traffic Authority of New South Wales	Blacktown
32	C	416811	Gidley	Cumberland	Roads and Traffic Authority of New South Wales	Blacktown
33	61	777770	Gidley	Cumberland	Roads and Traffic Authority of New South Wales	Blacktown
34	M7 Motorway				Roads and Traffic Authority of New South Wales	Blacktown
35	509	708140	Gidley	Cumberland	The Council of the City of Blacktown	Blacktown

Property Identification Number	Lot	DP	Parish	County	Owner	Local Government Area
36	299	701163	Gidley	Cumberland	The Council of the City of Blacktown	Blacktown
37	1	634220	Gidley	Cumberland	Roads and Traffic Authority of New South Wales	Blacktown
38	1	594263	Gidley	Cumberland	The Commissioner for Main Roads	Blacktown
39	Symonds Road					Blacktown
40	6	31178	Gidley	Cumberland	Minister Administering the Environmental Planning and Assessment Act 1979	Blacktown
41	19	4971	Gidley	Cumberland	Minister Administering the Environmental Planning and Assessment Act 1979	Blacktown
42	18	4971	Prospect	Cumberland	Minister Administering the Environmental Planning and Assessment Act 1979	Blacktown
43	1	1042105	Prospect	Cumberland	Minister Administering the Environmental Planning and Assessment Act 1979	Blacktown
44	Quakers Hill Parkway					Blacktown
45	60	773002	Prospect	Cumberland	The Council of the City of Blacktown	Blacktown
46	1	1029672	Prospect	Cumberland	Sydney Water Corporation	Blacktown

Table 2 – Concentrate Pipeline (Seven Hills to Dundas)

Property Identification Number	Lot	DP	Parish	County	Owner	Local Government Area
1	D	36666	Prospect	Cumberland	The Council of the City of Blacktown	Blacktown
2	1	1002415	Prospect	Cumberland	Rail Corporation of NSW	Blacktown
3	B	36093	Prospect	Cumberland	The Council of the City of Blacktown	Blacktown
4	200	203575	Prospect	Cumberland	The Council of the City of Blacktown	Blacktown
5	121	35876	Prospect	Cumberland	The Council of the City of Blacktown	Blacktown

6	1	35876	Prospect	Cumberland	Housing Commission of NSW	Blacktown
7	1	1016522	Prospect	Cumberland	Rail Corporation NSW	Blacktown, Holyroyd & Parramatta
8	Station Road					Parramatta
9	57	29128	Prospect	Cumberland	The Council of the City of Parramatta	Parramatta
10	17-20	8408	Prospect	Cumberland	The Council of the City of Parramatta	Parramatta
11	2	574582	Prospect	Cumberland	The Council of the City of Parramatta	Parramatta
12	28-32	8408	Prospect	Cumberland	The Council of the City of Parramatta	Parramatta
13	24	243410	Prospect	Cumberland	The Council of the City of Parramatta	Parramatta
14	48	245140	St John	Cumberland	The Council of the City of Parramatta	Parramatta
15	1	42694	St John	Cumberland	The Council of the City of Parramatta	Parramatta
16	49	245140	St John	Cumberland	The Council of the City of Parramatta	Parramatta
17	4	589814	Prospect	Cumberland	The Council of the City of Parramatta	Parramatta
18	155	259861	Prospect	Cumberland	The Council of the City of Parramatta	Parramatta
19	13	246608	Prospect	Cumberland	The Council of the City of Parramatta	Parramatta
20	89	237372	Prospect & St John	Cumberland	The Council of the City of Parramatta	Parramatta
21	88	237372	St John	Cumberland	The Council of the City of Parramatta	Parramatta
22	7020	1028265	St John	Cumberland	The Council of the City of Parramatta	Parramatta
23	Old Windsor Road					Parramatta
24	22	1071654	St John	Cumberland	Roads and Traffic Authority of New South Wales	Parramatta
25	10	264580	St John	Cumberland	Roads and Traffic Authority of New South Wales	Parramatta
26	21	1071654	St John	Cumberland	Private Owner	Parramatta
27	22	248267	St John	Cumberland	Private Owner	Parramatta

28	21	248267	St John	Cumberland	Private Owner	Parramatta
29	58B	421208	St John	Cumberland	Private Owner	Parramatta
30	58A	421208	St John	Cumberland	Roads and Traffic Authority of New South Wales	Parramatta
31	9	632567	St John	Cumberland	Roads and Traffic Authority of New South Wales	Parramatta
32	61	12346	St John	Cumberland	Roads and Traffic Authority of New South Wales	Parramatta
33	10	632567	St John	Cumberland	Roads and Traffic Authority of New South Wales	Parramatta
34	Hammers Road					Parramatta
35	39	207197	St John	Cumberland	Integral Energy Australia	Parramatta
36	40	207197	St John	Cumberland	The Council of the City of Parramatta	Parramatta
37	7011	1028212	St John	Cumberland	The Council of the City of Parramatta	Parramatta
38	Kleins Road					Parramatta
39	7001	1028209			The Council of the City of Parramatta	Parramatta
40	1	86836	St John	Cumberland	Hillsbus Co Pty Ltd	Parramatta
41	1	734689	Field of Mars	Cumberland	Department of Corrective Services	Parramatta
42	1	618753	Field of Mars	Cumberland	Parramatta Linen Service	Parramatta
43	69	526125	Field of Mars	Cumberland	Private Owner	Parramatta
44	1	128124	Field of Mars	Cumberland	Carpeteria (NSW) Pty Ltd	Parramatta
45	1	724342	Field of Mars	Cumberland	The Council of the City of Parramatta	Parramatta
46		CL RD	Field of Mars	Cumberland	The Council of the City of Parramatta	Parramatta
47	Belmore Street					Parramatta
48	7	RCK FARM EST	Field of Mars	Cumberland	The Council of the City of Parramatta	Parramatta
49	8	RCK	Field of Mars	Cumberland	The Council of the City of Parramatta	Parramatta

		FARM EST				
50	38	203042	Field of Mars	Cumberland	The Council of the City of Parramatta	Parramatta
Alternative Route (Powers Road)						
2a	1	634841	Prospect	Cumberland	The Council of the City of Blacktown	Blacktown
3a	2	634841	Prospect	Cumberland	The Council of the City of Blacktown	Blacktown
4a	1	617806	Prospect	Cumberland	The Council of the City of Blacktown	Blacktown
5a	32	828295	Prospect	Cumberland	The Council of the City of Blacktown	Blacktown
6a	2	617806	Prospect	Cumberland	The Council of the City of Blacktown	Blacktown

Note: Title information is based on Land and Property Information New South Wales – Title Searches conducted on or after the 03/07/06.

Figure A1a Affected land and property details

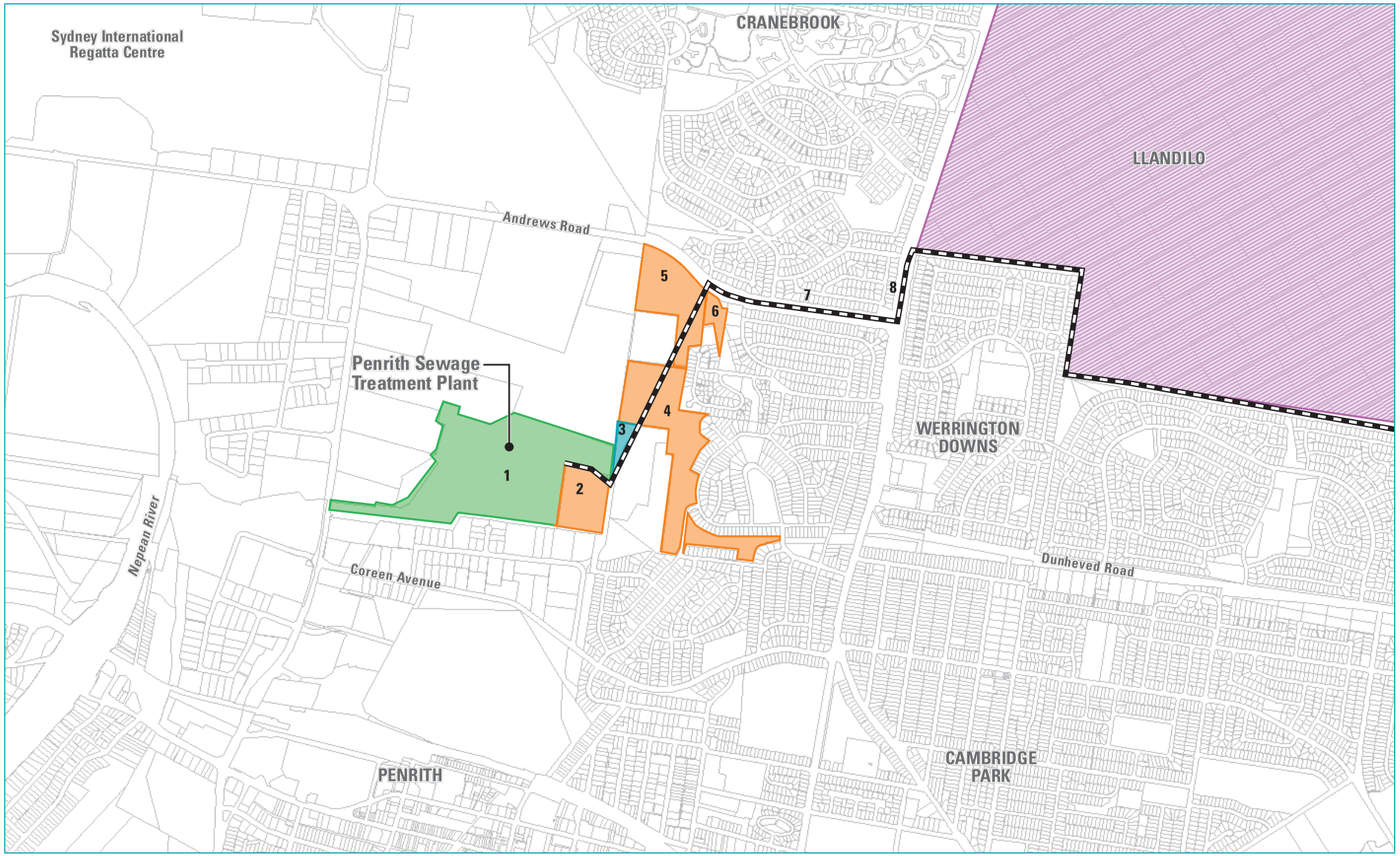


Figure A1b Affected land and property details

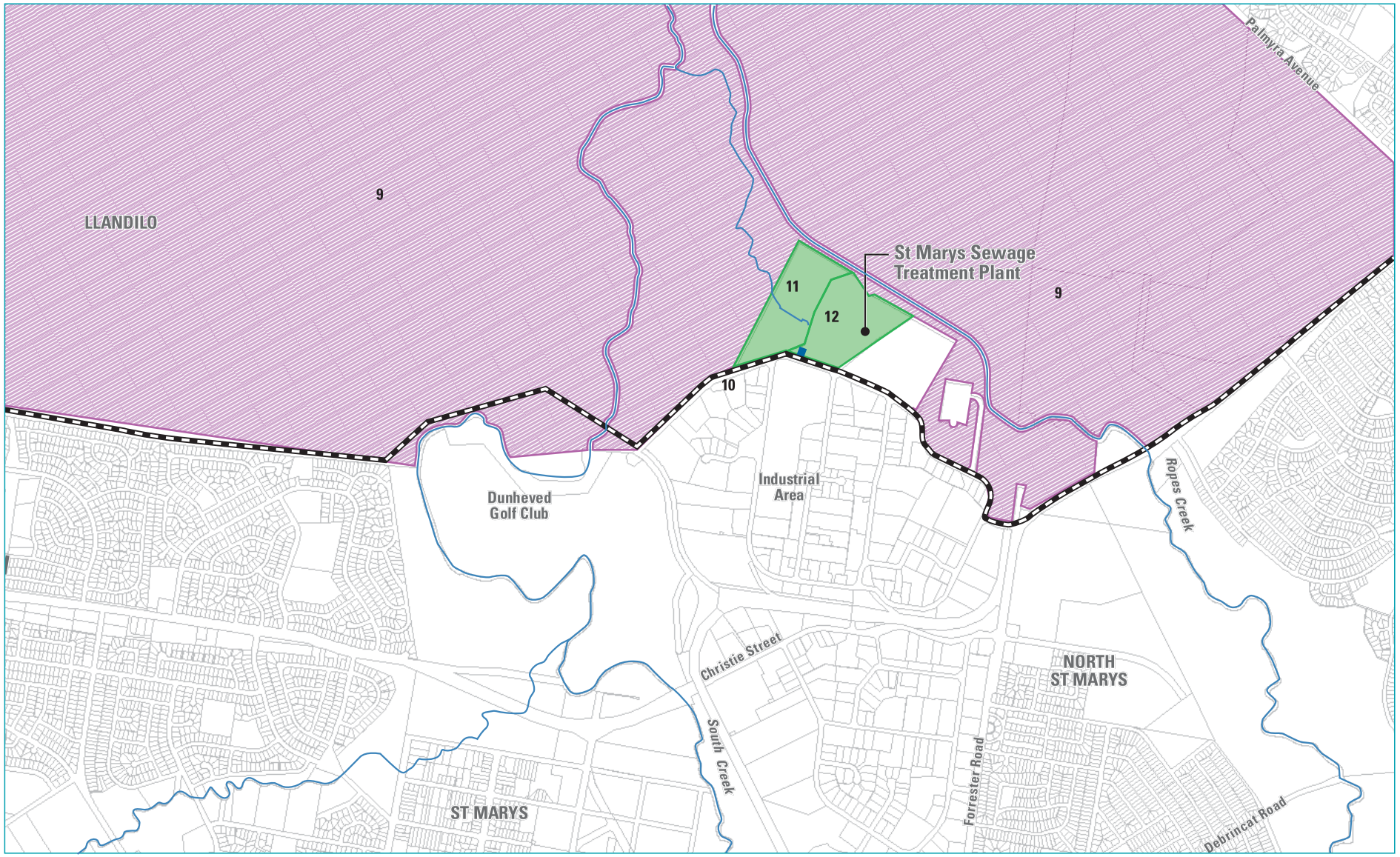


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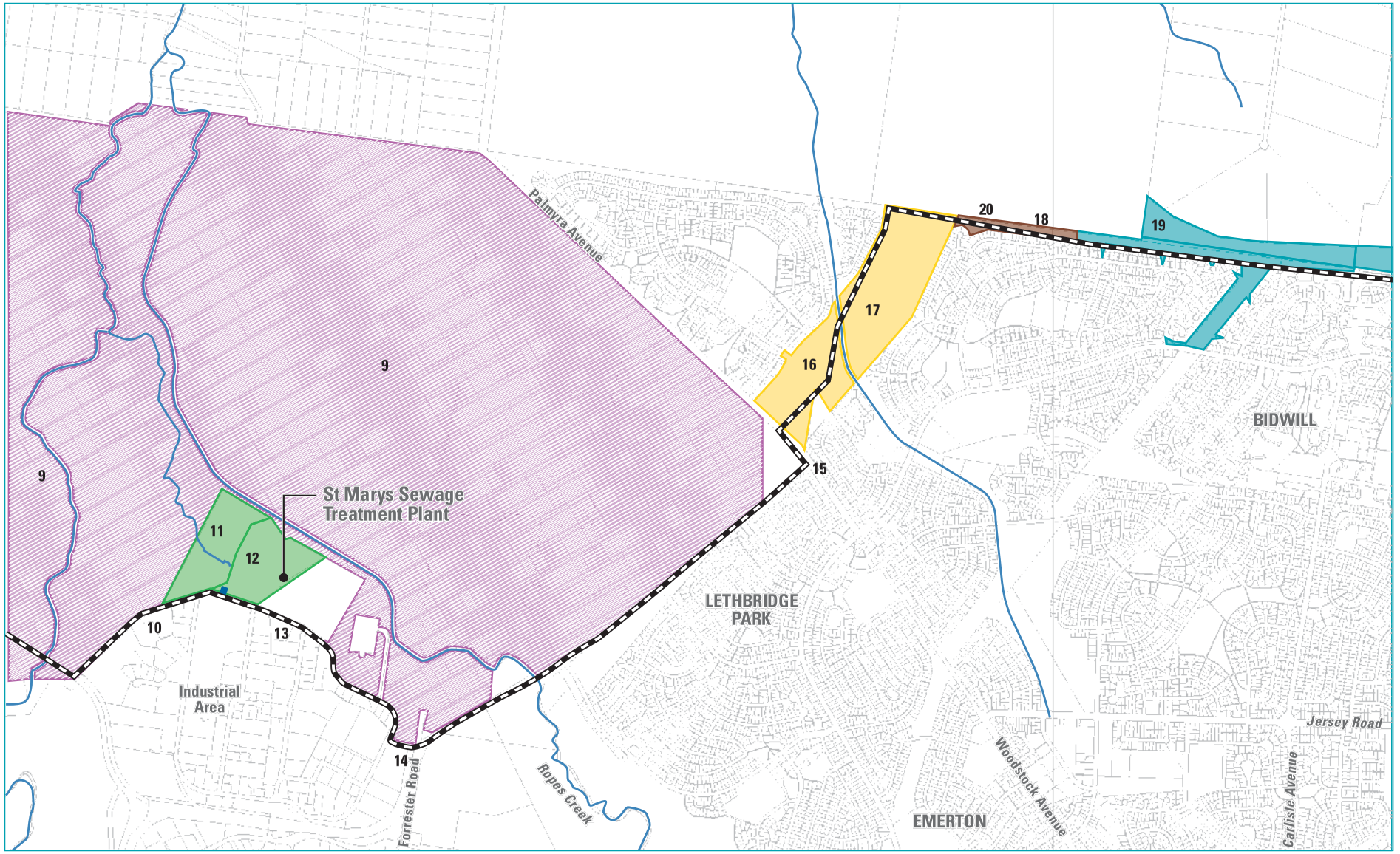


Figure A1d Affected land and property details

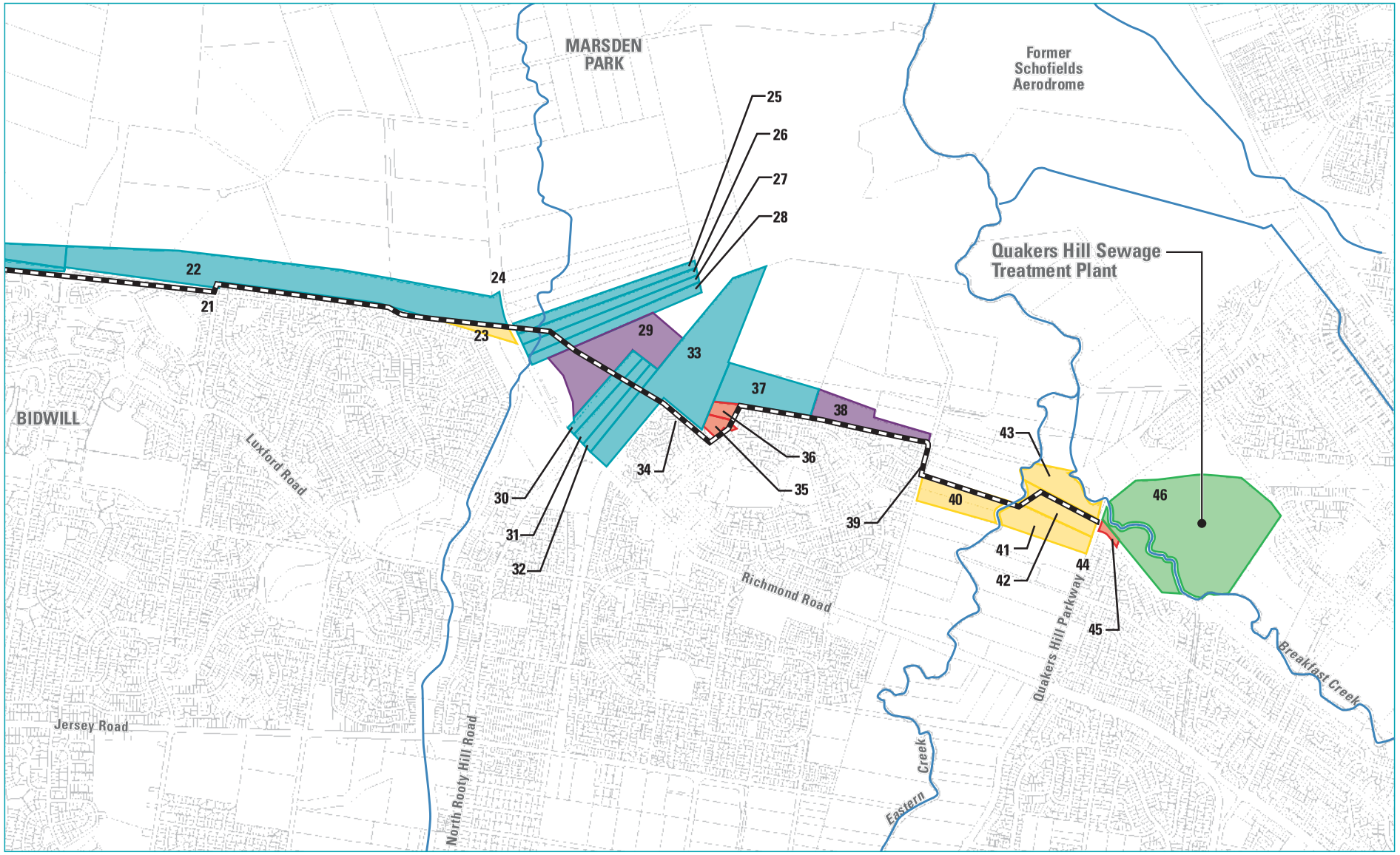


Figure A2a Affected land and property details



Figure A2b Affected land and property details

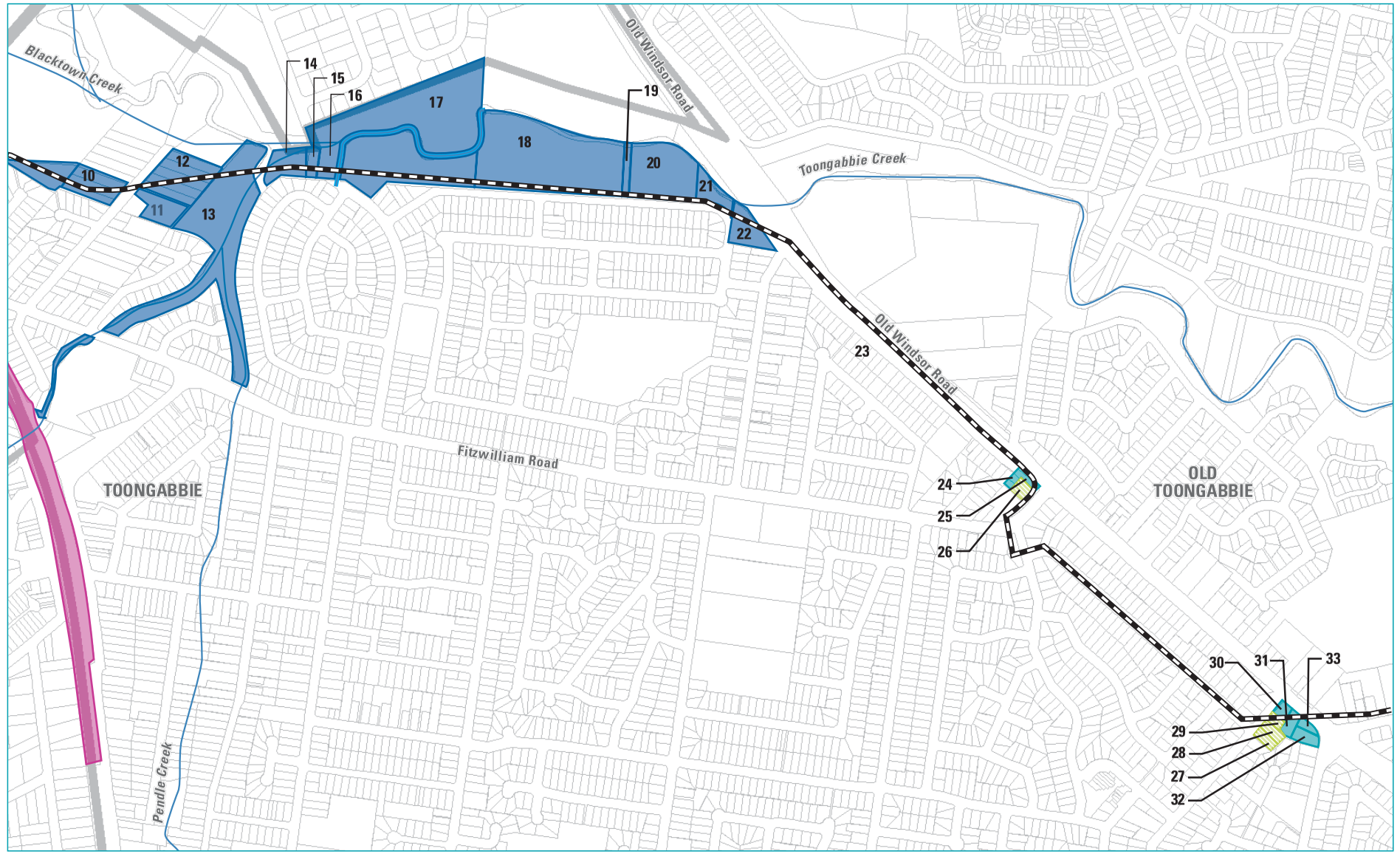


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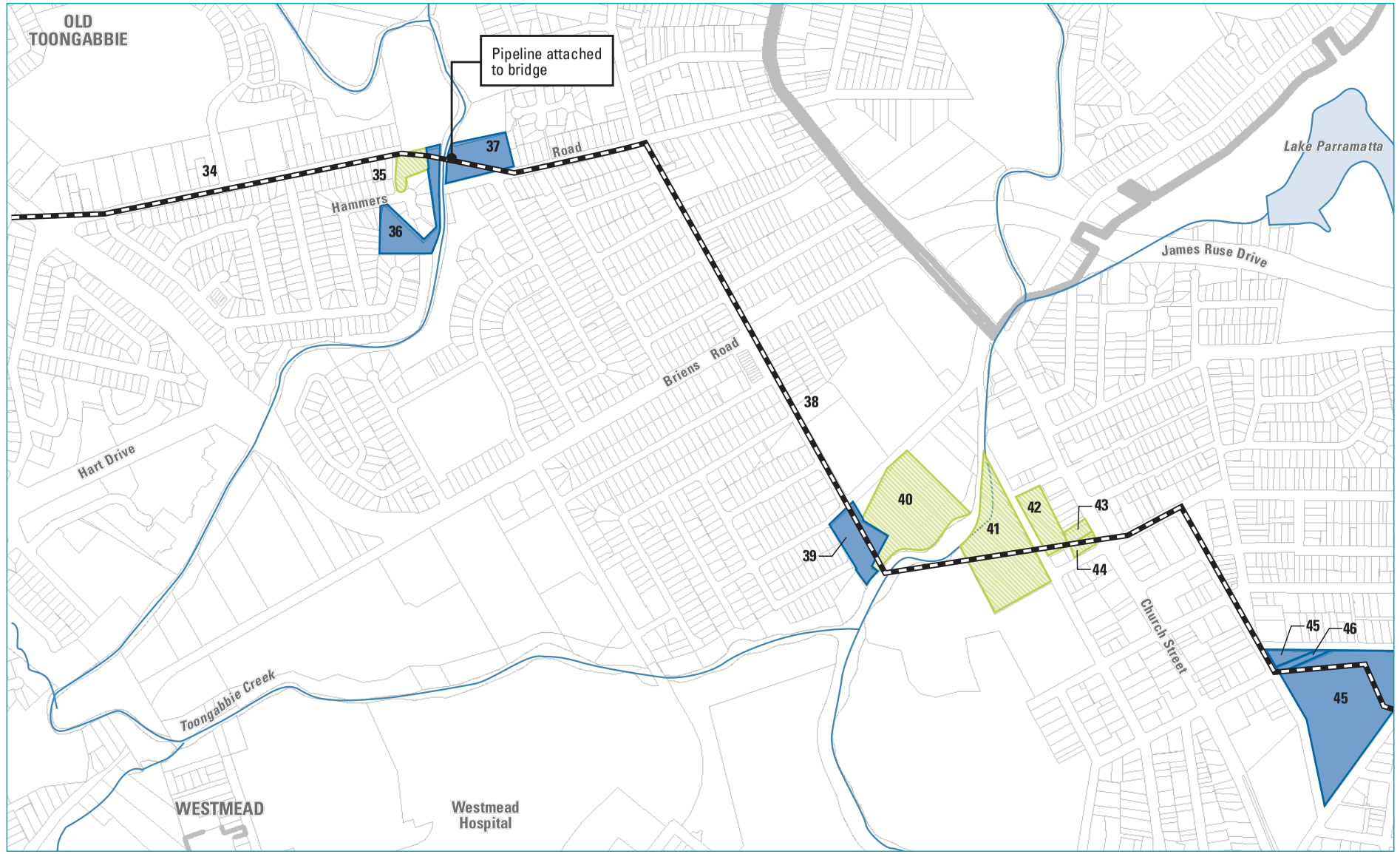


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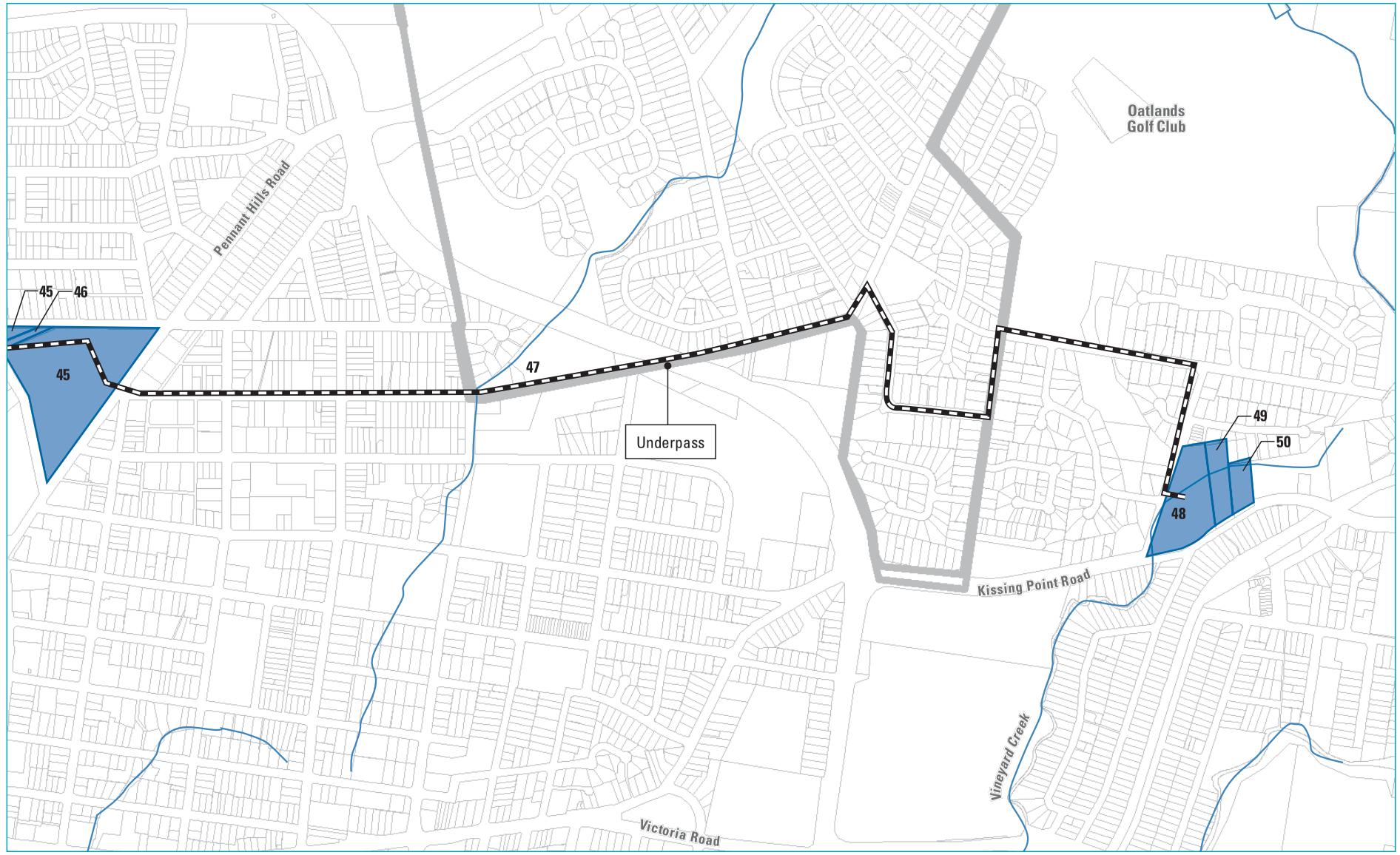


Figure A3a Zoning

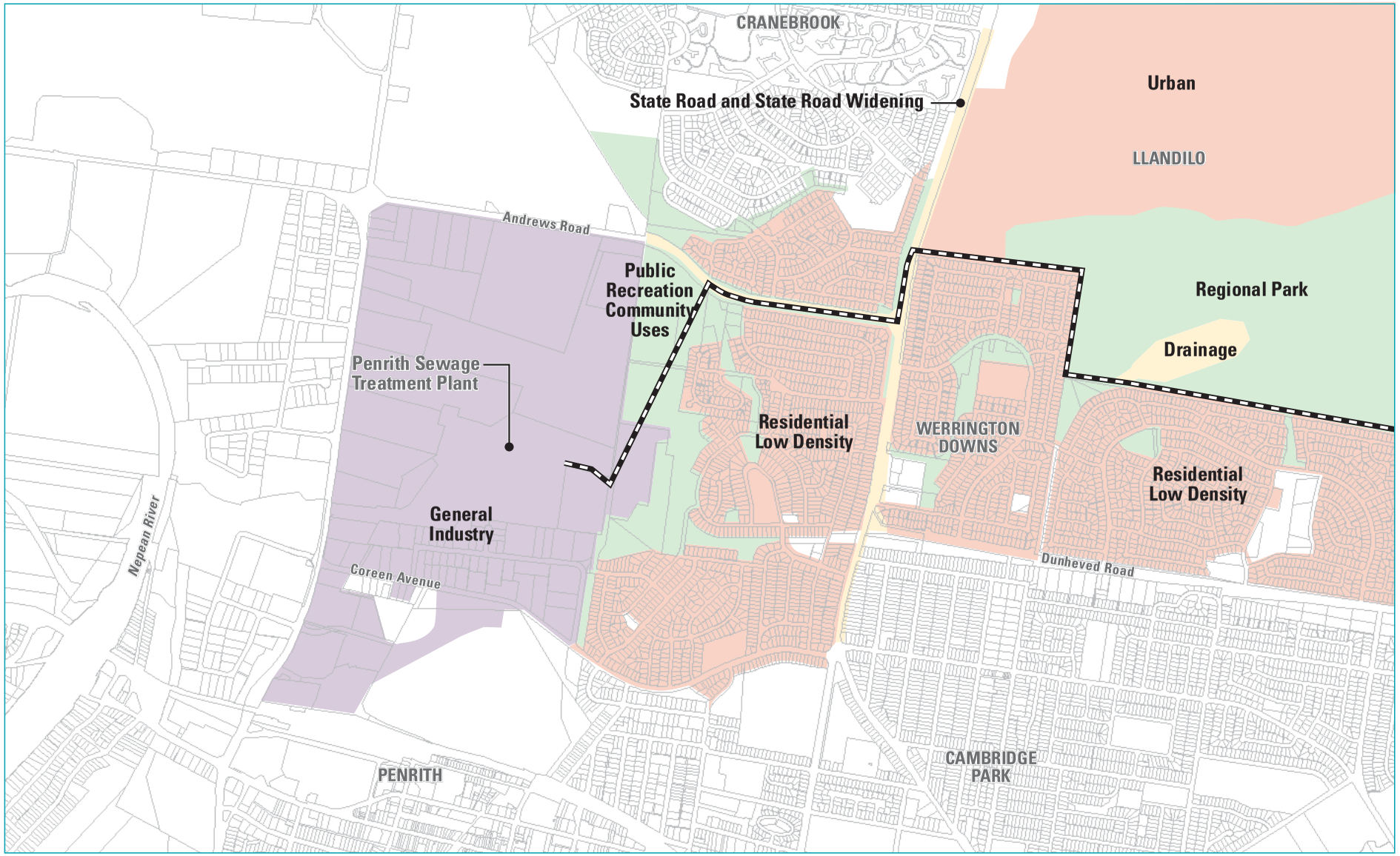


Figure A3b Zoning



Figure A3c Zoning

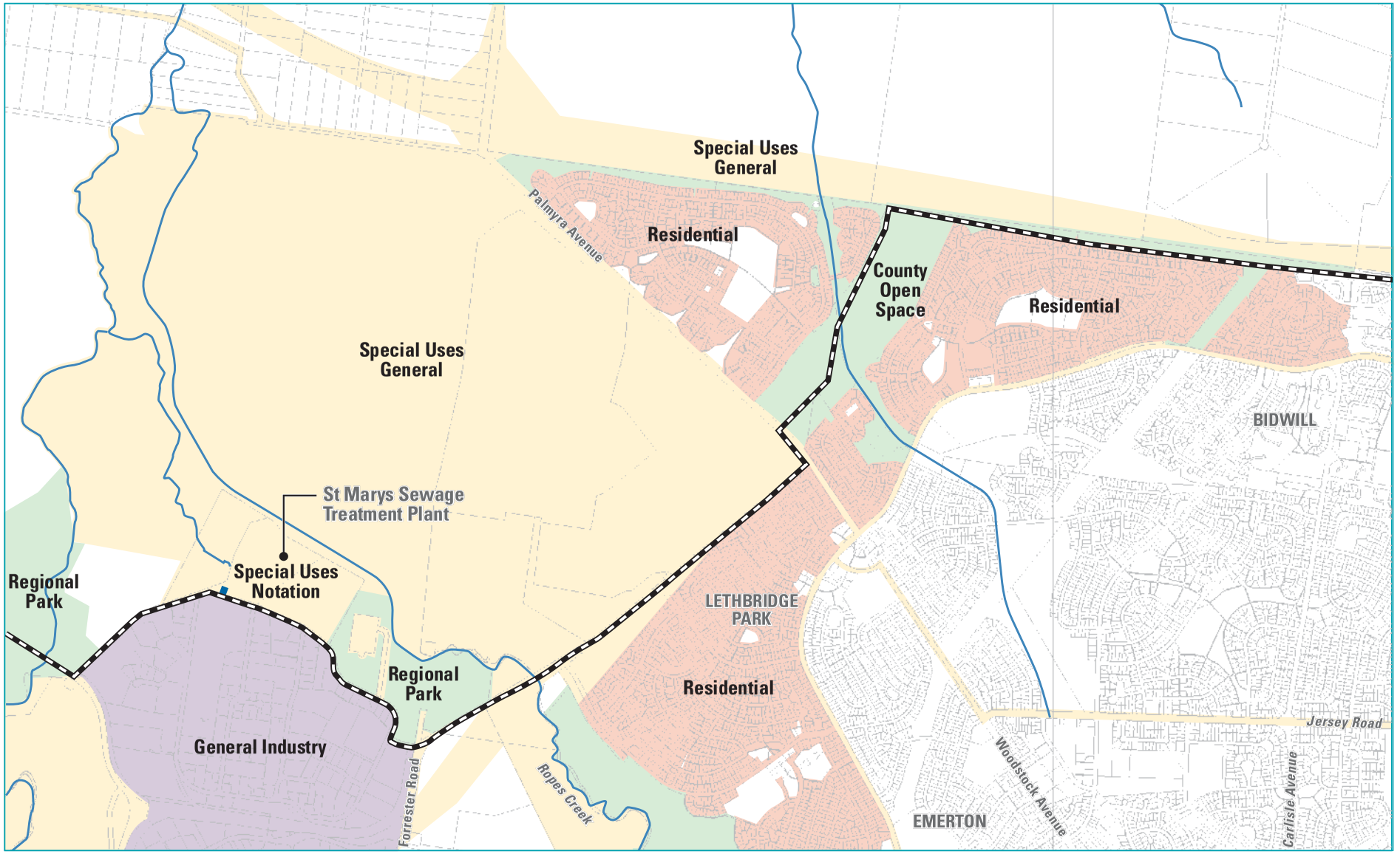


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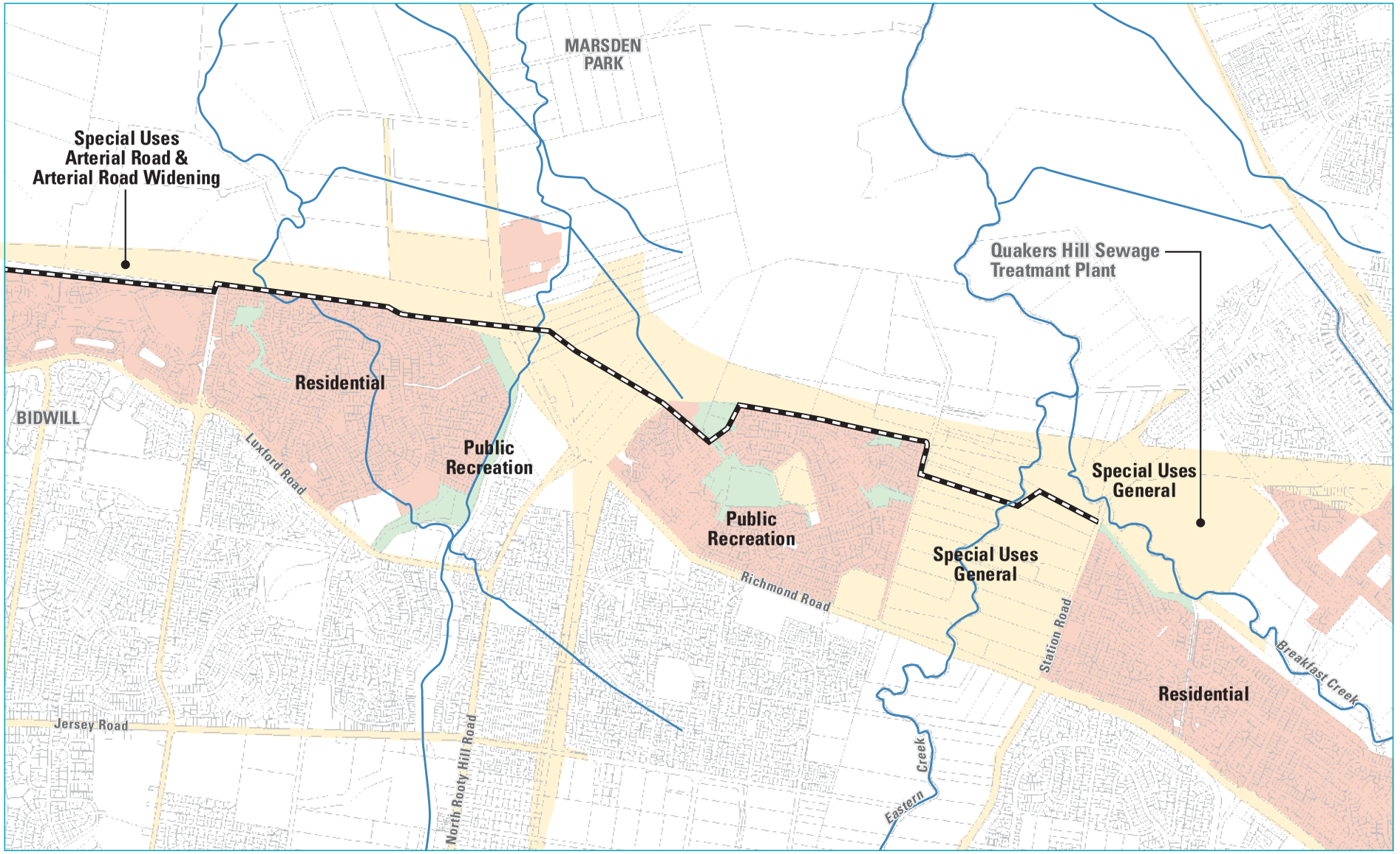


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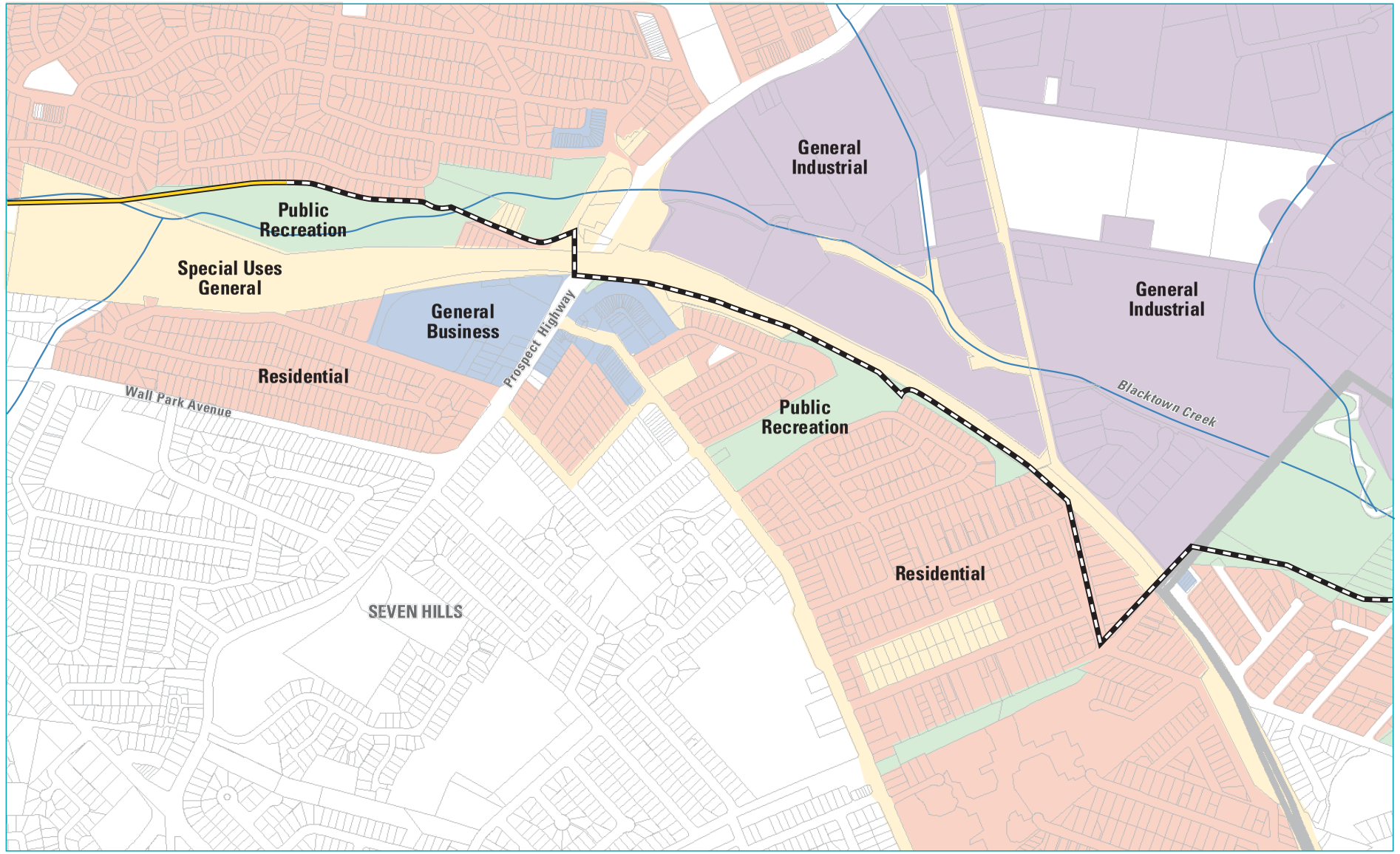


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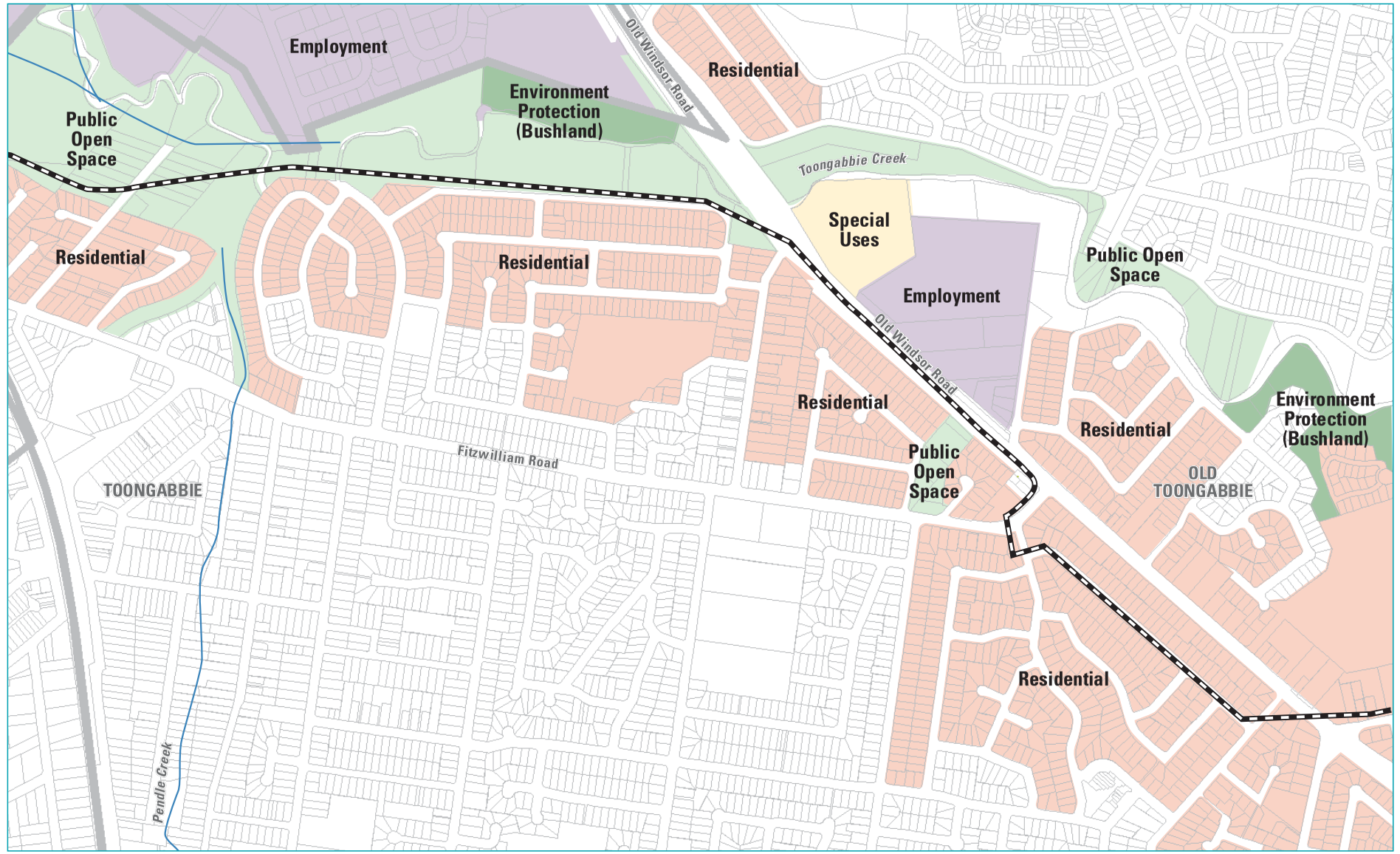


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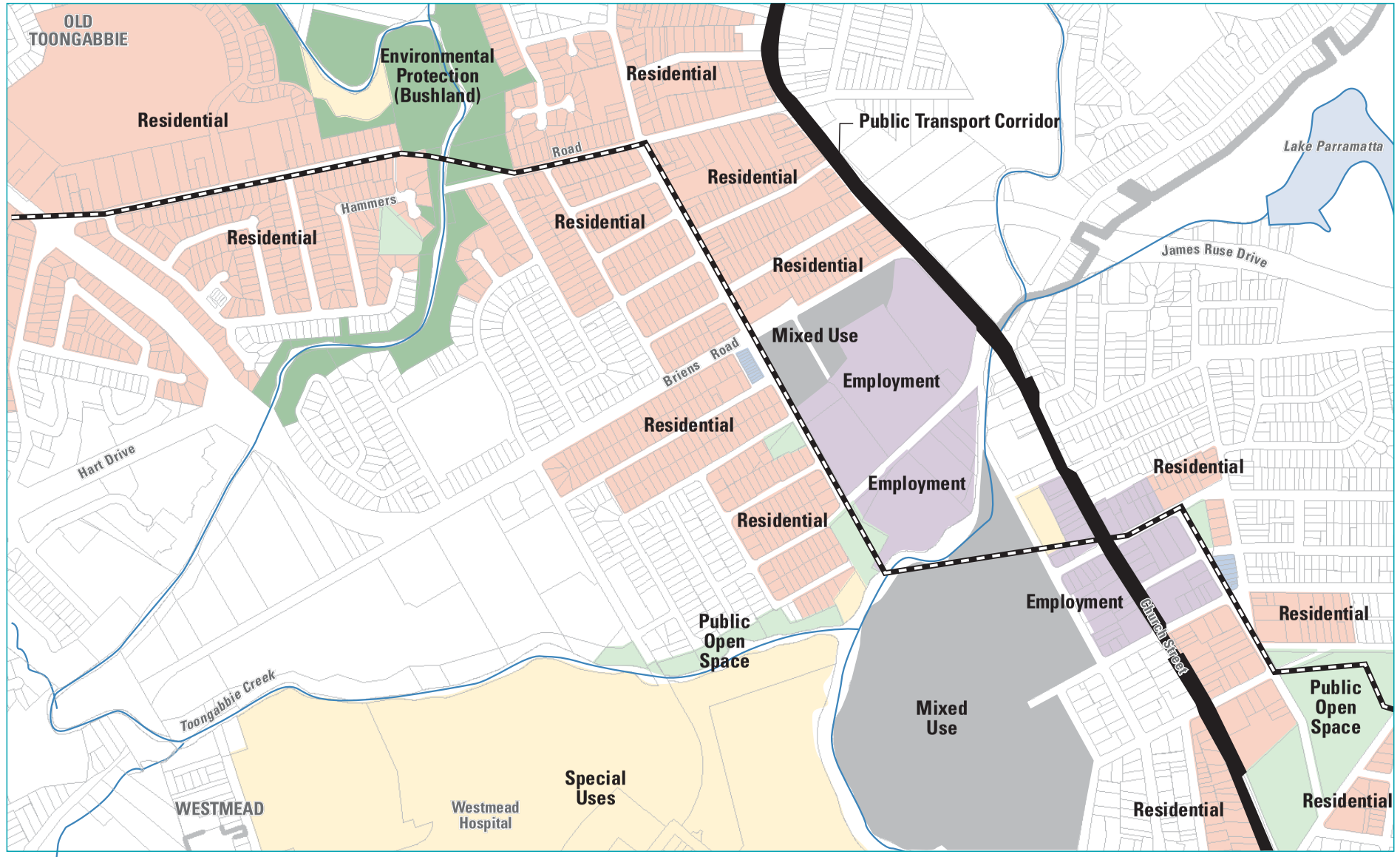
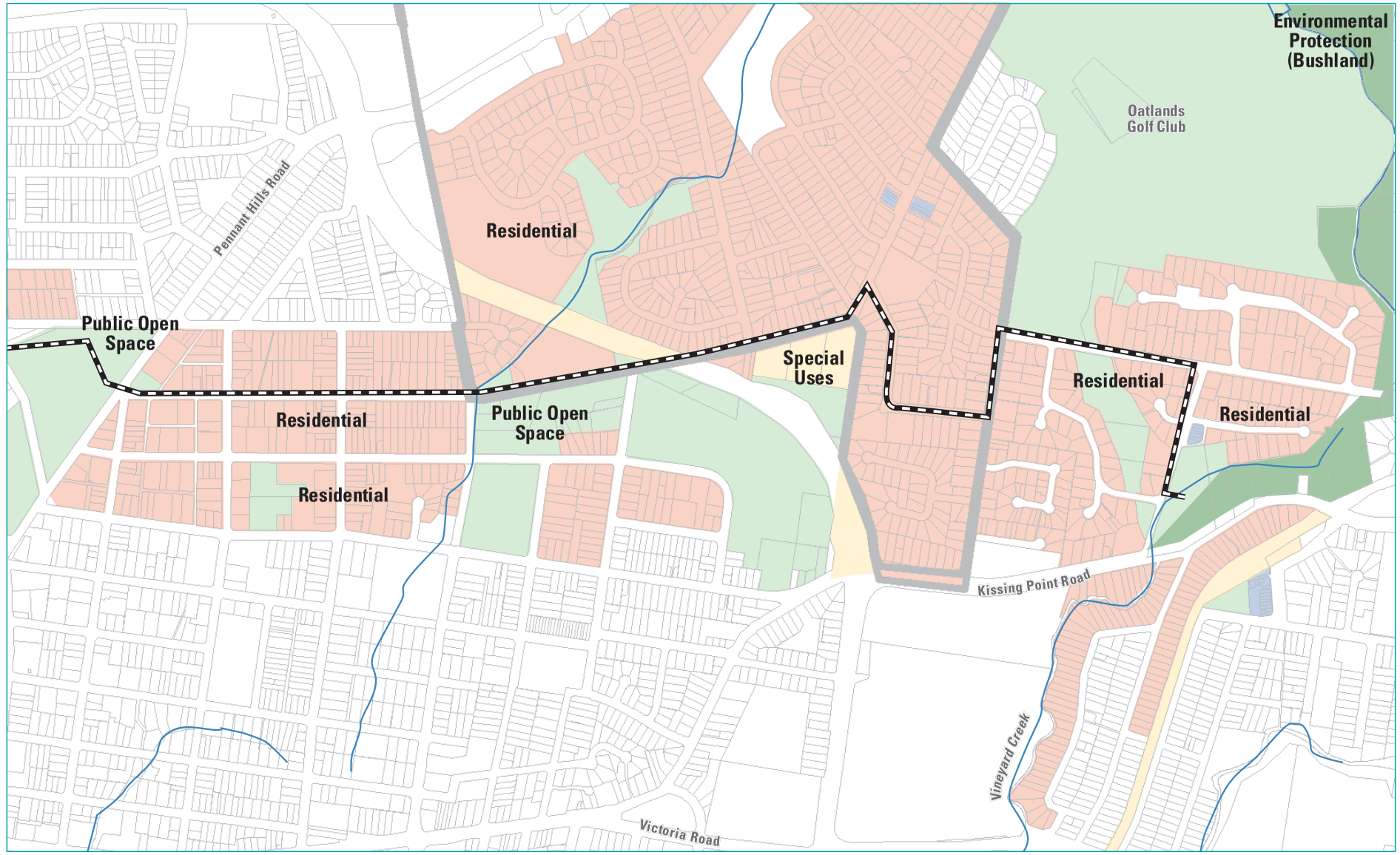


Figure A4d Zoning



Appendix B

Project Declaration and Environmental Assessment Requirements



ORDER DECLARING DEVELOPMENT TO BE A PROJECT UNDER PART 3A OF THE ENVIRONMENTAL PLANNING AND ASSESSMENT ACT 1979

I, the Minister for Planning, having formed the opinion that the project referred to in the Schedule is of State and regional environmental planning significance, declare that project, pursuant to section 75B of the *Environmental Planning and Assessment Act 1979,* to be a project to which Part 3A of the *Environmental Planning and Assessment Act 1979* applies.

Frank Sartor MP
Minister for Planning

Sydney, 23rd July 2006

SCHEDULE

The construction and operation of the Western Sydney Recycled Water Initiative – Replacement Flows Project, including:

- an advanced water treatment plant at St Marys sewage treatment plant;
- effluent transfer pipelines from Quakers Hill, Penrith and St Marys sewage treatment plants to the advanced water treatment plant;
- a brine transfer pipeline and pumping station for the transfer of brine from the advanced water treatment plant to a storage pond at Quakers Hill sewage treatment plant, and a pipeline to transfer brine from the storage pond to the Northern Suburbs Ocean Outfall Sewer;
- balance storage tanks and effluent pumping stations at Penrith, Quakers Hill and St Marys sewage treatment plants;
- a recycled water pipeline for the transfer of treated recycled water (replacement flow) produced by the advanced water treatment plant to Penrith sewage treatment plant; and
- discharge of the replacement flow via the existing effluent outlet into Boundary Creek, which discharges into the Hawkesbury-Nepean River below Penrith Weir.

NSW GOVERNMENT
Department of Planning

Contact: Ingrid Ilias
Phone: (02) 9228 6411
Fax: (02) 9228 6466
Email: ingrid.ilias@dipnr.nsw.gov.au

Our ref: 9043442
Your ref:

Dr Judi Hansen
General Manager, Sustainability
Sydney Water Corporation
PO Box A53
SYDNEY SOUTH NSW 1232

Dear Dr Hansen

Proposed Western Sydney Recycled Water Initiative – Replacement Flows Project (Application: 06_0190)

I refer to your application dated 14 July 2006 and accompanying Preliminary Environmental Assessment document. The Director-General's Environmental Assessment Requirements for the abovementioned project are attached, pursuant to section 75F(2) of the *Environmental Planning and Assessment Act 1979*. The Director-General's requirements have been prepared based on the information provided to date, specifically:

- the Preliminary Environmental Assessment document submitted;
- information presented at the Planning Focus Meeting held on 27 July 2006; and
- subsequent consultation with the attendees of that meeting.

Under section 75F(3) of the Act, the Director-General may alter or supplement these requirements if necessary in light of any additional information that may be provided prior to the proponent seeking approval for the project.

Sydney Water's Environmental Assessment should be prepared using valid and accepted technical and scientific tools and methodologies, focussing on key environmental impacts and robust mitigation measures to address potential impacts from the project.

You should ensure that you consult with the Department prior to submission of a draft Environmental Assessment to determine:

- fees applicable to the application;
- consultation and public exhibition arrangements that will apply; and
- number and format (hard-copy and/or CD-ROM) of the Environmental Assessments that will be required.

Once you have lodged the Environmental Assessment, the Department will consult with the relevant authorities to determine the adequacy of the Environmental Assessment. Following this review period the Environmental Assessment will be made publicly available for a minimum period of 30 days.

You should keep the contact officer for this project, Ingrid Ilias ((02) 9228 6411 ingrid.ilias@planning.nsw.gov.au), up to date with the progress of preparation of the Environmental Assessment, and seek clarification of any issues that may be unclear or may arise during this process.

Yours sincerely

1.9.06

Chris Wilson
Executive Director
As delegate for the Director-General

WESTERN SYDNEY RECYCLED WATER INITIATIVE – REPLACEMENT FLOWS PROJECT, BLACKTOWN, PENRITH, BAULKHAM HILLS AND PARRAMATTA LOCAL GOVERNMENT AREAS

ENVIRONMENTAL ASSESSMENT REQUIREMENTS UNDER PART 3A OF THE ENVIRONMENTAL PLANNING AND ASSESSMENT ACT 1979

Project	The Western Sydney Recycled Water Initiative – Replacement Flows Project, involving the interconnection of three existing sewage treatment plants and treating the available effluent from these plants via a new advanced water treatment plant to replace the water that is currently released from Warragamba Dam for extraction and river health purposes. The project involves the construction and operation of the following key components (Major Project Application: 06_0190): a) an advanced water treatment plant at St Marys sewage treatment plant; b) effluent transfer pipelines from Quakers Hill, Penrith and St Marys sewage treatment plants to the advanced water treatment plant; c) a brine transfer pipeline and pumping station for the transfer of brine from the advanced water treatment plant to a storage pond at Quakers Hill sewage treatment plant. This will connect with a pipeline which will transfer brine from the pond to the Northern Suburbs Ocean Outfall Sewer (NSOOS); d) balance storage tanks and effluent pumping stations at Penrith, Quakers Hill and St Marys sewage treatment plants; e) a recycled water pipeline for the transfer of treated recycled water (replacement flow) produced by the advanced water treatment plant to Penrith sewage treatment plant. The replacement flow is proposed to be discharged via the existing effluent outlet into Boundary Creek, which discharges into the Hawkesbury-Nepean River below Penrith Weir.
Site	The advanced water treatment plant is to be located within the current boundary of the St Marys sewage treatment plant on Lot 1, DP 223888, Lot 1, DP 31910 and Lot 1, DP 803832, within the Dunheved Industrial Area. The effluent transfer, brine transfer and replacement flows discharge pipelines would be located adjacent to the northern edge of urban areas within road reserves, service easements or asset protection zones. The pipelines traverse four local government areas – Penrith, Blacktown, Baulkham Hills and Parramatta. *Note: The location of the project and indicative alignment of pipelines is provided in the Preliminary Environmental Assessment for the project (Sydney Water, 15 August 2006)*
Proponent	Sydney Water Corporation
Date of Issue	1 September 2006
Date of Expiration	1 September 2008
General Requirements	The Environmental Assessment must be prepared to a high technical and scientific standard and must include: • an executive summary; • a description of the proposal, including construction, operation, and staging; • an assessment of the environmental impacts of the project, with particular focus on the key assessment requirements specified below; • justification for undertaking the project with consideration of the benefits and impacts of the proposal; • a draft Statement of Commitments detailing measures for environmental mitigation, management and monitoring for the project; and • certification by the author of the Environment Assessment that the information contained in the Assessment is neither false nor misleading.
Key Assessment Requirements	The Environmental Assessment must include assessment of the following key issues: • **Project Scope, Technology and Operation –** the Environmental Assessment must provide a detailed description of the project, its components, technology (including options where a preferred technology has yet to be selected), any

staging of project implementation and interfaces with existing sewage treatment plants and infrastructure. The Environmental Assessment must include:

- consideration of wastewater treatment technologies for the removal/ reduction of key water quality constituents including, but not limited to, phosphorus and nitrogen. Particular consideration must be given to options to reduce readily bioavailable forms of nutrients;
- details of the proposed wastewater treatment process at the Advanced Water Treatment Plant, alternative treatment processes evaluated and reasons for the selection of the preferred treatment process;
- details of the approach to be applied to brine management including measures to ensure that any overflow only occurs in exceptional circumstances. Consideration of management measures should include, but not necessarily be limited to, options for storage capacity at St Marys sewage treatment plant or elsewhere, improvement to sewers to increase capacity or reduce wet weather infiltration, reduction of the throughput of the Advanced Water Treatment Plant;
- details of the current condition of the Northern Suburbs Ocean Outfall Sewer (SOOS) and the available capacity of the sewer to transport brine from the project now and in the future;
- details of the expected composition of brine including the expected concentration of key constituents (i.e. nitrogen, phosphorus, total dissolved solids);
- details of the likely frequency and volume of overflows and the load of pollutants that would be discharged during those events;
- assessment of the capacity of St Marys sewage treatment plant to receive backwash waste from the plant and any potential impacts on the performance of the sewage treatment plant;
- details of pipeline routes, construction methods and construction environmental management;
- clear maps indicating the location of project components, including plant and pipelines, including an indication of land tenure and land use zoning.

- **Strategic Planning and Project Context –** the Environmental Assessment must clearly outline the strategic context of the project, having regard to the 2006 Metropolitan Water Plan. The Environmental Assessment must also outline the context of the project within the suite of other relevant water supply, recycling and demand management projects currently being undertaken or proposed by Sydney Water, in order to provide a clear picture of the position of this project in the broader scheme of water management initiatives.
- **Water Quality and Water Cycle Management –** the Environmental Assessment must include a comprehensive assessment of the impacts of the project on water quantity and quality, including:
  - a detailed description (supplemented by simple and clear diagrams) of the position of the project within the Hawkesbury-Nepean River System, including all points at which water flows will be altered as a result of the project (increased and decreased). The Environmental Assessment must indicate how the project will affect flowrates and the water balance across the System, both during wet weather and dry weather scenarios;
  - details of how the project will be designed and operated to meet water quality criteria detailed in *Australian and New Zealand Water Quality Guidelines 2000* (ANZECC, 2000) for discharges from existing sewage treatment plants and the replacement flow into the Hawkesbury-Nepean River System;
  - details of the likely water quality impacts of the replacement flows during wet weather and dry weather, with specific (but not necessarily exclusive) reference to total nitrogen, total phosphorus, ammonia and total dissolved solids;
  - details of the likely water quality impacts generated by a reduction in discharges from the St Marys and Quakers Hill sewage treatment plants;
  - details of the likely impacts from the cessation/ alteration of flow from Warragamba Dam between the dam wall and Penrith Weir;
  - a clear demonstration of how the project will protect (or otherwise not compromise) water quality and river flow objectives for the Hawkesbury-Nepean River System where they are currently being achieved and contribute toward (or otherwise not compromise) the achievement of these objectives

over time where they are currently not being achieved;

The Environmental Assessment must also outline a framework for a monitoring program to be applied to the project with respect to the impacts on water quality and aquatic ecology. The framework monitoring program shall be developed having regard to flow regime, phytoplankton (abundance and composition), submerged aquatic vegetation(abundance and composition), flowering aquatic vegetation (abundance and composition), macro invertebrates (abundance and composition), fish (abundance and composition), human pathogens (abundance and composition), nutrients (nitrogen and phosphorus). The framework should also include provision for the collection of baseline data prior to the operation of the project, and timing for monitoring both prior to and during operation.

- **Impacts on Ecology** – - the Environmental Assessment must include a comprehensive ecological impact assessment, including in relation to both terrestrial and aquatic ecosystems, in accordance with the DEC's *Guidelines for Threatened Species Assessment* and *Guidelines for Developments Adjoining National Park Lands*, and DPI's *Fish Habitat Protection Plan No. 1:General* and *Fish Habitat Protection Plan No. 3 – Hawkesbury-Nepean River System*. The Assessment must consider impacts on ecological values directly attributable to the project, as well as indirect impacts that may be associated with changes in water quality conditions and flow characteristics. The Environmental Assessment must also consider consistency of the project with the NSW State Rivers and Estuaries Policy.

  With respect to aquatic ecology, the Assessment must include a particular focus on the reach from Warragamba Dam to Penrith Weir and downstream of the three sewage treatment plants. Specifically, the following issues are required to be addressed:
  - impacts on fish movement past Boundary Creek and Penrith Weir;
  - impacts on migratory fish species in the catchment;
  - impacts on aquatic weed growth, including a demonstration that the discharge of readily bioavailable forms of nitrogen, such as ammonia, have been minimised and that the project will not result in the exacerbation of aquatic weed growth downstream;
  - impacts of changes to the flow regime in South Creek, Eastern Creek, Breakfast Creek and Ropes Creek and associated potential ecological impacts;
  - impacts on the stability of Boundary Creek and measures to rehabilitate the banks and bed of the creek;

  With respect to terrestrial ecology, the Assessment must demonstrate a design philosophy of avoiding sensitive ecosystems and environments, and the minimisation of vegetation removal. The Environmental Assessment must specifically identify any impacts on Endangered Ecological Communities, and where relevant, detail mitigation, management and off-set measures with respect to impacts on those Communities.
- **Human Health Impacts** – the Environmental Assessment must include a detailed assessment of impacts on human health as a result of the project. The Assessment must consider the impact of replacing environmental flows with treated effluent on the current users of the Hawkesbury-Nepean River System. The Environmental Assessment must specifically consider microbiological and chemical hazards and relevant cumulative effects with other sources in the catchment. The Environmental Assessment must consider:
  - consumers of drinking water drawn from the river:
    - → without further treatment such as direct extraction via camping areas or caravan parks;
    - → with further treatment such as the Richmond Water Treatment Plant;
  - recreational users of the river engaged in activities including swimming, water skiing and use of watercraft;
  - irrigators and the potential implications from the use of water on their produce;
  - residents who use the water for non-potable private use e.g. home grown crops such as vegetables, irrigation, other domestic uses;

	° irrigation of public open space; ° any other significant use that may impact on human health. • **Noise and Vibration Impacts –** the Environmental Assessment must include an assessment of the noise impacts of the project in accordance with the *NSW Industrial Noise Policy* (EPA 2000) and noise control guidelines *Construction Site Noise* (previously Chapter 171 of the Environmental Noise Control Manual, 1994). With respect to potential vibration impacts, the Environmental Assessment must include consideration in accordance with the DEC's Environmental *Noise Management – Assessing Vibration: a Technical Guideline*. The Environmental Assessment must consider noise and vibration impacts during construction and operation, and in a cumulative context with existing developments. • **Waste Generation and Management –** the Environmental Assessment must detail the likely waste quantities and qualities generated during the construction (including spoil generation) and operation of the project. Specific focus must be placed on sludges, solids and aqueous wastes produced through the operation of the project, with details of appropriate waste management and disposal options for those materials. • **General Environmental Risk Analysis –** notwithstanding the above key assessment requirements, the Environmental Assessment must include an environmental risk analysis to identify potential environmental impacts associated with the project (construction and operation), proposed mitigation measures and potentially significant residual environmental impacts after the application of proposed mitigation measures. Where additional key environmental impacts are identified through this environmental risk analysis, an appropriately detailed impact assessment of the additional key environmental impact(s) must be included in the Environmental Assessment.
Consultation Requirements	You must undertake an appropriate and justified level of consultation with the following parties during the preparation of the Environmental Assessment: • NSW Department of Environment and Conservation; • NSW Department of Primary Industries; • NSW Department of Health; • NSW Department of Natural Resources; • Hawkesbury-Nepean Catchment Management Authority; • Sydney Catchment Authority; • relevant local councils. In addition, appropriate consultation with the local community should be undertaken. The Environmental Assessment must clearly indicate issues raised by stakeholders during consultation, and how those matters have been addressed in the Environmental Assessment.
Deemed refusal period	Under clause 8E(2) of the *Environmental Planning and Assessment Regulation 2000*, the applicable deemed refusal period is 60 days from the end of the proponent's environmental assessment period for the project.

Appendix C

Assessment of the water cycle, water quality and aquatic ecology



Western Sydney Recycled Water Initiative –
Replacement Flows Project



Assessment of impact of the Replacement Flows Project on the water cycle, water quality and aquatic ecology

October 2006

Appendix C

Technical paper prepared for the Replacement Flows Project
Environmental Assessment

Sydney WATER

SKM

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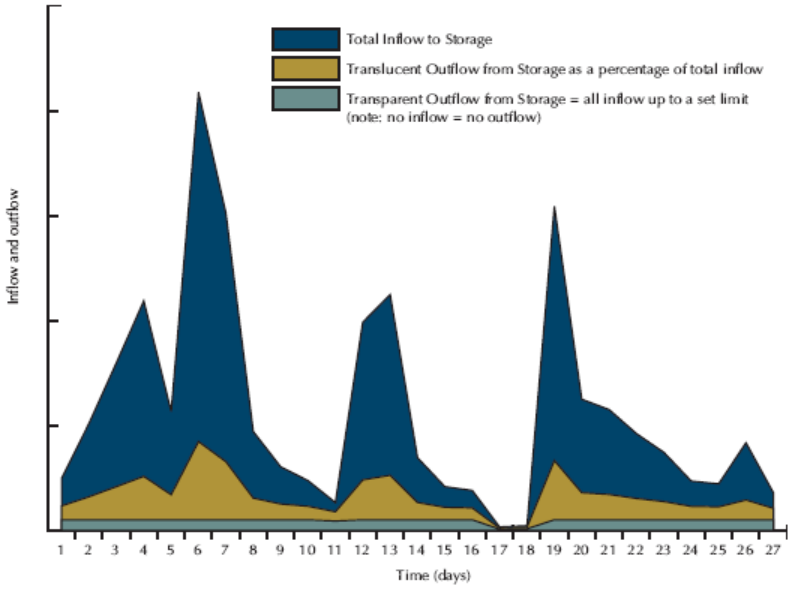
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Technical terms explained

The following terms are explained to assist in the understanding of this report.

Term	Meaning
Flow	
Transparent environmental flow releases	Flows passed through a storage and released from a dam, which equal all inflows to the storage and mimic the timing of natural conditions.
Translucent environmental flow releases	Flows passed through a storage and released from a dam, which equal a percentage of the inflows to the storage and mimic the timing of natural conditions. Translucent flows are added to transparent flows. An example of translucent and transparent components of a hypothetical environmental flow regime together are shown below.  **Translucent and transparent components of an environmental flow regime**
Megalitres (ML)	Measure of volume equal to one million litres (1,000,000 L). One megalitre is approximately the volume of a one metre deep Olympic sized swimming pool.
Gigalitre (GL)	Measure of volume equal to one billion litres (1,000,000,000 L). One Gigalitre is approximately the volume of one thousand Olympic sized swimming pool that are one metre deep.
Water quality	
Turbidity	A measure of the “muddiness” of water - important because it determines how much light can penetrate for important biochemical processes such as photosynthesis.
Electrical conductivity	A measure of the amount of dissolved salts in the water - important as some plants and animals are salt sensitive while others require higher salt concentrations.

Term	Meaning
pH	A measure of acidity or alkalinity of water. Most freshwater and estuarine biota have a range of tolerances between approximately 6.5 and 8.
Dissolved oxygen (measured as % saturation and mg/L):	A measure of the amount of oxygen dissolved in water. Dissolved oxygen is vital for many riverine and estuarine biota including native fish and is also vital for the functioning of healthy aquatic ecosystems.
Nutrients	Nitrogen (N) and Phosphorus (P) are essential nutrients to ecosystem biota at certain concentrations. However, excess nutrients stimulate excessive growth of aquatic plants such as phytoplankton, cyanobacteria, macrophytes, sea grasses and algae. Measures of N and P indicate how eutrophied a waterbody is and how susceptible it will be to nuisance plant growths. *Nitrogen* The most common forms of nitrogen available for plant growth in water are the inorganic forms such as nitrate, nitrite and ammonia. In aquatic ecosystems nitrogen is typically the nutrient limiting plant growth in marine environments, and sometimes estuaries with variable salinity. Excess nitrogen has been known to lead to algal blooms in freshwater systems and can lead to eutrophication of water. The main species of nitrogen of interest to this study are oxidised nitrogen and ammonia/total uncombined ammonia (NH_4). Oxidised nitrogen comprises the two nitrogen species of nitrite (NO_2) and nitrate (NO_3) which are dissolved forms of inorganic nitrogen. Oxidised nitrogen is soluble in water and is readily taken up by aquatic plants. When present in excess, it can stimulate algal production. Oxidised nitrogen can be reduced to NH_4 or converted to nitrogen gas via a process called denitrification. *Total ammonia (as N)* Total ammonia comprises soluble ionised ammonium (NH_4) and gaseous un-ionised ammonia (NH_3). Ammonium is readily taken up by aquatic plants and can stimulate primary production. Un-ionised ammonia is also toxic to aquatic biota. The proportion of the two chemical forms in water varies, with the proportion of un-ionised ammonia increasing with temperature and pH. Where oxygen is present, ammonium can be oxidised to nitrite then nitrate via a process called nitrification. *Phosphorus* Phosphorus is an essential nutrient for life and generally considered the limiting nutrient to primary production in freshwater systems. In excess, phosphorus is associated with excessive plant and algal production. Total phosphorus (TP) is a measure of all the various forms of phosphorus (dissolved and particulate) found in water. Soluble phosphorus (or filterable phosphorus) is present predominantly as the ionic species orthophosphate and is considered to be the form readily taken up by plants.

Term	Meaning
Chlorophyll-*a*	Chlorophyll-*a* is a green pigment found in plants and used for photosynthesis. Chlorophyll-*a* concentrations are an indicator of phytoplankton abundance and biomass. Increases in chlorophyll-*a* indicate that planktonic alga or cyanobacteria are actually growing or present in high densities. Chlorophyll-*a* is an effective measure of trophic status and is commonly used as a measure of water quality. High levels often indicate poor water quality.
Cyanobacteria	Also known as blue-green algae these are a naturally occurring component of most aquatic ecosystems and occur in freshwater, estuarine and marine environments. They are most prominent in waterways that have elevated nutrients, warm water temperatures, adequate sunlight and long residence times. Many species have the potential to produce toxins (toxic cyanobacteria) that present a hazard to human and animal health.

1. Introduction

1.1 Background to project

The *2006 Metropolitan Water Plan* details measures to ensure Sydney's water needs are secured into the future. One of the key components of the plan is the Western Sydney Recycled Water Initiative of which the Replacement Flows Project (the Project) is the major element. The overall objectives of the Project include:

- saving up to 18 billion litres a year of current Warragamba Dam discharges by providing high quality recycled water to the Nepean River as a replacement for existing Warragamba Dam releases
- reducing the discharge of nutrients from Penrith, Quakers Hill and St Marys STPs into the Hawkesbury-Nepean River and South Creek
- maintaining appropriate flows for irrigation
- ensuring environmental values are maintained – including aquatic ecosystems, primary industries, recreation and aesthetics and drinking water.

Sydney Water has been tasked with developing and obtaining planning approval for the Project. To develop the project further and to define a preferred option for the basis of project approval and environment assessment, Sydney Water commissioned Sinclair Knight Merz to prepare a scoping study to assess treatment and configurations options for the project. The scoping study concluded that the preferred option for the project was an Advanced Water Treatment Plant (AWTP), which will utilise microfiltration/ultrafiltration and reverse osmosis treatment technology to produce up to 50 ML/day of highly treated recycled water that will be discharged below Penrith Weir as a replacement flow. The replacement flow discharge would be substituted for water that is currently released from Warragamba Dam for extraction and river health purposes.

Effluent from Quakers Hill, St Marys and Penrith sewage treatment plants (STPs) would be transferred to the AWTP located at the St Marys STP site. This would result in a substantial reduction in the volume of treated effluent discharged into the Hawkesbury-Nepean River from these sewage treatment plants.

The AWTP would also produce about 8 ML/day of liquid concentrate consisting of dissolved salts and other minerals. The concentrate would be transferred to the Northern Suburbs Ocean Outfall System (NSOOS) where it would be discharged into the ocean via the North Head deep ocean outfall.

Sydney Water is seeking planning approval from the Minister for Planning under Part 3A of the *Environmental Planning and Assessment Act* for the construction and operation of the Replacement Flows Project. As part of the approval process, Sydney Water is required to prepare an Environmental Assessment Report (EA Report), which assesses the impact of the proposed development, focusing on key environmental aspects. A risk assessment undertaken by Sydney Water and the Environmental Assessment Requirements provided by the Director-General of the Department of Planning have identified the following key issues that require detailed assessment in the EA Report:

- **Water Quality & Water Cycle Management** – This includes impacts upon water quality, flow volumes and patterns, and water users in the study area.
- **Ecology** – Aquatic ecosystems in the river are sensitive to changes in flow and water quality.
- **Human health** – The potential risks to human health of the replacement flows discharge needs to be assessed for a number of possible scenarios – A separate technical report addressing this key issue has been produced and can be found in **Appendix D** of the Environmental Assessment.

This report has been prepared to assess the water quality, water cycle management and aquatic ecology component of the Director-General's Environmental Assessment Requirements. The report provides an overview of existing flow, water quality and aquatic ecology within the study area. It assesses the operating impacts of the project and provides recommendations to mitigate identified impacts.

The report is divided into chapters addressing the key issues of water cycle, water quality and aquatic ecology. These are:

- **Chapter 2** - Description the waterways that comprise the study area for the assessment
- **Chapter 3** - Description of existing flow conditions and an assessment of predicted hydrological changes
- **Chapter 4** - Description of existing water quality conditions and an assessment of predicted water quality changes
- **Chapter 5** - Description of existing aquatic ecology conditions and an assessment of the predicted flow and water quality changes on ecological values
- **Chapter 6** - Description of existing water based recreation activities and an assessment of the predicted flow and water quality changes on recreational values
- **Chapter 7** - Description of primary industry activities and an assessment of the predicted flow and water quality changes on primary industries.

1.2 Assessment assumptions

In 2009, a number of river and water cycle management activities will be implemented in addition to the Replacement Flows Project. They are:

- increased environmental flows releases from the Upper Nepean Dams as described in the *2006 Metropolitan Water Plan*
- modification of the weirs in the Upper Nepean River to allow environmental flows to be passed downstream
- greater control over the volume and timing of agricultural water extraction from the Upper Nepean River to protect low flows
- upgrade of West Camden STP to improve the quality of effluent discharged into the Upper Nepean River
- implementation of new local and residential water recycling schemes.

In undertaking this assessment it has been assumed that all of these activities will be in place when the project begins operation. As a result, the impacts and benefits of the project cannot be considered in isolation of these activities. Therefore, the assessment of the predicted affects of the project in 2009 includes the water flow and quality conditions that will result from the implementation of the river and water cycle management activities listed above. These conditions are referred to as the '2009 flow and water quality conditions' within this assessment.

2. Study Area

2.1 Introduction

The Hawkesbury-Nepean River system is about 300km long and drains a catchment area of approximately 22,000 square kilometres and includes the Cordeaux, Cataract, Avon, Nepean, Hawkesbury, Warragamba, Wollindilly and Wingecarribee Rivers (HNRMF, 2004). The Hawkesbury-Nepean River system can be divided into a fluvial and an estuarine section, with the mainstream receiving inflows from 14 large tributaries (SPCC, 1983). Many of the tributary watersheds to the north and west are undeveloped, whereas the flatter terrain to the west and south-west of Sydney (originally pastoral and agricultural land) is now generally urbanised.

The average dry weather flows discharged from the Hawkesbury-Nepean River System are estimated to be approximately 1,970 ML/day and the tidal exchange is estimated (at Brooklyn) to be approximately 14,062 ML/day (AWT, 1999). Much of the catchment is bushland, however there are major urban centres and extensive use of the catchment for grazing and agriculture activities. In addition to these, commercial fisheries, coal mining, power generation, water supply (dams and weirs) and sand and gravel extraction are also significant activities within the catchment, which have altered flows, water quality and ecological conditions of the river system.

The Nepean River (which is upstream of Yarramundi) drains a large catchment area. The river itself can be divided into the Upper, Mid and Lower Nepean River. The Upper Nepean River includes the Nepean, Avon, Cataract and Cordeaux storages and the tributaries downstream of the storages. Numerous weirs control the Mid Nepean River, including Maldon Weir at its upper reaches and Wallacia Weir at its downstream end. Intensive rural and agricultural areas, urban areas including Camden and Picton and West Camden have impacted the catchment and river.

The Lower Nepean River extends from the Warragamba River inflow to Yarramundi upstream of the Grose River inflow, where it becomes the Hawkesbury River. This section of the river drains a variety of landuses including agricultural and grazing land, urban and industrial areas such as Penrith. The river also receives discharges of tertiary treated effluent from Penrith STP downstream of Penrith Weir and Winmalee STP. The Lower Nepean River is one of the areas that would be impacted upon by the project.

Below Yarramundi, the Nepean River becomes the Hawkesbury River. Like the Nepean, the Hawkesbury River drains a large catchment area and can be divided into upper and lower parts. The Upper Hawkesbury River extends from the tidal limit at Yarramundi to Lower Portland. Water quality and aquatic health are not only influenced by the quality of the Nepean River but also by the catchment it drains which comprises the urban areas of North Richmond, Richmond and Windsor, agriculture, and inflows from South, Eastern and Cattai Creeks.

The Lower Hawkesbury River is a tidal estuary extensively used for recreational and commercial fishing. Its water quality and aquatic health are influenced by the Upper Hawkesbury River, inflows from Colo and Macdonald Rivers, Mangrove and Mooney Mooney creeks and tidal waters from the Pacific Ocean. Due to regular tidal flushing, the water quality in the lower estuary is generally considered good.

For the purpose of describing existing environmental conditions and assessing the impact of the Project, the Hawkesbury-Nepean River and its tributaries, which would potentially be affected by the project, have been separated into a series of reaches. These reaches have been assessed in a

downstream direction from the freshwater areas of the Nepean and Warragamba Rivers to the freshwater tidal zone of the Hawkesbury River. The river reaches that may be impacted by the operation of the Project include:

- Warragamba River
- Hawkesbury-Nepean River
  - Wallacia Weir to Penrith Weir (Nepean River)
  - Penrith Weir to Yarramundi (Nepean River)
  - Yarramundi Bridge to South Creek (Hawkesbury River)
  - South Creek to Sackville (Hawkesbury River)
- South Creek catchment (South and Eastern Creeks)

The study area and the above river reaches are shown in **Figure 2-1**.

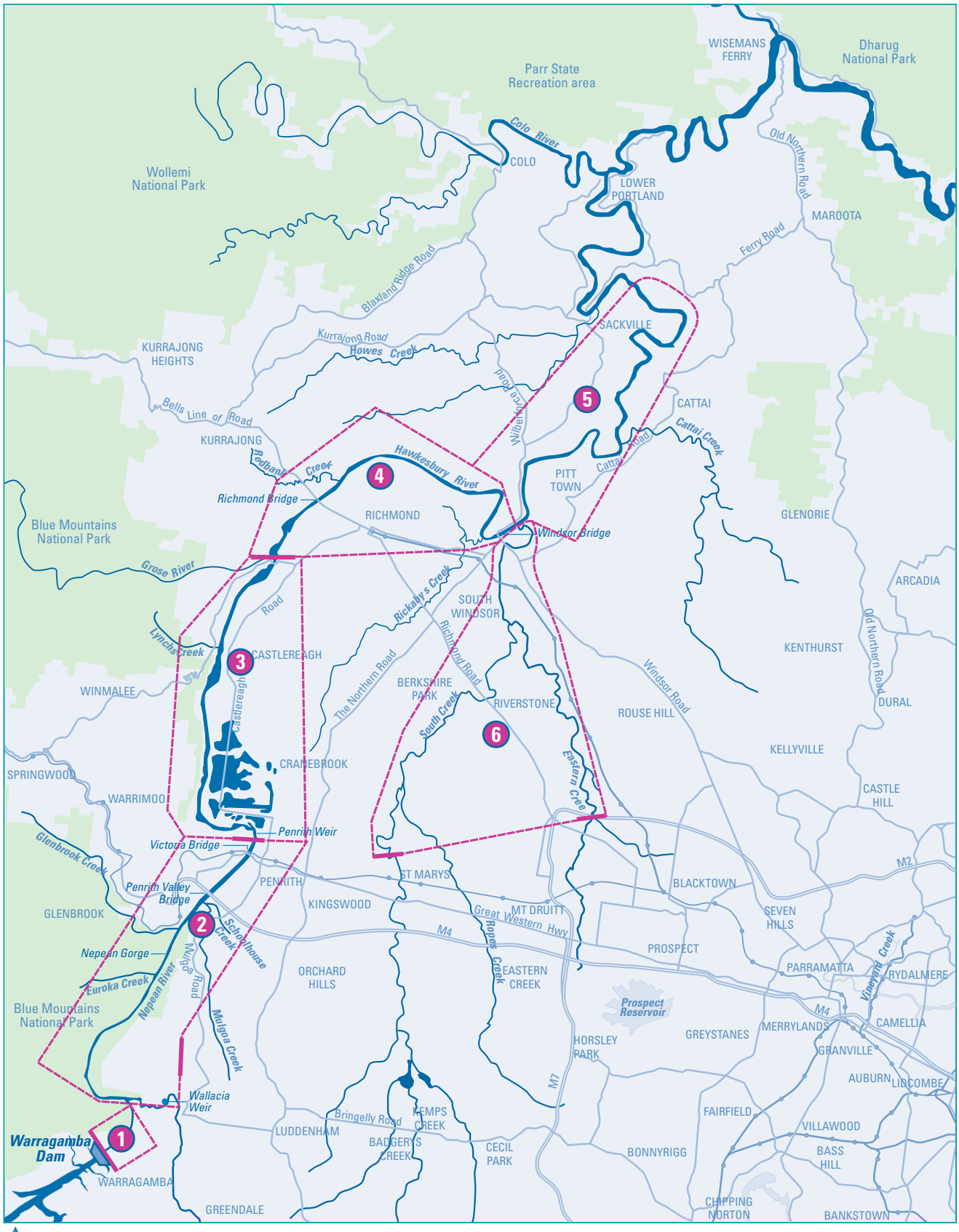
2.2 Warragamba River

The Warragamba River catchment supports the major water supply system for Sydney, Lake Burragorang (Warragamba Dam). Flows released from the dam are discharged into Warragamba River. The study area includes the section of the river downstream of the dam wall, which extends to its confluence with the Nepean River.

The Warragamba River downstream of Warragamba Dam to the confluence with the Nepean River comprises:

- 1.4 km reach immediately downstream of the dam to Warragamba Weir. This reach does not receive any interim environmental flow releases from Warragamba Dam and only receives minor flows comprising dam seepage, groundwater discharge and catchment runoff. In prolonged wet weather periods, Warragamba Dan may spill into this reach;
- 2.1 km section from the weir to the confluence with the Nepean River. Penrith Weir causes water to back up almost to the Warragamba Weir, and has drowned out the pools and rock-bars to depths ranging from approximately 0.5 – 11 m. Wallacia STP (which now replaces the decommissioned Warragamba STP) currently discharges into this section of the river approximately 1.5km upstream of the Nepean River confluence. This section of the Warragamba River currently receives flow releases from Warragamba Dam.

Figure 2.1 Study area showing assessment reaches



2.3 Nepean River - Wallacia Weir to Penrith Weir

This reach is situated upstream of Boundary Creek and the discharge location of Penrith sewage treatment plant (STP) and the Replacement Flows Project. Wallacia Weir (the upstream extent of the study area) controls flow from the Upper Nepean and its dams. Below Wallacia Weir, the river traverses through gorge country and receives inflows from Warragamba River, the current interim flow releases from Warragamba Dam and a number of other creeks, the largest being Erskine Creek. This reach is regulated by Penrith Weir, behind which a 6000 ML weir pool has formed. The weir pool extends to the Warragamba River junction and the typical residence time for dry weather 'interim flow' releases from Warragamba Dam is the 180 days. Flow velocities in this river reach are low due to Penrith Weir.

2.4 Nepean River - Penrith Weir to Yarramundi

This reach commences downstream of Penrith Weir and includes Boundary Creek which is the current discharge location for Penrith STP and would be the discharge location for replacement flows. Winmalee STP also discharges into this reach of the river further downstream.

This reach of the river generally has higher flow velocities in comparison to other river reaches as it is unregulated (ie no downstream dams or weirs) however, flow velocities decrease near Yarramundi due to the effects of the natural freshwater tidal pool in the downstream river reaches. There are still some remaining riffle zones in this river reach although sedimentation and other river processes have resulted in a decrease in their quality. There are a number of tributaries which inflow into this river reach, most notably the Grose River, which provides significant volumes of water even in dry weather.

2.5 Hawkesbury River - Yarramundi to South Creek

This reach is bounded by Yarramundi and the inflow of South Creek, which carries tertiary treated effluent from Riverstone, Quakers Hill and St Marys STPs. This reach is located in the freshwater tidal section of the river with its hydrology dominated by the freshwater tidal pool that forms behind the saline intrusion from the estuary and ocean. The vast majority of water in the freshwater tidal pool is from large wet weather events rather than dry weather inflows. Due to the large volume of the freshwater tidal pool and the regulating effect of downstream saline waters of the estuary, flow velocities in the pool are low and often change directions due to the influence of the tide. It is from this reach that North Richmond Water Filtration Plant extracts water from the river to supply drinking water for local urban areas. This reach is also a source of water for irrigated agriculture and horticulture.

2.6 Hawkesbury River - South Creek to Sackville

The South Creek to Sackville reach is the downstream section of the freshwater tidal pool and has largely the same characteristics as described for the Yarramundi to South Creek reach. Water Quality in this river reach is affected by the inflow of South Creek, especially in dry weather when discharges from the STPs located within the South Creek catchment dominate flow conditions. Water extraction for agriculture and horticulture are important existing uses of this river reach.

2.7 South and Eastern Creek

South Creek originates north of Narellan and flows into the Hawkesbury River at Windsor, downstream of Fitzroy Bridge. Tributaries feeding South Creek include Eastern, Badgerys, Ropes, Kemps and Rileys Creeks. South Creek is freshwater tidal at its downstream reaches.

There are a number of land uses that influence the water quality of South Creek, its tributaries and the Hawkesbury River near Windsor. These land uses include rural, grazing and market gardening, intensive agriculture such as poultry farming, and both urban and industrial land uses. South Creek also receives tertiary treated effluent discharged from St Marys STP and Hawkesbury Council's McGraths Hill and South Windsor STPs.

Eastern Creek is a major tributary of South Creek and their confluence is near Riverstone. Eastern Creek receives tertiary treated effluent from Riverstone and Quakers Hill STPs.

2.8 Boundary Creek

Boundary Creek is a small tributary of the Hawkesbury-Nepean River which flows into the main river channel about 50 m downstream of Penrith Weir. Its relevance to the project is that approximately 22 ML/day of tertiary treated effluent from Penrith STP is currently discharged into the creek approximately 500m upstream of its junction with the Nepean River. Boundary Creek flows through the Penrith STP site where its riparian zone has been cleared or contains patchy re-growth of casuarinas and terrestrial and aquatic weed species.

Downstream of the Penrith STP, Boundary Creek crosses under the Castlereagh Road through a culvert before entering an industrial and commercial zone. A 10-20 m riparian zone either side of the creek has been maintained through this area, which increases in width as the creek flows towards the Nepean River. The riparian zone is heavily infested with weeds and there is some re-growth of endemic native vegetation. There is evidence of significant erosion of the alluvial soils in the lower sections of the creek near where it flows into the Nepean River.

The creek has a catchment of 304 ha, which does not contribute any flows to the creek in dry weather. However in wet weather, flows in the creek increase significantly. For a 1 in 2 year storm, flows are estimated as 3,255 ML/day, increasing to 5731 ML/day for a 1 in 20 year storm.

3. Hydrology

3.1 Introduction

This chapter describe the existing flow conditions within the study area. It also provides an assessment of the operation of the Project.

Why flow is important?

Flows are critical for maintaining the health of waterways upon which ecosystems, adjoining landuses and water users depend. The term 'environmental flows' refers to the portion of flow within a waterway that is reserved solely for the purpose of maintaining or improving aquatic ecosystems and water quality. These flows are protected as 'environmental health water' under section 8 of the *Water Management Act 2000*. Flow conditions within the Hawkesbury-Nepean River system have been modified by the development of the Sydney metropolitan area. The establishment of drinking water (i.e. dams and diversion of flows via pipeline networks) and wastewater management infrastructure, weirs, river extraction activities, sand and gravel mining and construction of hard surfaces that restrict infiltration of rainfall (i.e. buildings, car parks and roads etc) have had an altering affect on the natural flow regime of the Hawkesbury-Nepean River system.

Why is this topic important in relation to the Replacement Flows Project?

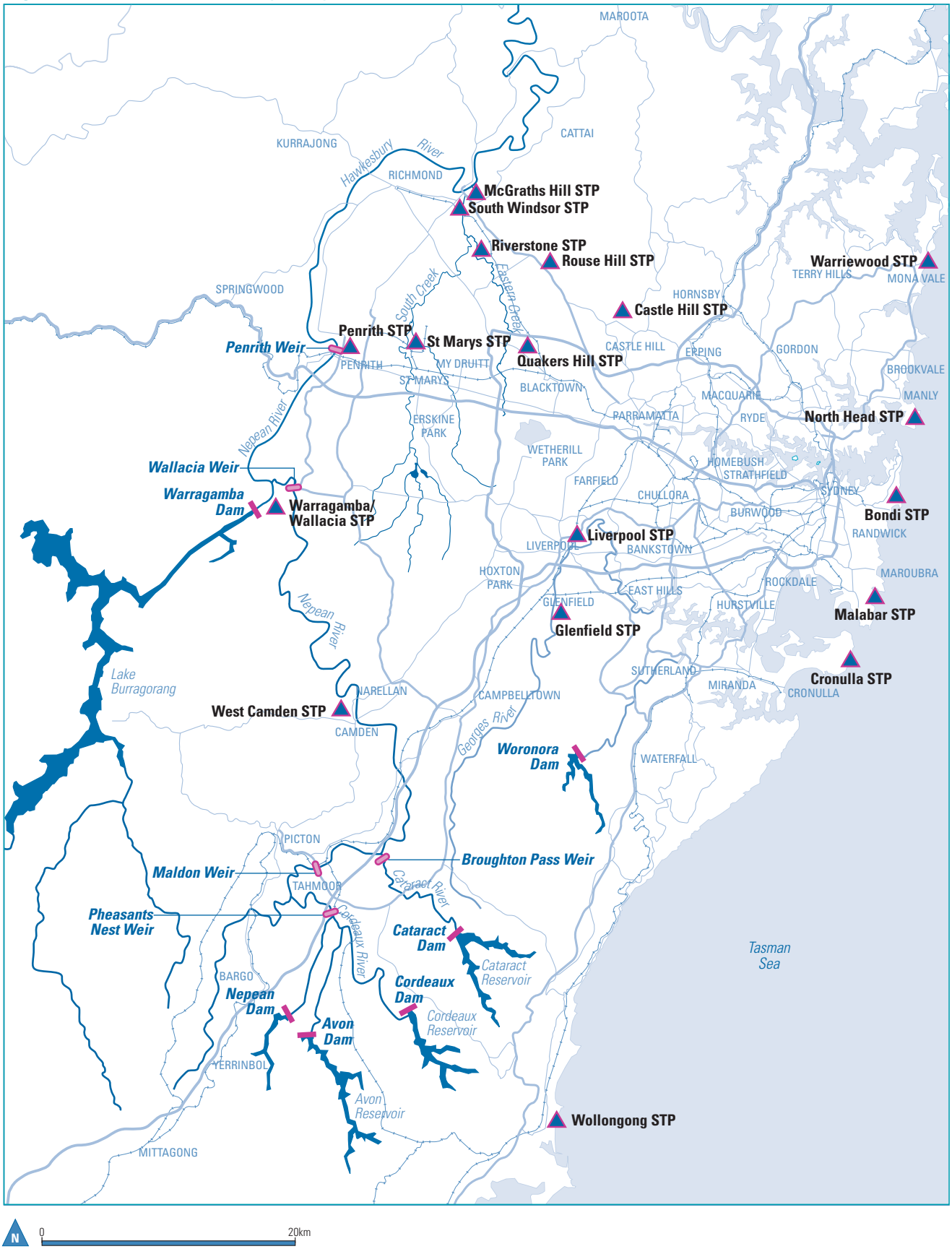
The Replacement Flows Project and other river management changes detailed in the *2006 Metropolitan Water Plan* will change the existing flow volumes and patterns within the Hawkesbury-Nepean River System. The affected waterways would include Warragamba River, the Lower Nepean River, Upper Hawkesbury River and the South Creek catchment. The following alterations to flow conditions within the Hawkesbury-Nepean River system would occur directly from the operation of the Project alone (ie not including other 2009 river management changes):

- Cessation in interim flow releases from Warragamba Dam;
- flow reduction in 2009 of approximately 43ML/day in the South Creek catchment with the transfer of approximately 39% of the effluent from Quakers Hill and 76% from St Marys sewage treatment plants to the AWTP (It should be noted that flows would increase over time as the sewerage catchments are developed) ; and
- approximately 100% increase in flow (consisting of the replacement flow) discharged to the Nepean River below Penrith Weir.

3.2 Existing Environment

The Hawkesbury-Nepean River system has a total catchment area of 22,000 km^2 and drains into the sea at Broken Bay. Five major water supply dams are located within the catchment namely the Warragamba, Nepean, Avon, Cordeaux and Cataract Dams, which have a combined catchment area of 10,000 km^2. Downstream of Yarramundi the river is tidal and is referred to as the Hawkesbury River, whilst upstream it is referred to as the Nepean River. There are two main arms upstream of Penrith, the Upper Nepean and Warragamba/Wollondilly. This study is only concerned with the portion of the catchment located downstream of the water supply dams (**Figure 3-1**).

Figure 3.1 Lower Hawkesbury - Nepean River Basin



3.2.1 Drinking Water Supply

The Upper Nepean includes the Nepean, Avon, Cordeaux and Cataract Dams (collectively known as the Upper Nepean Dams), whilst the Warragamba/Wollondilly Arm includes Warragamba Dam. In the Upper Nepean approximately 50% of the mean annual dam inflows are diverted to provide water supplies for Sydney and Wollongong. Avon Dam supplies Wollongong via a pipeline, whilst the other dams supply Sydney. Nepean and Cordeaux Dams provide water supply by releases into their downstream channels, which are diverted at Pheasants Nest Weir into the Upper Canal. Cataract Dam also provides water supply by releasing water into its downstream channel, which is diverted at Broughtons Pass Weir to the Upper Canal.

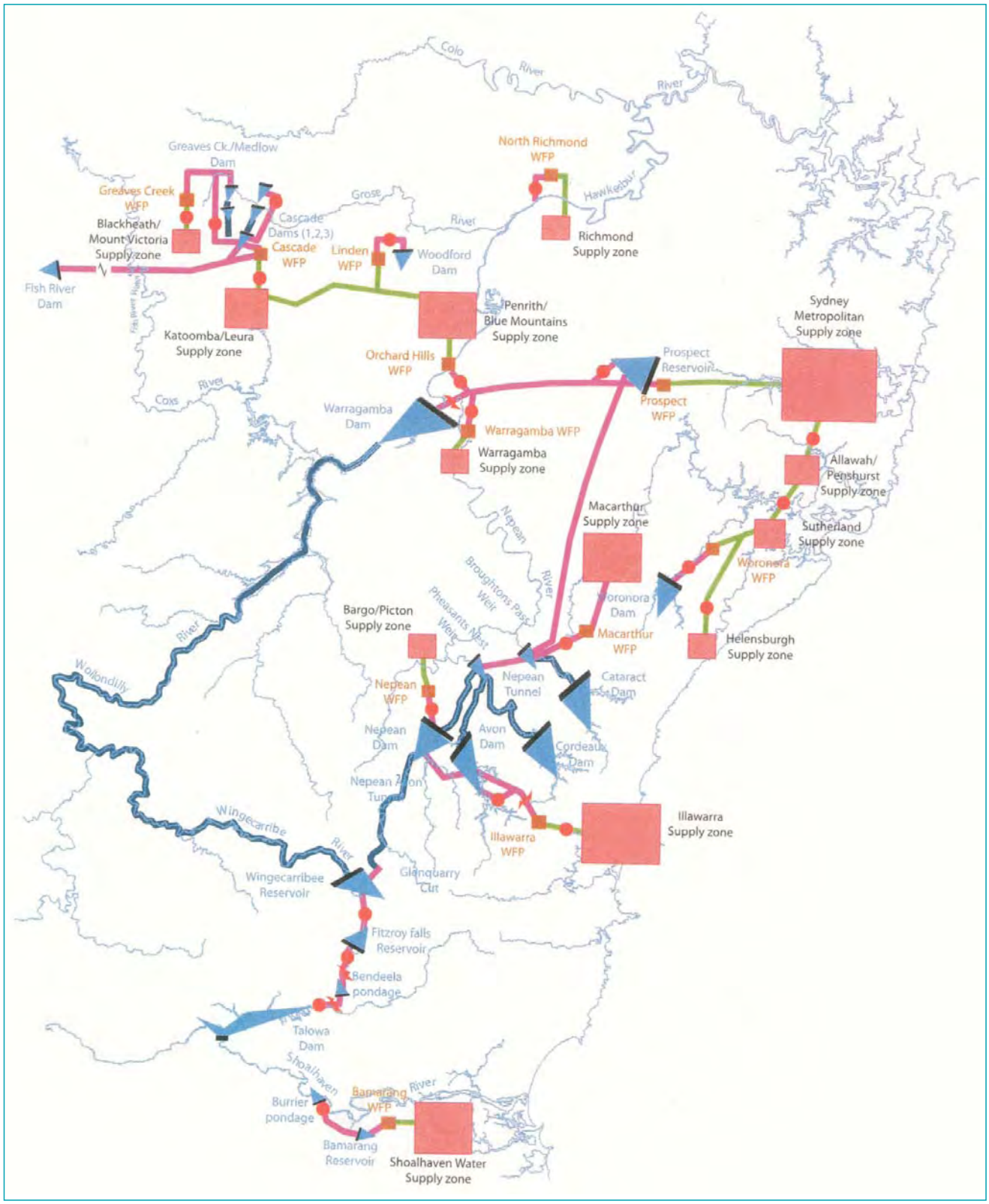
The water supply systems for the greater Sydney metropolitan area are shown in **Figure 3-2**. Warragamba Dam delivers approximately 80% of all drinking water to the area supplied by Sydney Water. Normally, the balance comes from the Upper Nepean and Woronora Dams as well as from Oberon Dam on the Fish River in the Macquarie River catchment, which supplies towns in the upper Blue Mountains. During extended dry periods, transfers of bulk water from Tallowa Dam on the Shoalhaven River are used to supplement this system. Currently, pumping from Tallowa Dam to supplement storage capacity in the Hawkesbury/Nepean Dams can commence when the overall storage level in those dams falls to 60% capacity (HNRMF, 2004). **Table 3-1** presents the storage capacity of the major water supply dams for the Sydney, Blue Mountains and Illawarra area.

Table 3-1: Major Water Storage Capacities

Dam or Reservoir	Capacity[a] ML
Nepean	40,810
Avon	146,700
Cordeaux	93,635
Cataract	94,300
Warragamba	1,886,000
Wingecarribee	24,100
Fitzroy Falls	10,000
Tallowa	36,000
Woronora	71,790
Blue Mountains[b]	3,644

(Source: HNRMF, 2004)
a. As specified in the Sydney Catchment Authority's Water Management Licence.
b. Combined capacity for Greaves Creek, Medlow, Cascade and Woodford Creek storages (6 storages in total).

Figure 3.2 Diagrammatic layout of water supply systems for the Sydney, Blue Mountains, Illawarra and Shoalhaven regions



In addition to the water consumed by Sydney Water's customers, water is extracted directly from the rivers for a range of uses including industry, town water supplies, irrigation of agricultural land and riparian uses (refer to Section 7 for more detail on primary industry water usage). In the Hawkesbury-Nepean River, this extraction may be up to 100 GL per year. The rate of extraction is highly variable. The 8 GL per year (22 ML/day) for the North Richmond water distribution system (extracted from the Hawkesbury River) is the only constant extraction (HNRMF 2004).

The North Richmond Water Filtration Plant draws its raw water directly from the Hawkesbury River at North Richmond. This plant can treat up to 50 ML/day and supplies high quality drinking water to approximately 16,000 lots in Hawkesbury region including North Richmond, Richmond, Toorah, South Windsor, Pitt Town, Wilberforce, Kurrajong and Glossodia. The North Richmond Water Filtration Plant treats water from the Hawkesbury River to a standard that meets the National Health and Medical Research Council (NHMRC) guidelines for drinking water.

A human health risk assessment has been undertaken for the Project- including assessing risks associated with drinking treated and untreated water from the river. A copy of the human health assessment has been included as **Appendix D** to the Environmental Assessment.

3.2.2 Environmental flows

In addition to managing the dams for potable water supply, the Sydney Catchment Authority (SCA) is also responsible, under the terms of its Water Management License, for releasing flows from dams as 'interim environmental flows' into the rivers downstream of the dams. Water is also released to meet basic landholder rights and to ensure that a minimum flow of 50 ML/day is maintained over the Penrith Weir, if required. The latter requirement dates from the construction of Warragamba Dam and was designed to ensure adequate water remained available for downstream riparian users and town water supply requirements (HNRMF 2004).

During dry weather, and under current operating rules, the dams in the Upper Nepean make a constant 'interim environmental flow' release equivalent to the 95th percentile flow (refer to **Table 3-2** for details). This is a relatively small flow that represents a small portion of the mean annual flow. The bulk of the average flows downstream of the dams are made up of spills during flood events.

In a wet year the dams may spill many times, with spills persisting for many weeks. However, during a drought spills may not occur for periods of up to 5-10 years. The residual catchment area between Pheasants Nest Weir and the Warragamba River junction is similar to the combined catchment area of the Upper Nepean Dams, although runoff is not as high due to lower rainfall in this catchment area. The Upper Nepean River includes 14 compensation weirs, which were constructed to maintain sufficient water depth to allow irrigators to extract water by pumping. These weirs do not have any outlets and only pass flows when they are full and spilling. During dry weather, the summer irrigation demand frequently exceeds the river flows generated by the residual catchment and environmental flow releases. Hence, the weir water levels are drawn down below the crest and flow essentially ceases. During these periods the river becomes a sequence of pools. The Upper Nepean River also receives discharge from the West Camden STP. The discharges from the West Camden STP are small compared to average annual river flow, but represent a significant proportion of flow during dry weather.

Table 3-2: Interim Environmental Flow Releases from Water Supply Dams/Weirs

Water Management Works	95th Percentile Flow Estimates (ML/d)
Cataract Dam	1.3
Nepean Dam	4.4
Cordeaux Dam	1.9
Avon Dam	1.8*
Pheasants Nest Weir	10.5
Broughtons Pass Weir	1.7
Warragamba Dam	33.3

* The outlet works on Avon Dam do not normally allow the release of the interim environmental flows. This will be remedied by late 2006 in conjunction with capital works currently underway at the dam.

The current water management licence was issued to the SCA on 23 April 2001 by the (then) Department of Land and Water Conservation. The licence was issued to manage the SCA's access to water resources within its area of operations in accordance with the principles of ecologically sustainable development. Schedule 4 of the licence specifies the environmental releases to be made from each of the SCA's water management works (current releases are summarised in **Table 3-2**). Other water releases for riparian purposes are specified under Schedule 5 of the water management licence (currently 10ML/day is discharged from Warragamba Dam for riparian purposes).

In accordance with licence condition 7.6, a temporary variation to the terms of the licence for a specified time period upon written application by the SCA may be approved. The SCA has utilised this provision during the current drought to negotiate reductions and suspensions of release requirements as a drought management measure to preserve water in storage for supply of drinking water. Accordingly, the current Warragamba Dam release has been reduced from 43.3 ML/day to 22 ML/day in response to the current drought conditions.

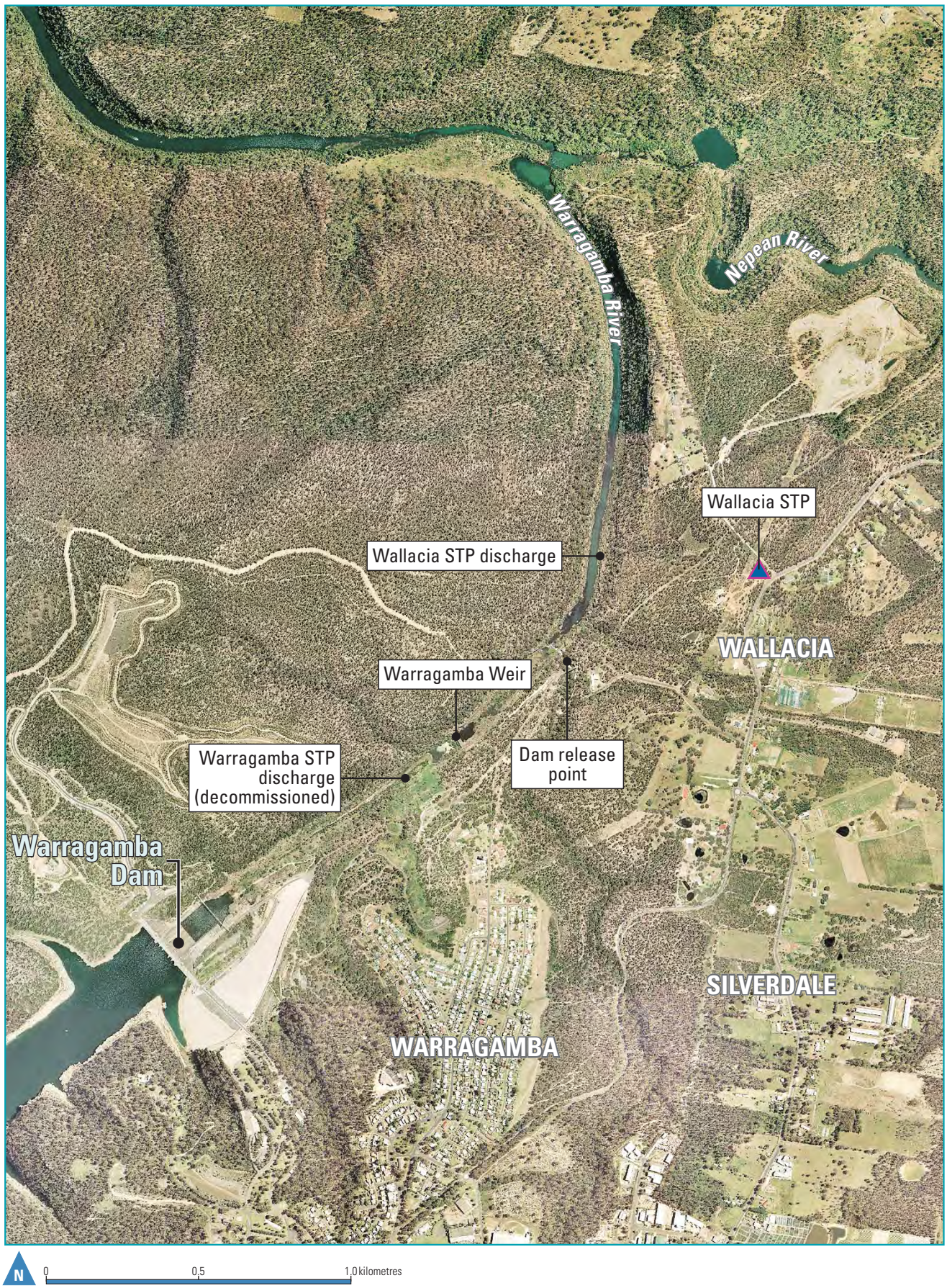
3.2.3 Hydrological characteristics of the study area

This section provides a description of the hydrological characteristics for each of the study waterway reaches.

Warragamba River

Warragamba River has been altered by the construction of Warragamba Dam. The dam has reduced the length of the river to approximately 3.5 km. The remaining section of the river (downstream of the dam wall to the confluence with the Nepean River) is divided into two distinct sections, which are separated by the Warragamba Weir. Environmental flow releases from the dam are discharged into the river downstream of the weir at Megarritys Creek via the Warragamba to Prospect water supply pipeline. The section of river upstream of Warragamba Weir, a distance of approximately 1.4 km, receives no environmental flow release. However, it receives seepage flows from Warragamba Dam (approximately 0.3 ML/day) and up to August 2006 effluent discharges (approximately 0.41 ML/day) from the Warragamba STP.

Figure 3.3 Location of water management infrastructure of Warragamba River



The Warragamba STP was decommissioned in August 2006 and was replaced by a new STP (called Wallacia STP). The Wallacia STP receives flows from the existing sewer catchment of the Warragamba township and future connections are planned from previously unsewered areas of Warragamba, Wallacia and Silverdale. Following connection of all of the unsewered dwellings, the Wallacia STP will discharge approximately 1.4 ML/day downstream of the Warragamba Dam environmental flow release point. **Figure 3-3** shows the location of the associated water management infrastructure that have had or have an influence on the flow regime of Warragamba River.

In addition to the above, Penrith Weir also influences the flow regime of Warragamba River. The reach downstream of Warragamba Weir contains a sequence of rock bars and pools that have been drowned by backwater from Penrith Weir. It is estimated that the residence time for the environmental flow releases from Warragamba Dam to Penrith Weir is approximately 180 days due to the effect of this weir pool.

During dry weather and under current operating rules, the Sydney Catchment Authority is required to make a constant interim environmental flow release equivalent to the 95th percentile flow from Warragamba Dam, which is 33.3 ML/day and an additional 10 ML/day to provide for riparian users. There is also a requirement to maintain a minimum flow of 50 ML/day at Penrith Weir, which typically requires Warragamba Dam to make additional releases since flows from the Upper Nepean system are often negligible. Due to the drought, the SCA is currently releasing about 22 ML/day from the dam to preserve potable water supplies. In wet years the dam may spill several times, with spills persisting for many weeks. However, during droughts it is common to experience periods of up to ten years without spills occurring.

Nepean River - Wallacia Weir to Penrith Weir

Key features of this reach include the long pool formed behind Penrith Weir (which extends for a distance of approximately 18 km). Under existing conditions, environmental flow releases from the Upper Nepean Dams often do not reach the Nepean River at Wallacia Weir, which is just upstream of the Warragamba River junction. Flows greater than the 60th percentile are required to produce any measurable flows over Wallacia Weir. Below the 60th percentile the upper section of this reach only receives flow from the Warragamba River from the dam releases.

Between the junction of Warragamba River and Penrith Weir, the Nepean River receives inflow from a number of tributaries and surrounding catchment. Approximately 62 ML/day flows over Penrith Weir under very low flow conditions (95th percentile). Under median flow conditions (50th percentile) approximately 146 ML/day flows over Penrith Weir.

Nepean River - Penrith Weir to Yarramundi

Immediately downstream of Penrith Weir, Boundary Creek flows into the Nepean River. Boundary Creek is the discharge location for Penrith STP, which discharges approximately 22 ML/day of tertiary treated effluent into the creek.

Further downstream, Winmalee STP discharges approximately 15 ML/day of tertiary treated effluent to this reach and a small tributary contributes approximately 3 ML/day. The Grose River, which is downstream of Yarramundi, contributes approximately 60 ML/day in low flow conditions to this reach.

The river reach downstream of Penrith Weir has been significantly modified due to sand and gravel mining, producing artificial low flow velocities, which has impacted on habitat conditions.

Hawkesbury River - Yarramundi to Sackville

The Upper Hawkesbury River extends from Yarramundi to Lower Portland. This reach is a large freshwater tidal pool which is bounded upstream by the Nepean River and downstream by saline waters from the estuary. The vast majority of water in the freshwater tidal pool is from large wet weather inflows which are trapped behind the saline estuarine water, rather than from dry weather catchment flows and STP discharges.

Redbank Creek contributes only approximately 1 ML/day to this reach under dry conditions, which is predominately from tertiary treated effluent from the North Richmond STP. Flows from South Creek are augmented by the discharge of tertiary treated effluent from several STPs that operate within the South Creek catchment. Irrigation extractions occur along this reach, which can be significant in dry weather during summer, when irrigation demands may occasionally exceed natural river inflows.

South Creek catchment

South Creek catchment covers an area of approximately 620 km^2. The main tributaries include Eastern Creek, Badgerys Creek and Ropes Creek. During low flow conditions 70 to 80 ML/day of water flows into the Hawkesbury River from the South Creek catchment. The lower reach of South Creek is tidal affected.

There are five sewage treatment plants that operate within the South Creek catchment area. Sydney Water operates three of these plants, which are a dominant flow source within the catchment. St Marys STP discharges approximately 36 ML/day of highly treated tertiary effluent to Ropes Creek. Quakers Hill STP discharges approximately 31 ML/day of highly treated tertiary effluent to Breakfast Creek (a tributary of Eastern Creek). The dry weather base flow upstream of both the St Marys and Quakers Hill STPs is approximately 0.5 ML/day. Riverstone STP discharges approximately 2 ML/day of effluent to the lower reach of Eastern Creek, near Bandon Road. Other STPs (not operated by Sydney Water) that discharge to the lower reach of South Creek include South Windsor and McGraths Hill, which have a combined discharge volume of approximately 5.5 ML/day.

Other Relevant Areas

Boundary Creek

Boundary Creek discharges to the Nepean River approximately 50m downstream of the Penrith Weir. Flows in Boundary Creek are dominated by the discharge of highly treated tertiary effluent from Penrith STP (approximately 22 ML/day).

Penrith STP discharges to Boundary Creek via a concrete culvert towards the upper reach of the creek. Boundary Creek is an ephemeral stream above the Penrith STP discharge point, which only receives flow from surrounding parklands and stormwater drains from urban and light industrial catchment areas.

3.3 Assessment of Impacts

The Department of Natural Resources is currently preparing a Water Sharing Plan, which will provide statutory rules for the management and sharing of water within the Hawkesbury-Nepean River system. The implementation date for the Water Sharing Plan has not yet been determined, however the NSW Government has committed, in the *2006 Metropolitan Water Plan*, to implementing a number of key elements of the Water Sharing Plan in 2009 that are relevant to the

Project. One of the key elements of the Water Sharing Plan to be implemented in 2009 would be new environmental flow rules for the Upper Nepean Dams in line with the recommendations of the Hawkesbury-Nepean Independent Expert Panel.

The proposed environmental flows vary according to the dam inflow and provide greater variability and volume of releases than the current 'interim rules', which are based on a fixed release. The new environmental flow rules aim to protect all low flows that fall below a nominated trigger value, so that they are passed through the dam and released. This portion of the protected flow is referred to as 'transparent flow' (i.e. all flow passes as though the dam was transparent). A fixed proportion of flow above this trigger value will also be passed and this flow is referred to as translucent flow. The proposed flow rules are summarised in **Table 3-3** and **Table 3-4** provides an example of how the environmental flows will work, by showing the releases that would apply at Nepean Dam for different inflow conditions. For Warragamba Dam, the *2006 Metropolitan Water Plan* commits to maintaining the 'interim flow' releases until 2009 when a review of the proposed flow rules and water availability would be undertaken. Final flow rules for dam would be implemented in 2015.

Other elements of the *2006 Metropolitan Water Plan* that will be introduced to ensure effective delivery of environmental flows include:

- modification of weirs in the Upper Nepean to allow environmental flows to pass downstream; and
- protection of low flows through a 'cease to pump' rule for irrigators.

It should be noted that the transparent flows for the Upper Nepean Dams are based on the 80th percentile flow and are much higher than the proposed transparent flow for Warragamba Dam, which is based on the 95th percentile flow. The more generous allocation for the Upper Nepean Dams is partly because the Upper Nepean River has a longer flow path and the instream and riparian environments are of a higher quality and would respond favourably to increased flows. Also rainfall is higher in the coastal catchments of the Upper Nepean Dams compared to Warragamba Dam. Other factors that influence flow conditions within the Hawkesbury-Nepean River system, below Warragamba Dam, are:

- the Lower Nepean River, upstream of Penrith, is entirely flooded by Penrith Weir which has very large storage relative to the environmental flows. The storage in the weir pool is estimated to be 6,000 ML, meaning that a release of 33.3 ML/day from Warragamba Dam will take approximately 180 days to pass through this reach, having an insignificant impact on hydraulic properties and water quality;
- the Lower Nepean River, downstream of Penrith, has been greatly enlarged due to sand mining and has a large volume relative to the environmental flow; and
- the Hawkesbury River receives inflows from the residual catchment which is much larger than the proposed environmental flow releases from Warragamba Dam.

The proposed environmental flows require infrastructure upgrades to the outlets of some of the dams before they can be implemented. These upgrades will be implemented before the operation of the Project.

Table 3-3: Environmental Flow Releases Proposed for 2009

Location	Transparent Trigger Value	Translucent Ratio
Nepean Dam	80th percentile flow (28.5 ML/d)	20% of flow above trigger
Avon Dam	80th percentile flow (10.4 ML/d)	20% of flow above trigger
Cordeaux Dam	80th percentile flow (12.6 ML/d)	20% of flow above trigger
Cataract Dam	80th percentile flow (16.5 ML/d)	20% of flow above trigger
Pheasants Nest Weir	80th percentile flow (63.0 ML/d)	20% of flow above trigger
Broughtons Pass Weir	80th percentile flow (20.3 ML/d)	20% of flow above trigger
Warragamba Dam*	33.3 ML/d + 10 ML/day riparian releases	None

* Note: The recommended environmental flow release from Warragamba Dam is 95th percentile transparent trigger flow and 20% of translucent flow above trigger. A review to increase environmental flow releases would be undertaken in 2009 and would be dependent on water availability. Final rules would be developed by 2015.

Table 3-4: Example of Environmental Flow Releases for Nepean Dam

Dam Inflow (ML/day)	Environmental Release (ML/day)	Explanation
10	10#	Inflow < Transparent Trigger –► Release = inflow
28.5	28.5#	Inflow = Transparent Trigger –► Release = inflow
50	32.9#	Inflow > Transparent Trigger –► Release = 28.5 + (0.2*(50-28.5))
500	122.8	Inflow > Transparent Trigger –► Release = 28.5 + (0.2*(500-28.5))

Note: A higher release may be required to maintain a minimum flow of 50 ML/day at Penrith Weir, although this requirement will generally be met by releases from the Upper Nepean Dams following implementation of the revised environmental flow releases.

Changes to the hydrology of the Hawkesbury-Nepean River system, as a result of the Replacement Flows Project was assessed through hydrologic modelling (SMEC 2006). Modelling was used to simulate daily flows over a 25 year time period for a range of different scenarios in order to allow the hydrologic impact of the Project to be quantified. Modelled flow conditions for key study locations are presented in **Table 3-5**.

A comparison between existing non-drought flows with the predicted 2009 flow conditions is shown in **Figure 3-4**. A comparison between existing drought flows with the predicted 2009 flow conditions is shown in **Figure 3-5**.

The flow values presented in **Table 3-5**, **Figure 3-4** and **Figure 3-5** form the basis of the hydrology assessment presented below and the water quality assessment in Chapter 4.

Table 3-5: Modelled flow conditions at key study area locations

Location	Percentile Flow (%)	Current Non-Drought Flows (ML/day)	Current Drought Flows (ML/day)	Predicted Flows in 2009 with RFP (ML/day)
Wallacia Weir	95	0	0	39
	90	0	0	52
	80	0	0	74
	50	14	14	99
	20	250	250	350
Junction of Warragamba River & Nepean River	95	43	22	39
	90	43	22	52
	80	43	22	74
	50	57	36	99
	20	293	272	350
Penrith Weir	95	62	41	67
	90	75	54	86
	80	91	70	115
	50	146	125	189
	20	2000	1979	2100
Discharge via Boundary Creek	All flow conditions	22	22	50
Downstream of Penrith Weir	95	84	63	117
	90	96	75	136
	80	113	92	165
	50	168	147	239
	20	2022	2001	2150
St Marys (South Creek)	All flow conditions	36	36	5
Quakers Hill (Eastern Creek)	All flow conditions	31	31	14

Based upon the table above the impacts associated with the operation of the project in wet weather (20^{th} percentile) are negligible, as catchment run-off and Upper Nepean Dam releases would dominate flows in the river (e.g. flows from the AWTP downstream of Penrith Weir would be less than 3% of the wet weather total flow). Also the 2009 wet weather flows would be higher than existing wet weather flows. Consequently the impacts associated with the operation of the Project during wet weather conditions is not further discussed.

Figure 3.4 Comparison of existing non drought flows with predicted 2009 flows (with Replacement Flows Project)

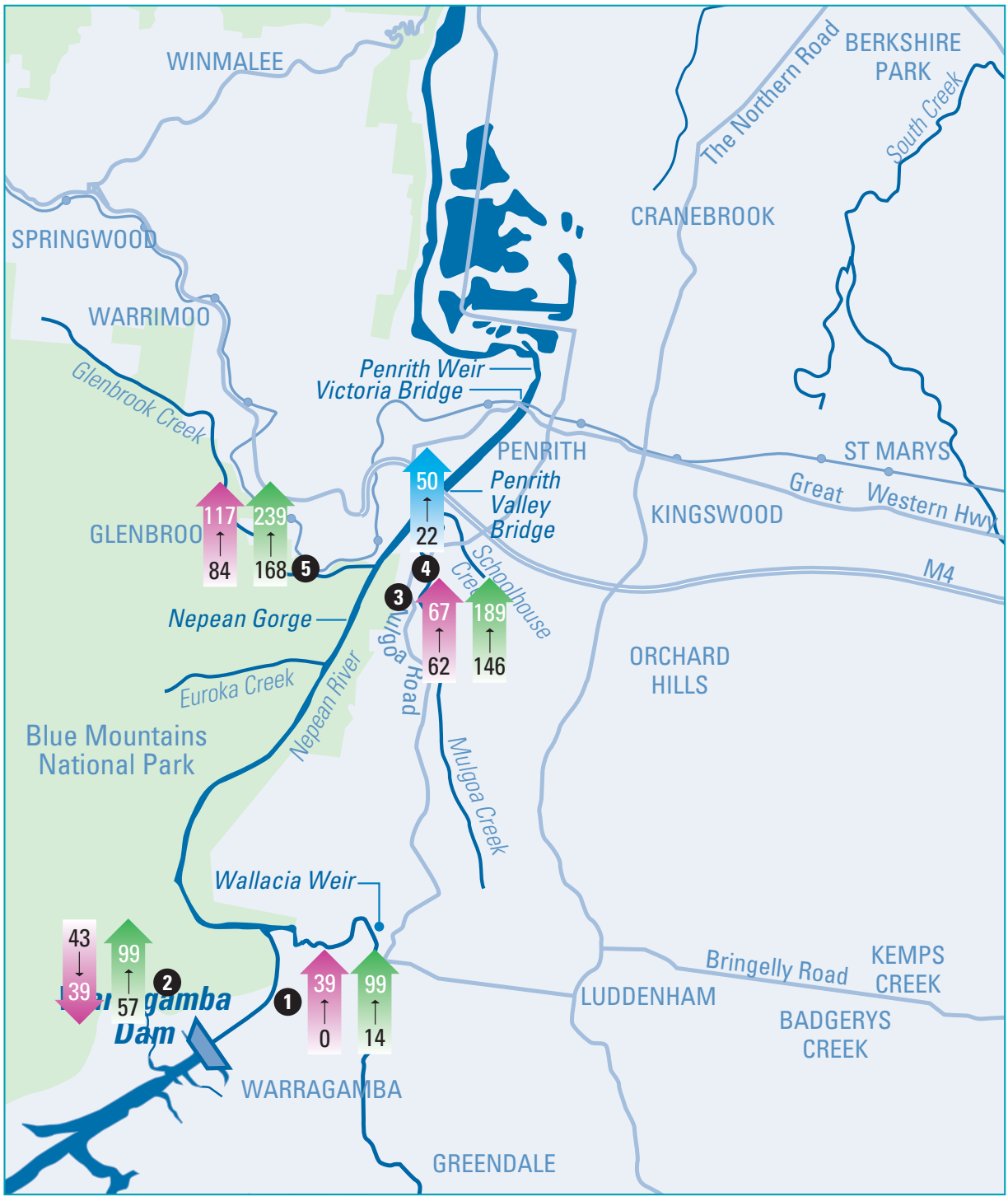
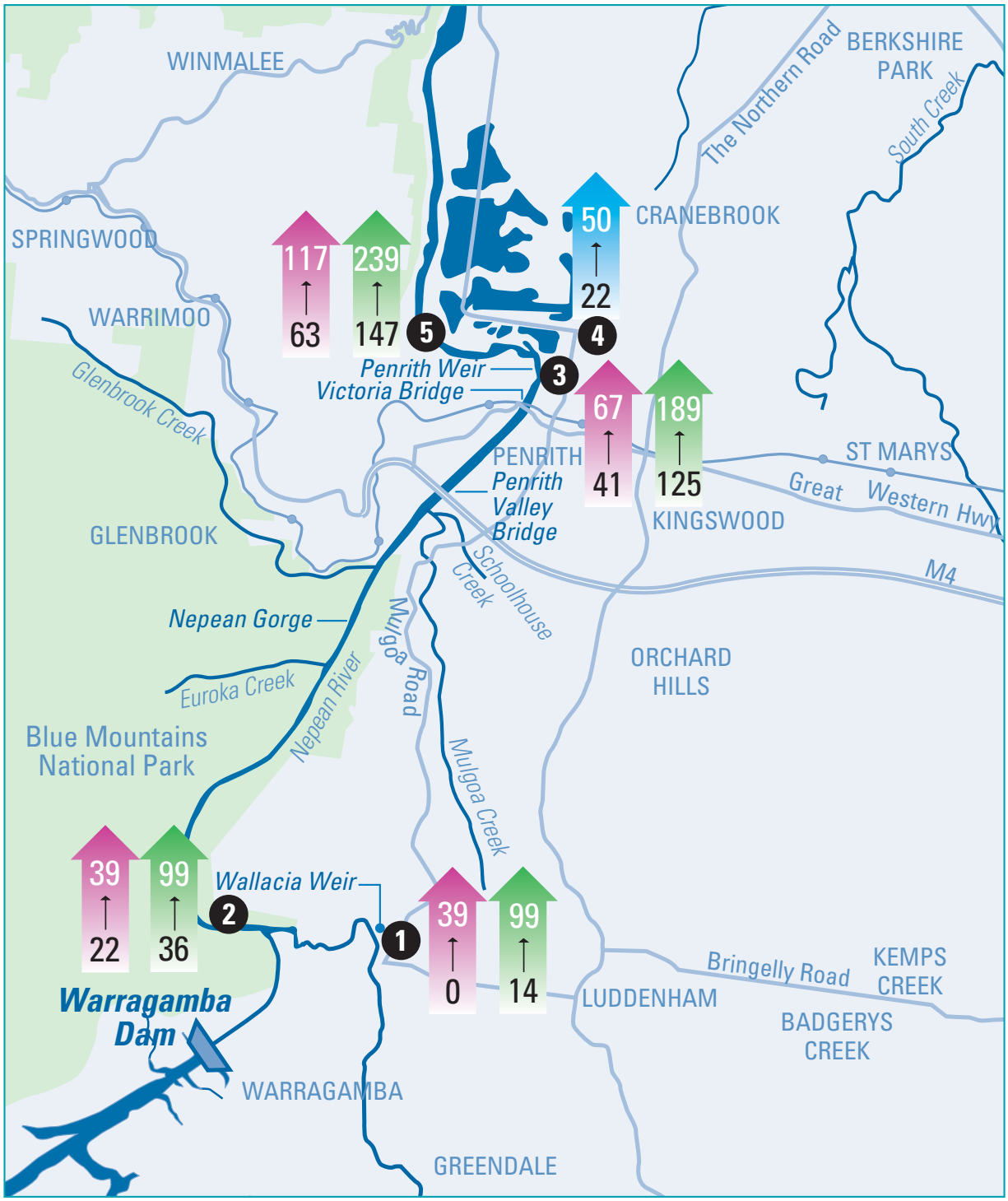


Figure 3.5 Comparison of existing drought flows with predicted 2009 flows (with Replacement Flows Project)



1. Wallacia Weir
2. Junction of Warragamba River and Nepean River
3. Penrith Weir
4. Discharge via Boundary Creek
5. Downstream of Penrith Weir

Low flows: Current 43 ↓ 2009 39

Median flows: 2009 99 ↑ Current 14

All flow conditions (STP or AWTP discharges): 2009 50 ↑ Current 22

3.3.1 Warragamba River

The reach upstream of Warragamba Weir (and discharge location for Warragamba Dam environmental flow releases) would continue to receive significant flows on the rare occasions when the dam spills. Otherwise this reach of the river would only receive low flows from its small catchment area and seepage from the dam.

The section of Warragamba River downstream of the weir would not receive the interim flow releases from Warragamba Dam and would experience long periods without effective flow (see **Figure 3-4** and **Figure 3-5**). Although the Penrith Weir pool would ensure the river does not run dry as downstream of Warragamba Weir is drowned by backwater from Penrith Weir.

With the cessation of the Warragamba Dam releases, the new Wallacia STP would contribute a major portion of flows within the Warragamba River. This would influence water quality conditions within the river with an increased residence time for discharged effluent. Options would be developed to ensure that the discharge from this STP does not have unacceptable environmental impacts. Small volume releases of water from Warragamba Dam may be considered to flush the river to dilute and transport the slow accumulation of nutrients within this reach.

Environmental flow releases from Warragamba Dam would be reviewed in 2009 and final rules established in 2015 as part of the Water Sharing Plan.

3.3.2 Nepean River - Wallacia Weir to Penrith Weir

With the increased releases from the Upper Nepean Dams, the modification of Upper Nepean River weirs and the protection of low flows from extraction, higher flows would be experienced in the upper section of this reach (**Figure 3-4** and **Figure 3-5**). However, due to the cessation of the interim flow releases from Warragamba Dam, the flow over Wallacia Weir would be the major source of inflow into this reach. Apart from very low flows (95th percentile), the flows over Wallacia Weir would be higher than the existing flows in this section of the river. This is particularly evident for median flow where flows would be almost twice the current flow volume (**Figure 3-4**).

For very low flows (95th percentile) there would a small decrease in flow (39 ML/day) compared to the existing non-drought situation (43 ML/day) at the junction of Warragamba River and Nepean River (**Figure 3-4**). However, downstream of this location, flows would increase (primarily due to the protection of low flows from extraction) until Penrith Weir where very low flows (67 ML/day) would be higher than the existing situation (62 ML/day). The median flows over Penrith Weir (189 ML/day) would also be higher than the existing situation (146 ML/day).

3.3.3 Nepean River - Penrith Weir to Sackville

Boundary Creek which flows into the Nepean River downstream of Penrith Weir currently receives 22 ML/day of tertiary treated effluent from Penrith STP. With the project the Penrith STP discharge would cease and instead up to 50 ML/day of highly treated recycled water would be discharged, providing an additional source of flow for this section of the river. Combined with the increased flow associated with the 2009 changes to river management, the flows downstream of Penrith Weir (117 ML/day) would be higher in very low flow conditions compared to the existing situation (84 ML/day). For median flows (50th percentile) flows (239 ML/day) would also be higher than the existing flows (168 ML/day).

Up to 70% of the tertiary treated effluent currently discharged into South Creek by Quakers Hill and St Marys STPs would be diverted to the AWTP as a result of the Project. This would result in a decrease in the volume of water flowing into the freshwater tidal pool from South Creek in dry weather.

However it should be noted that the freshwater tidal pool is not dependent on dry weather flows to maintain water levels. The vast majority of water in the freshwater tidal pool is from large wet weather inflows, which are trapped behind the saline estuarine water, rather than from dry weather catchment flows and STP discharges. The reduction in flows into the freshwater tidal pool from South Creek would be compensated for by the increased flows from the Nepean River upstream of Yarramundi. Therefore it is not expected that the reduced discharge would affect water levels or availability in the freshwater tidal pool.

There would be negligible movement of the interface between saline and freshwaters due to the project.

3.3.4 South Creek

As noted above, a significant volume of tertiary treated effluent would be diverted from Quakers Hill and St Marys STPs as a result of the project (i.e. in 2009 30 ML/day from St Marys and 14 ML/day from Quakers Hill). This compares with the current STP discharges of approximately 31 ML/day from Quakers Hill STP and 36 ML/day from St Marys STP.

Effluent from the STPs dominates the flow conditions in the South Creek catchment, especially during prolonged dry weather periods when the upstream catchment contribution is only approximately 1 ML/day. The significant reduction in effluent discharges from the STPs would result in flows in the South Creek catchment returning to a more natural regime. However, the STP flows would still dominate low flow conditions.

3.3.5 Boundary Creek

Boundary Creek is a small tributary of the Hawkesbury-Nepean River, with a catchment of 304 ha, which flows into the main river channel about 50 m downstream of Penrith Weir. Its relevance to the Project is that approximately 22 ML/day of tertiary treated effluent from Penrith STP is currently discharged into the creek, approximately 500m upstream of its junction with the Nepean River.

Downstream of the Penrith STP, Boundary Creek crosses under Castlereagh Road through a culvert before entering an industrial and commercial zone. A 10 - 20 m riparian zone either side of the creek has been maintained through this area, which increases in width as the creek flows towards the Nepean River. The riparian zone is heavily infested with weeds and there is some re-growth of endemic native vegetation. There is evidence of significant erosion of alluvial soils in the lower sections of the creek, near the confluence with the Nepean River.

The creek catchment does not contribute any flows to the creek in dry weather. However, in wet weather flows in the creek increase significantly. For a 1 in 2 year storm estimated flows are 3,255 ML/day, increasing to 5,731 ML/day for a 1 in 20 year storm. These volumes are significantly greater than the current Penrith STP discharge of 22 ML/day and the proposed replacement flow of 50 ML/day.

An assessment was undertaken of the potential of the current discharge and proposed replacement flows discharge to cause erosion of the alluvial areas currently affected. In the eroding stretch of the creek, the current discharge has a depth between 0.1 to 0.3m and a velocity

between 0.1 to 0.7 m/s. With the discharge of the replacement flows the depth would increase marginally to between 0.1 to 0.5m and velocity to between 0.2 to 0.9 m/s. This water depth is within the natural channel and below the level of alluvial sediments which are eroding. There would also not be sufficient velocity to cause any significant additional erosion. The main causes of the erosion appear to be high wet weather flows and receding floodwaters from the Nepean River. Consequently no additional mitigation measures are required to manage erosion in Boundary Creek, which may result from operation of the Project.

3.3.6 Flow Variability

The planned Upper Nepean Dam releases would provide a significant increase in flow variability across all flow conditions. The increase in flow variability would be most notable upstream of Penrith Weir. Downstream of Penrith Weir, there would be some loss in the gained variability due to the consistent discharge of replacement flows. The loss of variability would decrease as flow in the river increases, as the replacement flows would make up a smaller proportion of the total flow. Compared to the existing situation, the flow regime would exhibit greater variability. It should also be noted that the discharge location for the replacement flows is not far upstream of the freshwater tidal pool within the Hawkesbury River. Flow velocities in the freshwater tidal pool do not vary greatly (except in large wet weather events) because of the regulating effect of the natural saline estuarine barrier.

When environmental flow releases from Warragamba Dam are reviewed (as stated within the 2006 Metropolitan Water Plan) there may be further increases in variability if transparent and translucent dam releases are adopted.

4. Water Quality

4.1 Introduction

This chapter describes the existing water quality conditions within the study area. It also provides an assessment of impacts from the operation of the Project.

Why water quality is important?

Water quality, in conjunction with flow, is critical for maintaining the health of waterways upon which ecosystems, adjoining landuses and water users depend. Water quality is measured through a number of physico-chemical and chemical parameters (indicators) which give an indication of the suitability of the water for sustaining aquatic life, undertaking recreational activities, for human consumption and agricultural use. The factors influencing water quality include flows and pollutant contributions to the river system, from both diffuse and point sources.

Water quality in the Hawkesbury-Nepean River system has been significantly impacted by changing land uses within the catchment including increased rural, urban, and industrial development. These land uses contribute nutrients, bacterial contamination, chemical contaminants and sediment to the Hawkesbury-Nepean River. Significant sources of pollutants include stormwater runoff (diffuse source) and sewage treatment plant discharges (point source).

Why is this topic important in relation to the Replacement Flows Project?

The Replacement Flows Project would change the location and volume of treated water discharges to the Hawkesbury-Nepean River, with its primary impact on the loads of nutrient loads into the river. The impacted waterways would include South Creek and its tributaries, the Lower Nepean River and the Upper Hawkesbury River. In addition to the Replacement Flows Project, upgrade works at West Camden STP and the re-use of tertiary treated effluent in a number of local schemes would also reduce the loads of nutrients contributed to the river system.

4.2 Relevant water quality indicators

Water quality was assessed using relevant water quality indicators compared against appropriate guidelines. The appropriate water quality guidelines for this project are:

- Default trigger values for chemical and physical stressors for the protection of aquatic ecosystems for south-east Australia for slightly disturbed estuarine and lowland river ecosystems as outlined in the *Australian and New Zealand Guidelines for Fresh and Marine Water* (ANZECC/ARMCANZ 2000)
- Recommendations made by the Healthy Rivers Commission (HRC, 1998) for nutrients (total phosphorus and total nitrogen) and chlorophyll-*a.*

Guideline values vary depending on the location of the site within the river system. ANZECC/ARMCANZ (2000) recommends guidelines for a range of ecosystem types of which lowland rivers and estuarine ecosystems are represented in the study area. Lowland rivers for South-east Australia are defined as those at less than 150m altitude.

The Healthy Rivers Commission identified a number of landuses present within the Hawkesbury-Nepean catchment and assigned relevant guidelines for nutrients and chlorophyll-*a* in accordance with the impact these landuses would have on water quality. The landuses relevant to this study are mixed use rural areas, urban mainstream, tributary streams and estuarine areas. **Table 4-1**

shows the water quality guidelines that have been used in this assessment. Compliance with guidelines and the corresponding discussion will focus on water quality during periods of low flow (less than the 95th percentile flows), together with median concentrations for relevant indicators. The primary focus for this assessment, however, is during periods of low flows as the discharge of replacement flows would make up a larger proportion of the total flow in the river and consequentially has its greatest potential impact. There would also be a significant reduction in the discharge of tertiary treated effluent into South and Eastern Creeks which would reduce the load of nutrients discharged in low flow conditions when tertiary treated effluent discharges makes up the majority of flow in these creeks.

Wherever possible, water quality data from 2000 to 2006 has been used to determine existing water quality except for Warragamba River which uses data during the period of 1994 to 2000. Although good quality data is available before 2000, there were a number of upgrades to STPs discharging to Hawkesbury-Nepean River in the 1980's and 1990's which have resulted in improvements to water quality. Therefore, data before 2000 is not representative of the current water quality conditions in the river.

Table 4-1: Relevant Guidelines for Assessment of Existing Water Quality

Water Quality Indicator	Guideline value	Source
Turbidity (NTU)	6-50 (lowland river) 0.5-10 (estuarine)	ANZECC/ARMCANZ (2000)
Conductivity (μS/cm)	125-2200 (lowland river) N/A (estuarine)	ANZECC/ARMCANZ (2000)
pH	6.5-8.0 (lowland river) 7.0-8.5 (estuarine)	ANZECC/ARMCANZ (2000)
Dissolved Oxygen (% saturation)	85-110 (lowland river) 80-110 (estuarine)	ANZECC/ARMCANZ (2000)
Ammoniacal Nitrogen (mg/L)	<0.02 (lowland river) <0.015 (estuarine)	ANZECC/ARMCANZ (2000)
Oxidised Nitrogen (mg/L)	<0.04 (lowland river) <0.015 (estuarine)	ANZECC/ARMCANZ (2000)
Total Nitrogen (mg/L)	<0.7 (mixed use rural areas) <0.5 (urban areas- mainstream) <1 (urban areas – tributary stream) <0.4 (estuarine)	HRC (1998)
Filterable Phosphorus (mg/L)	<0.02 (lowland river) <0.005 (estuarine)	ANZECC/ARMCANZ (2000)
Total Phosphorus (mg/L)	<0.035 (mixed use rural areas) <0.03 (urban areas mainstream and estuarine) <0.05 (urban areas – tributary stream)	HRC (1998)
Chlorophyll-*a* (μg/L)	< 20 (urban areas mainstream and tributary stream) < 7 (estuarine and mixed used rural areas and sandstone plateau)	HRC (1998)
Faecal Coliforms (CFU/100mL)	Median <150cfu/100mL (primary contact recreation) Median <1000cfu/100mL (secondary contact recreation)	ANZECC/ARMCANZ (2000)
Enterococci (CFU/100mL)	Median <35cfu/100mL (primary contact recreation) Median <230cfu/100mL (secondary contact recreation)	ANZECC/ARMCANZ (2000)

4.3 Existing Environment

4.3.1 Warragamba River

The Warragamba River downstream of Warragamba Dam to the confluence with the Nepean River can be characterised into two water bodies, which are separated by the Warragamba River Weir. The water quality of Warragamba River is influenced by seepage from the dam, the discharge of treated wastewater from Wallacia STP and the release of interim environmental flows from Warragamba Dam. Typical water quality in Warragamba River is presented in **Table 4-2** and is based upon water quality data collected from station N641during the period 1994 to 2000.

Table 4-2: Water quality data for Warragamba River downstream of Warragamba Dam

Item	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Ammonia (mg/L)
Measured data at N641 (median)	0.49	0.0220	0.0100

4.3.2 Wallacia Weir to Penrith Weir (Nepean River)

There are two monitoring sites in the Nepean River in this river reach as shown in **Table 4-3.** One site (N67) is upstream of the confluence with Warragamba River and one site, N57 is downstream of the confluence with Warragamba River. All sites are classified as lowland river ecosystems situated in mixed use rural landuse areas and have been assessed against the guidelines relevant to those areas.

Table 4-3: Water Monitoring Sites in the Nepean River Catchment

Site Code	Site Name	Monitoring Organisation	Data range	HRC Classification
N67	Nepean River at Wallacia	SCA	Jan 2000 – Jul 2006	Mixed use rural area
N57	Nepean River at Penrith Weir, upstream Boundary Creek (and Penrith STP)	SWC and SCA	Jan 2000 – Jun 2006	Mixed use rural area

The Nepean River at Wallacia Weir (N67) is impacted by tertiary treated effluent discharged from West Camden STP. Low flow and median results and compliance with guidelines are shown in **Tables A-1** and **Figures A-1** to **A-14** of **Attachment A.**

The physico-chemical indicators of water quality in this reach of the river generally complied with relevant guidelines. A turbidity of less than 4.5NTU was recorded at all sites during low flows and with only minor increases in median turbidity recorded due to runoff from the catchment. Dissolved oxygen levels were generally within the acceptable range of 85% to 110% saturation (ANZECC/ARMCANZ, 2000), although during low flow dissolved oxygen decreased to less than 85% saturation at Penrith Weir (N57)**.** Conductivity was higher at the sites upstream of the Warragamba River confluence, particularly during low flows. At Penrith Weir (N57), conductivities were at their lowest for this reach of the river.

Wallacia Weir (N67) had concentrations of nitrogen that were higher than relevant guidelines levels with the source of nitrogen likely to be tertiary treated effluent discharge from West Camden STP. During low flow the impact is more evident as the tertiary treated effluent makes up a greater proportion of the flow than during periods of higher flows. Nitrogen levels at Penrith Weir (N57) were lower than at the sites downstream of the Penrith STP discharge and complied with relevant guidelines.

In contrast, total phosphorus concentrations in the Nepean River at both Wallacia Weir (N67) and Penrith Weir (N57) were generally good, complying with the relevant HRC (1998) guidelines. At Penrith Weir (N57), filterable phosphorus concentrations also complied with the ANZECC/ARMCANZ (2000) guideline for both low flow and median concentrations.

All sites in this reach of the Nepean River had median and low flow faecal coliforms densities that complied with the primary contact recreation guideline of 150 CFU/100mL. In contrast, median Enterococci densities were elevated at Penrith Weir (N57) and compliance with the primary contact recreation guideline of 35 CFU/100mL was poor. Compliance with the secondary contact recreation guideline (ie. boating) of 230 CFU/100mL for Enterococci was achieved at all sites.

The Healthy Rivers Commission (1998) recommends chlorophyll-*a* concentrations less than $7 \mu g.L^{-1}$ for mixed use rural areas. Both low flow and median chlorophyll-*a* concentrations at Wallacia Weir (N67) and Penrith Weir (N57) were low and complied with the guidelines.

4.3.3 Penrith Weir to Yarramundi (Nepean River)

Downstream of Penrith Weir in the Nepean River to Yarramundi Bridge there are three water quality monitoring sites (refer **Table 4-4**). All sites are downstream of the Penrith STP discharge and are classified as lowland river ecosystems with mixed-use rural landuses.

Table 4-4: Water Monitoring Sites – Penrith Weir to Yarramundi Bridge

Site Code	Site Name	Monitoring Organisation	Data range	HRC Classification
N53	Nepean River at BMG Causeway, 700m downstream Boundary Creek (and Penrith STP)	SWC	Jan 2000 – Jun 2006	Mixed use rural area
N48	Nepean River at Smith Road, 8.7km downstream Boundary Creek (and Penrith STP)	SWC	Jan 2000 – Jun 2006	Mixed use rural area
N44	Nepean River at Yarramundi Bridge	SCA	Jan 2000 – Jul 2006	Mixed use rural area

Low flow and median results and compliance are shown in **Table A-2** and **Figures A-1** to **A-14** of **Attachment A.**

The physico-chemical indicators of water quality in this reach of the river generally complied with relevant guidelines. A turbidity of less than 4.5NTU was recorded at all sites during both low and median flows. pH levels complied with the relevant HRC (1998) lowland river guidelines at all sites except at Nepean River at Smiths Rd (N48) during low flow when pH levels marginally exceeded the upper limit of 8. Dissolved oxygen levels were generally within the acceptable range of 85 to

110% saturation (ANZECC/ARMCANZ, 2000), although during low flow dissolved oxygen decreased to less than 85% saturation immediately downstream of the Penrith STP discharge (N53)**.** Conductivity was higher at the Nepean River at Yarramundi Bridge (N44) compared to above Penrith Weir (N57).

Nitrogen levels in the Nepean River downstream of the Penrith STP discharge (N53) were higher than those measured at Penrith Weir (N57) and Wallacia Weir (N67). All forms of nitrogen for low flow and for median concentrations did not comply with relevant guidelines at the Nepean River downstream of the Penrith STP discharge (N53), Nepean River at Smith Road (N48) and at Nepean River at Yarramundi (N44). At the Nepean River downstream of the Penrith STP discharge (N53) ammonia, oxidised nitrogen and total nitrogen concentrations were consistently higher during low flows than median concentrations although both were elevated. At the Nepean River at Smith Street (N48), concentrations of nitrogen remained moderately elevated although there is a clear improvement in water quality with distance downstream. Noteworthy is the elevated median concentration for oxidised nitrogen at the Nepean River at Smith Road (N48) (0.28 mg/L) compared to the low flow concentration (0.06 mg/L) suggesting that either higher flows are contributing to poor water quality at this site or that oxidised nitrogen is being assimilated disproportionately during periods of low flow or a combination of both. At the Nepean River at Yarramundi Bridge (N44), nitrogen concentrations were again elevated, most likely due to the influence of Winmalee STP which discharges to the river between N48 and N44. Water quality results indicate that Penrith and Winmalee STPs are large contributors of oxidised nitrogen to the Nepean River and to a lesser extent ammonia and total nitrogen, and that the concentration of nitrogen decreases with distance downstream of the influence of these STPs.

Immediately downstream of the Penrith STP discharge in the Nepean River (N53), the median concentration of total phosphorus exceeded the relevant guideline while both low flow and median concentrations of filterable phosphorus exceeded the relevant guideline. At sites further downstream (N44 and N48), both total phosphorus and filterable phosphorus concentrations decreased and complied with their respective guidelines.

All sites in this reach of the Nepean River had median and low flow faecal coliforms densities that complied with the primary contact recreation guideline of 150CFU/100mL. In contrast, median Enterococci densities were elevated at all sites in this reach and compliance with the primary contact recreation guideline of 35 CFU/100mL was poor. During low flow, immediately downstream of the Penrith STP discharge (N53) and at Yarramundi Bridge (N44) also failed to comply with the Enterococci primary contact recreation guideline. Compliance with the secondary contact recreation guideline of 230 CFU/100mL for Enterococci was achieved at all sites.

The Healthy Rivers Commission (1998) recommends chlorophyll-*a* concentrations less than 7μg/L for mixed use rural areas. Both low flow and median chlorophyll-*a* concentrations immediately downstream of the Penrith STP discharges (N53) and at Yarramundi Bridge (N44) were low and less than the guidelines.

4.3.4 Yarramundi to South Creek (Hawkesbury River)

Table 4-5 presents the three water quality monitoring sites between Yarramundi Bridge and South Creek that have been used to assess existing water quality conditions in this reach. All these sites are lowland river ecosystems and fall within mixed use rural landuse areas.

Table 4-5: Water Monitoring Sites – Yarramundi Bridge to South Creek

Site Code	Site Name	Monitoring Organisation	Data range	HRC Classification
N42	Hawkesbury River at North Richmond, downstream Grose River and upstream Redbank Creek (and North Richmond STP)	SWC and SCA	Jan 2000 – Jun 2006	Mixed use rural area
N39	Hawkesbury River at Freemans Reach	SWC	Jan 2000 – Jun 2006	Mixed use rural area
N38	Hawkesbury River at Windsor Bridge	SWC	Jan 2000 – Jun 2006	Mixed use rural area

There were no exceedences of physico-chemical water quality guidelines (dissolved oxygen, pH, turbidity) in this reach of the river between Yarramundi and South Creek (refer to **Table A-3** and **Figures A-1** to **A-14** in **Attachment A**). During low flows, dissolved oxygen percent saturation varied between sites, with median saturations of 100% recorded at North Richmond (N42), increasing to 107% at Freemans Reach (N39) decreasing to 89% at Windsor Bridge (N38). There was little variation in the other physico-chemical parameters between sites, although electrical conductivity was marginally higher at Windsor Bridge (N38) during low flow (51 mS/m) than at other sites.

Nitrogen and phosphorus concentrations were generally similar at North Richmond (N42) and Freemans Reach (N39), however both increased at Windsor Bridge (N38). Median and low flow oxidised nitrogen concentrations exceeded the guidelines at all sites with exceedence at Windsor Bridge (N38) of greater magnitude than the other two sites. Both median and low flow total nitrogen concentrations complied with the HRC guidelines for mixed use rural areas at North Richmond (N42) and Freemans Reach (N39), while median and low flow concentrations exceeded 0.7mg/L at Windsor Bridge (N38). Ammonia concentrations showed little variation between sites at North Richmond (N42) and Freemans Reach (N39), with both median and low flow concentrations complying with ANZECC/ARMCANZ (2000). However, both low flow and median concentrations were marginally higher at Windsor Bridge (N38) and failed to meet the guidelines. Both total and filterable phosphorus concentrations in this reach of the river generally increased with distance downstream, but complied with both ANZECC/ARMCANZ (2000) and HRC (1998) guidelines.

Faecal coliform densities were similar to upstream sites and were within acceptable limits for primary contact recreation at all sites. Median Enterococci densities, however, exceeded the primary contact recreation guideline of 35CFU/100mL at Windsor Bridge (N38) and Freemans Reach (N39). On the whole median Enterococci densities were higher than low flow densities, likely as a result of runoff from surrounding landuses.

Chlorophyll-*a* concentrations at North Richmond (N42) were similar to those upstream at Yarramundi Bridge (N44) and were below the HRC (1998) recommended guideline of 7μg/L for median and low flow concentrations. At Freemans Reach (N39) and Windsor Bridge (N38), concentrations generally increased, particularly during low flows, and chlorophyll-a concentrations 7 μg/L and 12.9μg/L were recorded respectively, consequently exceeding the guidelines. At Windsor Bridge (N38), median chlorophyll-*a* concentrations also exceeded the guidelines.

4.3.5 South Creek to Sackville (Hawkesbury River)

Presented in **Table 4-6** is a summary of the sites in this river reach.

Table 4-6: Water Monitoring Sites - South Creek to Sackville

Site Code	Site Name	Monitoring Organisation	Data range	HRC Classification
N35	Hawkesbury River at Wilberforce downstream South Creek	SWC and SCA	Jan 2000 – Jun 2006	Mixed use rural area
N26	Hawkesbury River at Sackville Ferry	SWC	Jan 2000 – Jun 2006	Mixed use rural area

The sites in this reach of the Hawkesbury-Nepean River are all located downstream of South Creek. Wilberforce (N35) is the most upstream site and is located in the Hawkesbury River between South and Cattai Creeks. While all sites are tidally influenced, Wilberforce (N35) and Sackville Ferry (N26) have conductivities representative of freshwater tidal systems. Water quality results and compliance are provided in **Table A-4** and **Figures A-1** to **A-14** of **Attachment A**.

Whilst the water quality in this reach of the river was similar to the water quality in the upstream reaches of the Hawkesbury-Nepean River, it was considerably different to the water quality of the tributary streams (South and Eastern Creeks). Median and low flow dissolved oxygen levels in this section of the river complied with ANZECC/ARMCANZ (2000) guidelines at all sites. High dissolved oxygen levels at Sackville Ferry (N26) (generally greater than 100%), is most likely due to algal activity known to occur at this site. Median pH levels complied at all sites except at Sackville Ferry (N26), which classified as a lowland river due to low electrical conductivity readings and had median and low flow pH levels of 8. Median turbidities were low at all sites.

Median oxidised nitrogen concentrations exceeded the ANZECC/ARMCANZ (2000) guidelines at all sites with the highest concentrations at Wilberforce (N35) (0.52mg/L) followed by Sackville Ferry (N26) (0.19mg/L). Low flow oxidised nitrogen concentrations also exceeded guidelines at Wilberforce (N35) (0.29mg/L). Median total nitrogen concentrations were highest at Wilberforce (N35) (1.0mg/L) and Sackville Ferry (N26) (0.78mg/L) and exceeded the mixed use rural guideline of 0.7mg/L. During low flows, the only exceedence of total nitrogen guidelines was recorded at Wilberforce (N35) (0.79mg/L). Median ammonia concentrations were also elevated at Wilberforce (N35) (0.03 mg/L) while all other sites complied with the guideline under both median and low flow conditions. Generally nitrogen concentrations were high at the site nearest the South Creek inflow (Wilberforce N35) and decreased with distance downstream. This suggests that South Creek and the existing discharge of tertiary treated effluent is the major source of nitrogen especially in low flow conditions.

Total phosphorus and filterable phosphorus concentrations exceeded their respective guidelines at a number of sites in this river reach. Median and low flow concentrations of total phosphorus were generally higher at Wilberforce (N35) and Sackville Ferry (N26) than at other sites and exceeded the mixed use rural guideline of 0.035 mg/L (HRC, 1998). Generally total phosphorus concentrations followed a similar trend to nitrogen and decreased in concentration with distance downstream. In contrast, median and low flow filterable phosphorus concentrations failed to comply with the ANZECC/ARMCANZ (2000) guideline for estuarine ecosystems (0.005 mg/L).

Densities of indicator bacteria were considerably lower in this reach of the river with both Faecal Coliforms and Enterococci complying with the primary and secondary contact recreation guidelines at all sites.

Chlorophyll-*a* concentrations were consistently elevated in this reach of the river. Both low flow and median concentrations were highest at Wilberforce (N35) and Sackville Ferry (N26) with the highest median concentration (31.1μg/L) recorded at Sackville Ferry which has historically been the location of blue green algal blooms in the river.

Altered flows as a result of flow regulation and water extraction and pollutants from diffuse and point sources including STPs have contributed to conditions conducive to the growth of potentially toxic blue-green algae. The river reach between Windsor and Wisemans Ferry, centred around Sackville Reach has historically been the area most prevalent in blue-green algae primarily as a result of elevated nutrients including phosphorus and nitrogen (Church, *et al,* 1997) and altered flow regimes (Saunders and White, 1993; Hawkins and Hassan, 1997; Church *et al*, 1997).

The implications of increased nutrient loads on algal blooms occurring in the Hawkesbury-Nepean River system was investigated by Church *et al* (1997). The study involved an assessment of the distribution of blue-green algae during periods of low flows that occurred between September 1993 and January 1995. The first major bloom of blue-green algae that was studied occurred within the river at Sackville and had a cell count of 200,000 cells/mL. This bloom and the series that followed reflected the inputs of nutrients from effluent discharged from sewage treatment plants operating within the catchment. The first major bloom was characterised by a dominance of *Microcystis spp.*, whereas preceding blooms displayed a mix of filamentous algae *Pseudanabaena sp.* and blue-green algae *Microcystis spp* and *Anabaena spp*.

Each of the major blooms, which occurred between Sackville and Cattai, were in a period where there were elevated concentrations of total phosphorus and soluble reactive phosphorus in the river. At Cattai, soluble reactive phosphorus concentrations and Chlorophyll-*a* during bloom formation displayed no significant correlation, however, at Sackville, there was a high correlation between the two parameters, indicating that the algal bloom was incorporating total phosphorus during formation (Church *et* al, 1997). The second bloom that occurred between July and November 1994 displayed a similar pattern except for a strong correlation between soluble reactive phosphorus and Chlorophyll-*a* at Cattai. More importantly, soluble reactive phosphorus during this period at Sackville was below detection limits suggesting that soluble reactive phosphorus was being completely utilised by the algal bloom (Chruch *et al,* 1997). When the third bloom occurred between November 1994 and January 1995 there was no apparent relationship between total phosphorus, soluble reactive phosphorus and Chlorophyll–*a* at Cattai, whereas a strong positive relationship existed at Sackville. These results indicate that during bloom formation, phosphorus at Cattai and Sackville was being incorporated into the algal biomass and reducing soluble reactive phosphorus to levels below detection (Church *et al,* 1997).

Mitrovic *et al*. (2000) investigated the replacement of green algae by the cyanophyte *Microcystis aerauginosa* and observed that this replacement coincided with depletion in nitrate, meaning that the species is more competitive for nitrogen in the nitrate form. Mitrovic *et al* (2001a) then undertook *in situ* nutrient enrichment experiments at the Sackville Reach during winter 1997 and summer 1998 to assess the uptake of different nutrients by cyanobacteria. The study found that under nutrient rich conditions *Chlorophyceae* becomes the dominant species, but as nitrogen and

phosphorus concentrations decrease *Microcystis aeruginosa* out-competes the other algal species for nitrate and ammonia.

Flow regulation has also favoured the growth of algal blooms in the Hawkesbury-Nepean catchment. Saunders and White (1993) examined cyanobacteria blooms at Sackville during summer 1991 -1992. Elevated flows during December 1991 were able to flush a significant bloom of *Microcystis aeruginosa* (450, 000 cells/mL) that had developed between mid-November and mid-December 1991.

Hawkins and Hassan (1997) examined the occurrence of algal blooms between 1980 and 1996. During low flows (<300 ML/day over Penrith Weir) autochthonous production (endogeneous materials fixed or generated within the aquatic ecosystem) exceeded allochthonous production (exogeneous materials transported into the aquatic system) and point sources such as STP effluent discharge were the dominant source of nutrient supply within the system (Hawkins and Hassan, 1997). Increased nutrient levels promoted intense cyanobacterial blooms which were flushed during flows that exceeded 300 ML/day (Hawkins and Hassan, 1997). Church *et al* (1997) concluded that a combination of nutrient reduction strategies and reinstatement of flushing flows would reduce intense blue-green algal blooms occurring in the Hawkesbury-Nepean catchment. Mitrovic *et al* (2001b) concluded that increased flushing would result in a reduction of cyanobacteria blooms in the main river system and deplete the vertical distribution of *Microcystis aeruginosa* within embayments or 'dead zones' of the Hawkesbury-Nepean River.

Following detailed studies of the responses of algal blooms to nutrient inputs and flow regulation most of the sewage treatment plants operating within the Hawkesbury-Nepean catchment have been upgraded to tertiary treatment to reduce nutrient loads. Regular monitoring has shown that these upgrades have reduced nutrient levels in the catchment (SWC, 2005 a). However long, warm dry spells that occurred during 2003-2004 and 2004-2005 resulted in a greater incidence of algal blooms in the Hawkesbury-Nepean River (SWC, 2005 a). Cell counts ranged from 220, 000 cells/mL at Maldon Bridge in the upper Hawkesbury-Nepean catchment to 11, 000 cells/mL downstream of West Camden STP (SWC, 2005 a).

The worst affected sites were situated between Richmond and Wisemans Ferry downstream of the South Creek confluence. High nutrient concentrations between Richmond and Wisemans Ferry encouraged the development of algal blooms (SWC, 2005 a). Persistent dry weather during 2004-2005, which reduced river flows, also promoted the growth of algal blooms. At Sackville reach the most common algae were potentially toxic cyanobacteria *Microcystis*, *Anabaena* and *Cylindrospermopsis,* which exceeded the State Algal Coordination Committee (SACC 2001) recreational water quality guidelines limit of <15,000 cells/mL of toxic cyanobacteria (SWC, 2005 a). A similar situation was found at Leets Vale (SWC, 2005 a).

SWC (2005 b) examined the Sydney Water Hawkesbury-Nepean Wastewater Strategy and sewage related algal blooms in the Hawkesbury-Nepean River. This strategy has successfully reduced STP nutrient loads discharged to the river including a 54% reduction in dry weather total nitrogen loads and a 93% reduction in dry weather total phosphorus loads (SWC 2005 b). This reduction in nutrients has minimised the propensity for potentially toxic algal blooms in the river. The study found that 10 of a total of 13 sites had no exceedences of the SACC (2001) guidelines over the preceding 2 year period while only 15% of samples from Sackville Ferry site exceeded guidelines (compared to 61% 10 years ago). SWC (2005 b) concluded that while the benefits of further improvements in STP performance would be very small, during dry weather, STPs continue

to supply a continuous load of nutrient when contributions from other sources (i.e. diffuse sources) are minimal. It is reasonable to conclude therefore that further reductions in nitrogen and phosphorus loads to the river will be of benefit, in further reducing the occurrence of algal blooms during periods of low flow.

4.3.6 South Creek catchment

Eastern Creek

There are five water quality monitoring sites along Eastern Creek plus two sites on Breakfast Creek, a tributary of Eastern Creek as detailed in **Table 4-7**. For assessment purposes all sites are classified as lowland rivers in accordance with ANZECC/ARMCANZ (2000), and either mixed use rural, urban areas mainstream and urban areas tributary stream in accordance with the HRC (1998).

Table 4-7: Water Monitoring Sites in Eastern Creek

Site Code	Site Name	Monitoring Organisation	Data range	HRC Classification
NS094	Eastern Creek at Richmond Road upstream Breakfast Creek	SWC	Jan 2000 – Jun 2001	Urban mainstream
NS090	Breakfast Creek at Falmouth Road upstream Quakers Hill STP	SWC	Jan 2000 – Jun 2006	Urban tributary stream
NS087	Breakfast Creek at Station Road downstream Quakers Hill STP	SWC	Jan 2000 – Jun 2006	Urban tributary stream
NS085	Eastern Creek at Douglas Road downstream Breakfast Creek	SWC	Jan 2000 – Jun 2001	Urban mainstream
NS083	Eastern Creek at Garfield Road Bridge downstream Breakfast Creek	SWC	Jan 2000 – Jun 2001	Urban mainstream
NS082	Eastern Creek upstream Riverstone STP, upstream confluence with South Creek	SWC	Jan 2000 – Jun 2006	Mixed use rural area
NS081	Eastern Creek downstream Riverstone STP, upstream confluence with South Creek	SWC	Jan 2000 – Jun 2006	Mixed use rural area

Of the 7 sites, two sites are located upstream of Quakers Hill STP. NS094 is located on Eastern Creek upstream of Breakfast Creek, while NS090 is located on Breakfast Creek at Falmouth Road upstream of the STP. Downstream of the STP there is one site in Breakfast Creek (NS087). All remaining sites are in Eastern Creek downstream of the Breakfast Creek confluence. Results and compliance assessment are shown in **Tables A-5** to **A-6** and **Figures A-15** to **A-28** in **Attachment A**. It should be noted that data were not available for low flow conditions.

Upstream of Quakers Hill STP (NS090) low median dissolved oxygen levels were measured failing to comply with the ANZECC/ARMCANZ (2000) guidelines. Downstream of Quakers Hill STP, median dissolved oxygen concentrations increased and complied with the guidelines, a possible result of aeration due to mixing of the water in Breakfast Creek with discharge from the STP. Sites upstream and downstream of the Riverstone STP (NS082 and NS081) complied with the ANZECC/ARMCANZ (2000) guidelines for dissolved oxygen concentrations showing little difference between the two sites. Median turbidity levels failed to comply in Eastern Creek at NS083 downstream of Breakfast Creek although median turbidities were relatively elevated at all sites in the Eastern Creek. There were some minor differences in median conductivities between the sites in Eastern Creek and Breakfast Creek. Generally, conductivities were higher upstream of

STP discharges, decreasing by approximately 10-15mS/m between the upstream and downstream sites.

In Breakfast Creek nutrient concentrations exceeded the relevant guidelines at both sites except for total nitrogen. Total nitrogen concentrations complied with the HRC (1998) guideline of 1mg/L for urban tributary streams at NS090 upstream of Quakers Hill STP. Also upstream of Quakers Hill STP (NS090) a relatively high total phosphorus concentration (0.088 mg/L) was recorded. At site NS087, downstream of Quakers Hill STP, total nitrogen concentrations were significantly higher (more than 5 times the concentrations recorded upstream) and exceeded the HRC (1998) guidelines. Oxidised nitrogen concentrations also increased significantly between the upstream and downstream sites, however, concentrations were already high at the upstream site, exceeding the ANZECC/ARMCANZ (2000) trigger value of 0.04mg/L. As mentioned previously the increase in oxidised nitrogen and total nitrogen concentrations at the downstream site are the immediate result of the Quakers Hill STP discharge. In contrast, concentrations of filterable and total phosphorus downstream of the STP were low compared to upstream and were diluted by STP discharges, which are relatively low and consistent with the level of treatment at the STP.

At other sites in Eastern Creek nutrient concentrations were high, consistently failing to comply with both ANZECC/ARMCANZ (2000) and HRC (1998) guidelines. There were substantial differences in concentrations of oxidised nitrogen and total nitrogen between NS082 and NS081, upstream and downstream of Riverstone STP respectively. Median concentrations increased by approximately 1.5 times for oxidised nitrogen and total nitrogen, downstream of Riverstone STP, indicating the effects of the tertiary treated wastewater discharge. Concentrations of ammonia, filterable phosphorus and total phosphorus, whilst exceeding their respective guidelines, did not change substantially between the two sites, with concentrations slightly lower downstream of the STP, possibly as a result of the dilution from STP discharges. The other three sites within Eastern Creek showed similar trends, with site NS094, the most upstream site having significantly lower concentrations of oxidised nitrogen and total nitrogen than at sites NS085 and NS083 further downstream. Despite this, concentrations of all nutrients at all sites in Eastern Creek exceeded guidelines. It can be concluded that catchment sources are contributing elevated phosphorus loads to the system while STPs are contributing elevated loads of nitrogen to the system.

Median faecal coliform and Enterococci densities exceeded the primary contact recreation guidelines at both sites in Breakfast Creek (ie, up and downstream of Quakers Hill STP). Densities were generally higher at NS090 upstream of Quakers Hill STP, than at NS087, suggesting that STP discharges dilute faecal densities downstream of the STP. In Eastern Creek faecal coliform and Enterococci densities were elevated throughout suggesting the influence of higher flows and catchment runoff on water quality in general in this subcatchment.

Chlorophyll-a concentrations complied with the HRC (1998) guideline of 20μg/L at both sites in Breakfast Creek, however median concentrations at downstream of Quakers Hill STP (NS087) were generally higher, more than threefold those upstream of Quakers Hill STP (NS090). Chlorophyll-a concentrations complied with the HRC (1998) guideline at all sites in Eastern Creek.

South Creek

There are five water quality monitoring sites in South Creek that have been used to assess existing water quality (**Table 4-8**). All sites are considered lowland river ecosystems and are located in either urban mainstream or mixed use rural areas (ANZECC/ARMCANZ, 2000 and HRC, 1998)

Table 4-8: Water Monitoring Sites in the South Creek

Site Code	Site Name	Monitoring Organisation	Data range	HRC Classification
NS26	South Creek at Dunheved Golf Course upstream St Marys STP	SWC	Jan 2000 – Jun 2006	Urban mainstream
NS24	South Creek at ADI upstream St Marys STP	SWC	Jan 2000 – Jun 2006	Urban mainstream
NS23	South Creek at ADI Shanes Park downstream St Marys STP	SWC	Jan 2000 – Jun 2006	Urban mainstream
NS14	South Creek at Richmond Road Bridge upstream Eastern Creek	SWC	Jan 2000 – Jun 2001	Urban mainstream
NS04	South Creek at Fitzroy Bridge upstream confluence with Hawkesbury-Nepean	SWC	Jan 2000 – Jun 2001	Mixed use rural area

Two sites, NS26 and NS24 are located upstream of St Marys STP. Downstream of the STP there are three sites, NS23, NS14 and NS04. NS23 is immediately downstream of the STP discharge, NS14 is further downstream, but upstream of the Eastern Creek confluence with South Creek. The most downstream site, NS04 is upstream of the confluence with the Hawkesbury-Nepean River and is influenced by both South and Eastern Creeks. It should be noted that no sampling was undertaken during low flows at NS14 and NS04 during the period 2000-2006 and as such the water quality assessment for these sites is based on median concentrations.

The water quality of South Creek was very poor with the majority of water quality indicators failing to meet the relevant water quality guidelines (refer to **Table A7** and **Figures A-29** to **A-42** in **Attachment A**).

The physico-chemical water quality was generally good with the exception of dissolved oxygen. At all sites, median dissolved oxygen levels, failed to meet the lower limit of 85% saturation recommended by ANZECC/ARMCANZ (2000) for slightly disturbed lowland river ecosystems. Low flow dissolved oxygen saturation also failed to meet the guidelines at NS26 and NS24 with very low levels for ambient waters at both sites. Similarly to Eastern Creek, conductivities in South Creek, were generally slightly higher upstream of STP discharges and decreased downstream. At the upstream sites, median conductivities ranged between 84.4mS/m and 80.7mS/m at NS26 and NS24 respectively. Immediately downstream of the STP, conductivities were at their lowest with a median of 74.15mS/m at NS23, and remained around this level at NS14. At the most downstream site, conductivities increased to the highest levels in South Creek, with a median of 88.4mS/m. Although turbidity complied at all sites, levels were relatively elevated compared to mainstream sites with the highest median turbidity of 42.6 NTU recorded at NS04 at Fitzroy Bridge upstream of the confluence with the Hawkesbury River.

High levels of all forms of nitrogen were present at all sites in South Creek, exceeding both the ANZECC/ARMCANZ (2000) and HRC (1998) guidelines. Median concentrations of ammonia ranged from 0.04 to 0.05 mg/L upstream of the St Marys STP and ranged from 0.023 mg/L to 0.030 mg/L downstream of the STP. The highest median ammonium concentration of 0.1 mg/L was recorded at NS04 suggesting input from both the Eastern Creek subcatchment and the catchment below Richmond Road Bridge. In contrast, oxidised nitrogen and total nitrogen concentrations were considerably lower at sites upstream of St Marys STP (NS26 and NS24) than those downstream during both low flow and median conditions. During low flow, oxidised nitrogen concentrations in

South Creek upstream of the STP ranged from 0.02-0.04 mg/L while immediately downstream of the STP the low flow oxidised nitrogen concentration was 3.6 mg/L. A similar trend is apparent for median oxidised nitrogen concentrations. For total nitrogen a similar pattern is evident whereby low flow and median concentrations become elevated downstream of St Marys STP indicating that discharges from the STP are a significant source of both oxidised and total nitrogen to South Creek. Overall, concentrations of nitrogen were slightly higher during low flow conditions.

Phosphorus levels in South Creek were also high. Median and low flow filterable phosphorus concentrations complied with the ANZECC/ARMCANZ (2000) guideline of 0.02mg/L at both NS26 and NS24 upstream of St Marys STP with a negligible difference in concentrations between median and low flows. Downstream of the STP concentrations failed to meet the guidelines with a general increase in concentration with distance downstream of the STP. Median and low flow concentrations of total phosphorus exceeded the HRC (1998) guidelines for urban and mixed-use rural areas at all sites under all flow conditions. There was little difference in total phosphorus concentrations between the two upstream sites (NS26 and NS24) during low flow and median conditions. Median total phosphorus concentrations also showed little difference between upstream and immediately downstream of the STP. Median concentrations of total phosphorus increased further downstream at NS14 and NS04 which had concentrations two to three times higher than those at the other sites. It appears that these sites receive additional phosphorus loads from Eastern Creek and the surrounding catchment.

Faecal coliform and Enterococci densities were high at all sites, exceeding primary contact recreation guidelines, and in two instances (NS23 and NS14) exceeding secondary contact recreation guidelines for Enterococci. Densities of faecal coliforms were reasonably similar at sites NS26, NS24 and NS23 which suggests that the STP does not contribute substantially to faecal pollution in South Creek. Given that median faecal coliform densities increase with distance downstream it would appear that these increases are associated with higher flows and are most likely attributable to wet weather events and increased runoff and inflows from Eastern Creek and associated catchment landuses.

The Healthy Rivers Commission (1998) recommend that chlorophyll-*a* in urban areas (mainstream) should not exceed 10-15μg/L and 7μg/L in mixed use rural areas. Most sites in South Creek complied with these guidelines with exception at N26 which had a median low flow chlorophyll-*a* concentration of 20.7 μg/L.

Overall the quality of surface water in South and Eastern Creeks is poor due a number of factors. These include diffuse source discharges from urban and agricultural landuses together with point source discharges from St Marys, Quakers Hill and Riverstone STPs.

4.4 Assessment of Impacts

4.4.1 Load reductions

The Replacement Flows Project would result in a significant decrease in nutrient loads discharged to the Hawkesbury-Nepean River, immediately downstream of Penrith Weir, and into the South Creek catchment. **Table 4-9** shows the estimated load reduction in 2009 for Ammonia, Oxidised Nitrogen, Total Kjeldahl Nitrogen, Total Nitrogen and Total Phosphorus for Penrith, Quakers Hill and St Marys STPs as a consequence of the project. For each location the following information is provided:

- the 2009 predicted volume and loads of tertiary treated effluent produced by each STP;

- the 2009 predicted volumes and loads diverted to local recycling projects including dual reticulation to urban development in the North-West Sector;
- the 2009 predicted volumes and loads diverted to Advanced Water Treatment Plant as part of the project;
- the remaining volumes loads to be discharged as tertiary treated effluent to their current locations;
- the 2009 predicted volumes and loads of the highly treated recycled water to be discharged downstream of Penrith Weir.

Table 4-9: Load reductions associated with current and planned recycling and the Replacement Flows Project at Quakers Hill, St Marys and Penrith STPs

Location		Loads in kg/day					
	Flow ML/d	Suspended Solids	Ammonia	Oxidised Nitrogen	Total Kjeldahl Nitrogen	Total Nitrogen	Total Phosphorus
Quakers Hill STP							
2009 Effluent Produced	34.5	69	7.4	109.7	34.1	143.9	1.6
Current Reuse	1.3	2.6	0.3	4.1	1.3	5.4	0.1
Planned Reuse	5.6	11.2	1.2	17.8	5.5	23.4	0.3
Flow to AWTP	13.6	27.2	2.9	43.4	13.5	56.9	0.6
Discharge with RFP	**13.9**	**27.9**	**3**	**44.4**	**13.8**	**58.2**	**0.6**
St Marys STP							
2009 Effluent Produced	38.8	78.2	1.8	145.5	33.1	178.7	1.5
Current Reuse	4	8.1	0.2	15.0	3.4	18.4	0.2
Planned Reuse	0	0	0	0	0	0	0
Flow to AWTP	29.7	59.9	1.4	111.5	25.4	136.9	1.1
Discharge with RFP	**5**	**10.2**	**0.2**	**18.9**	**4.3**	**23.2**	**0.2**
Penrith STP							
2009 Effluent Produced	24.1	50.1	1.2	47.1	26.7	73.9	1.9
Current Reuse	3.7	7.7	0.2	7.2	4.1	11.3	0.3
Planned Reuse	5.4	11.2	0.3	10.6	6.0	16.6	0.4
Flow to AWTP	14.9	31.1	0.7	29.3	16.6	45.9	1.2
Discharge with RFP	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total							
2009 Effluent Produced	97.3	197.3	10.5	302.4	93.9	396.5	5
Current Resue	9	18.4	0.6	26.4	8.8	35.2	0.5
Planned Reuse	11	22.4	1.5	28.4	11.5	39.9	0.7
Flow to AWTP	58.3	118.3	5.1	184.1	55.4	239.6	2.9
STP Discharge with RFP	**19**	**38**	**3.2**	**63.3**	**18.1**	**81.4**	**0.8**
Replacement Flows	**50**	**0**	**0**	**22**	**17.5**	**39.5**	**0.3**

Table 4-9 shows that the Replacement Flows Project would result in significant load reductions due to approximately 39% or 13.6 ML/d of Quakers Hill tertiary treated effluent, 76% or 29.7 ML/d of St Marys' tertiary treated effluent, and all of the residual predicted 2009 tertiary treated effluent from Penrith STP being transferred to the AWTP. When combined with other current and planned

recycling projects the Replacement Flows Project results in 75% reduction in total nitrogen loads discharged to South and Eastern Creeks or approximately 88,000 kg/year, and a 71% reduction in total phosphorus loads or 800 kg/year. If the planned local recycling schemes do not proceed, the reduction in nutrient loads discharged to South Creek would be marginally lower with a decrease of 61% in total phosphorus loads and 65% in total nitrogen loads.

As the Replacement Flows Project involves the release of 50 ML/d of highly treated recycled water below Penrith Weir, it is important to consider the impact of this discharge. In comparison with the 2009 Penrith STP discharge of tertiary treated wastewater in the absence of the Replacement Flows Project, the Replacement Flows Project discharge would result in a reduction of 14% in the load of total nitrogen discharged and a 75% reduction in the load of total phosphorus discharged below Penrith Weir. No suspended solids loads would result from the Replacement Flows Project discharge due to the incorporation of micro-filtration and reverse osmosis. In terms of forms of nitrogen, there would be no ammonium discharged in the replacement flows due to the incorporation of breakpoint chlorination. Oxidised nitrogen loads discharged downstream of Penrith Weir would be reduced by approximately 9,000 kg/year or 47% compared to those estimated for 2009 without the Replacement Flows Project.

Overall the decrease in total nitrogen loads and total phosphorus loads as a result of the Replacement Flows Project (and assuming the other planned recycling schemes would go ahead) would be 67% and 78% respectively when compared with the current load of nutrients discharged from the three STPs.

4.4.2 In-stream Nutrient Concentrations

In-stream nutrient concentrations were assessed using two methods:

1. Mass water balance modelling
2. Integrated water modelling

Mass balance modelling was undertaken to determine the 2009 predicted nutrient concentrations in Warragamba River, the Nepean River adjacent to Boundary Creek and in South Creek catchment. Integrated modelling was only undertaken for the Hawkesbury-Nepean River.

Warragamba River

A mass balance model was developed to estimate the likely future nutrient concentrations in the Warragamba River downstream of the current interim environmental flow release at Megarritys Creek. With the implementation of the Project, the current interim environmental flows (43.3 ML/d) from Warragamba Dam would cease. As the Warragamba River also receives treated effluent from Wallacia STP, the dilution of Wallacia STP effluent would be significantly reduced as a result of the Project.

The model used a simple mass balance methodology for water and nutrients from the various sources that feed into the Warragamba River downstream of Warragamba Dam. The model did not take any assimilation or nutrient spiralling within the creek ecosystem into account and is therefore considered conservative.

The baseline conditions for the model were as follows:

- Wallacia STP effluent quality (total nitrogen (TN) =7.5mg/L; total phosphorus (TP) = 0.15 mg/L);
- Wallacia STP effluent discharge = 1.35 ML/d;
- Warragamba Dam release water quality remains identical to the current quality; and
- Seepage from Warragamba Dam remains identical to the current with respect to both flow and quality.

Results of the mass balance modelling are shown below in **Table 4-10**.

Table 4-10: Modelled results for 2009 Warragamba River water quality

Scenarios	Median Warragamba River Nutrient Concentrations		
	TN (mg/L)	TP (mg/L)	NH4-N (mg/L)
No Dam Release	6.72	0.139	0.445
Existing Water quality	0.58	0.026	0.020

Without any releases from the dam, the Warragamba River would eventually be dominated by sewage effluent with minor dilution from the dam seepage water. The resulting nutrient concentrations would be approximately 6.7 mg/L total nitrogen and 0.14 mg/L total phosphorus which reflects the characteristics of the sewage treatment plant effluent and exceeds relevant guidelines. Given that the volume of the Warragamba River is approximately 108 ML and the effluent flow is 1.35 ML/d, with some rainwater runoff, the expected detention time in the Warragamba River is greater than 50 days. This would provide significant potential for aquatic plant/algae growth in the Warragamba River.

It should be noted that this mass balance model does not incorporate the biological assimilation or sedimentation of nutrients in the Warragamba River, which would otherwise result in lower nutrient concentrations. Based upon other studies undertaken to assess the impact of Wallacia STP (Hawkins *et al* 2003) significant assimilation and loss of nutrients in Warragamba River is known to occur and final concentrations are likely to be lower.

South Creek catchment

Mass balance modelling results indicate that instream concentrations of all forms of nitrogen in Eastern Creek during median flows would decrease compared to the predicted concentrations in 2009 without the Replacement Flows Project but values would still exceed relevant guidelines for all nitrogen species (**Table 4-11**).

Table 4-11: Predicted nutrient concentrations in Eastern Creek downstream of Quakers Hill STP (median flows)

Scenario	In-stream Nutrient Concentrations (mg/L)			
	Ammonia	Oxidised Nitrogen	Total Nitrogen	Total Phosphorus
Without RFP	0.18	2.50	3.42	0.061
With RFP	0.15	2.04	2.91	0.055
% reduction	15%	18%	15%	11%

Mass balance modelling results indicate that instream concentrations of all forms of nitrogen and total phosphorus in Eastern Creek in 2009 would decrease when compared to existing conditions, but concentrations would still exceed relevant guidelines for all nutrients (See **Table 7-5**).

A similar pattern would occur for South Creek as a result of the changes to discharges from St Marys STP. Concentration of all forms of nitrogen would decrease (while still being above relevant guidelines). Total phosphorus concentrations would, however, increase slightly due to the loss of the dilution effects of the STP discharges and the continuing high upstream contributions from catchment runoff (**Table 4-12**).

Table 4-12: Instream concentrations in South Creek downstream of St Marys STP (low and median flows)

Scenario	In-stream Nutrient Concentrations (mg/L)							
	Ammonia		Oxidised Nitrogen		Total Nitrogen		Total Phosphorus	
Flow	Low	Median	Low	Median	Low	Median	Low	Median
Without RFP*	0.047	0.045	3.6	2.7	4.5	3.5	0.038	0.043
RFP*	0.046	0.042	2.9	1.1	3.7	1.8	0.039	0.049
% reduction	2%	7%	20%	60%	17%	48%	-3%	-14%

Hawkesbury Nepean River

- ***Mass Balance Modelling***

A mass balance model was also developed to predict the 95th percentile low flow water quality in 2009 with and without the Replacement Flows Project in the Hawkesbury Nepean River, adjacent to Boundary Creek.

The first scenario modelled represents predicted water quality in the Hawkesbury-Nepean River adjacent to the Penrith STP discharge from Boundary Creek without the Replacement Flows Project and includes:

- the translucent and transparent environmental flow releases from the Upper Nepean Dams;
- the continued release of 43.3 ML/d from Warragamba Dam;
- existing low flow water quality at Penrith Weir;
- the predicted tertiary treated effluent flows from Penrith STP in 2009 with allowance for current and planned recycling in the local area; and
- the quality of Penrith STP tertiary treated effluent based on current treatment processes.

The alternative scenario modelled represents predicted water quality in the Hawkesbury-Nepean River adjacent to the discharge from Boundary Creek with the Replacement Flows Project and includes:

- the translucent and transparent environmental flow releases from the Upper Nepean Dams;
- the cessation of flows from Warragamba Dam;

- existing low flow water quality at Penrith Weir;
- the release of 50 ML/d of highly treated recycled water from the AWTP; and
- the estimated quality of the highly treated recycled water based on advanced water treatment.

The flows without the Replacement Flows Project have been based on the Upper Nepean and Warragamba Dam releases and the protection of low flows and comprise approximately 110 ML/day over Penrith Weir at the 95th percentile plus 15 ML/day of tertiary treated wastewater discharged from Penrith STP totalling 125 ML/day. Flows associated with the project comprise the Upper Nepean Dam releases and the protection of low flows (less the interim flow release from Warragamba Dam) and are approximately 67 ML/day plus flows from the AWTP of 50 ML/day totalling 117 ML/day. **Table 4-13** shows the results of the mass balance modelling.

Table 4-13: Predicted 2009 in-stream water quality for the Nepean River adjacent to Boundary Creek without and with the Replacement Flows Project (RFP)

Scenario	95th%ile Flow (ML/d)	In-stream Nutrient Concentrations (mg/L)				
		Ammonia	Total Kjeldahl Nitrogen	Oxidised Nitrogen	Total Nitrogen	Total Phosphorus
No RFP	125	0.015	0.357	0.243	0.600	0.018
RFP	117	0.006	0.295	0.195	0.490	0.008

Shaded cells indicate an exceedence of relevant guideline values

The mass balance model predicts that in 2009 the Replacement Flows Project would result in an overall reduction in nutrient concentrations in the Hawkesbury-Nepean River adjacent to Boundary Creek. This is due primarily to the nutrient reduction associated with advanced water treatment process. The Replacement Flows Project would result in reductions for all forms of nutrient whereby all except oxidised nitrogen meet their respective ANZECC/ARMCANZ (2000) or HRC (1998) guidelines (**Table 4-13**). For ease of interpretation, the overall water quality footprint of the Base Case and the Replacement Flows Project are shown in **Figure 4-1** where the relative difference in water quality can be seen. As breakpoint chlorination removes all ammonia from the high quality recycled water, there would no residual ammonia/ammonium associated with the discharge. Oxidised nitrogen concentrations would be reduced by approximately 0.05 mg/L (or 20%) compared with the situation without the Replacement Flows Project while total phosphorous concentrations would be reduced by approximately 0.010 mg/L (or over 50%).

It should be noted that Chloramine would be used in the reverse osmosis process to disinfect the membranes. It is estimated that concentrations of Chloramine-N from single pass reverse osmosis would be approximately 0.27 mg/L. The chemistry of Chloramine-N suggests that in the environment, concentrations from Single Pass Reverse Osmosis will slowly convert to 0.18 mg/L of nitrogen gas and 0.09 mg/L of NH_3. With the incorporation of breakpoint chlorination, however, no ammonia would be discharged to receiving waters via the Replacement Flows Project. The remainder of nitrogen from chloramine residuals would be slowly biodegradable organic nitrogen and has been included in the term for total kjeldahl nitrogen in **Table 4-13** and **Figure 4-1**.

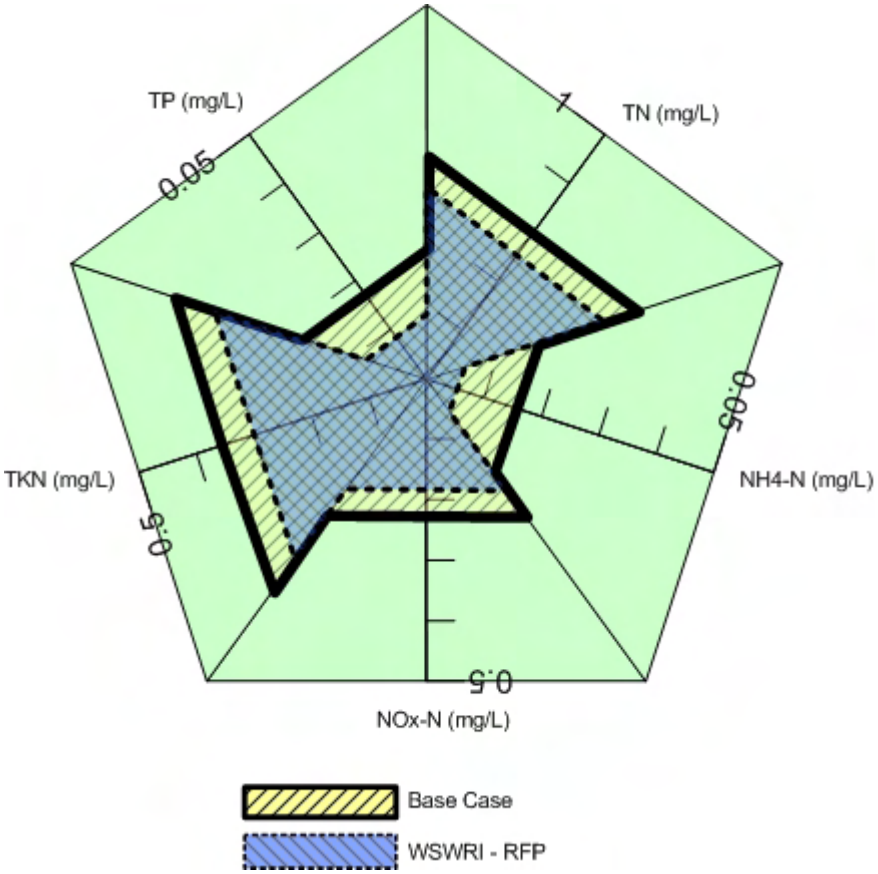


Figure 4-1: Water quality "footprint" downstream of Boundary Creek in the Hawkesbury-Nepean River for the (a) Without Replacement Flows Project (ie Base Case) and (b) With Replacement Flows Project

Integrated water modelling

In addition to the mass balance modelling, Sydney Water examined the impact of the Replacement Flows Project on Hawkesbury-Nepean River water quality using a set of integrated models. These models comprised HSPF for catchment hydrology, hydraulics and water quality, IQQM for the estimation of irrigation consumption, Wathnet for town water consumption and Salmon-Q for waterway hydraulics and water quality (SWC 2006). The Salmon-Q waterway modelling software simulates a number of important chemical and biological processes by dividing the river into four vertical sub-compartments including:

- Water column - this is the main body of water and it is assumed that variations only occur longitudinally;
- Fluffy mud layer or the unconsolidated mud layer that lies on top of the consolidated bed;
- Consolidated bed - underlies the fluffy mud layer; and
- Pore water - this is the water that lies between particles comprising the consolidated bed.

The Salmon-Q waterway modelling software simulates a number of important water quality indicators including:

- Salinity;
- Water Temperature;
- Suspended Solids;
- Nutrients including Nitrogen and Phosphorus;
- Algae and Macrophytes;
- Detrital Carbon;
- Dissolved Oxygen;
- Faecal Coliforms; and
- Chlorophyll-a.

For the purposes of this assessment, the Salmon-Q model was set up using the following information:

- Flow and water quality for the period 1991 to 1994 and verified using data for 1986-1990 and 1995-1996;
- Catchment landuse as existed in 1993. It is noted that landuse has changed in the catchment since 1993 however as the integrated modelling is to be used for comparative and trend assessment rather than predicting absolute concentrations, using the 1993 land use dataset is acceptable;
- Irrigation extractions with approximately 30% of irrigation extractions unaccounted for due to the nature of the limitations of the model;
- Water released from dams at 12^{o}C;
- Quantity and quality of STP discharges for the period 2004-2005 including upgrade to West Camden STP.

Using the integrated models, total nitrogen concentrations, total phosphorus concentrations and salinity were simulated for the purposes of this assessment. The scenarios tested included:

- Existing Case (Run 1a) including sewage treatment plant discharges, IQQM estimated irrigation demands and current provisional 95th%ile dam releases including Warragamba Dam plus historical tributary flows with no regulation of extraction;
- Replacement Flows Project with breakpoint chlorination (Run 11) including the implementation of the Upper Nepean Dam releases and other river management changes, 0 ML/d discharge from Warragamba Dam, 50 ML/d discharge of highly treated recycled water below Penrith Weir with total nitrogen 0.78 mg/L, total phosphorus 0.01 mg/L, 0 mg/L ammonium and oxidised nitrogen 0.44 mg/L. This case examines the water quality outcomes of the Replacement Flows Project with the upgrade to West Camden STP including 6.5 ML/d flow, 5.0 mg/L total nitrogen and 0.04 mg/L total phosphorus combined with effluent reuse.

Figure 4-2 shows the longitudinal profile for total nitrogen concentrations during predominately low flow conditions commencing in the vicinity of Maldon Weir, 255 km from the ocean. Heading downstream from right to left of the graph, the existing case (Run 1a) shows the influence of the West Camden STP with highly elevated total nitrogen concentrations evident immediately downstream of the discharge at approximately 215 km from the ocean. Approximately 180 km from the ocean the combined influence on water quality from the Warragamba Dam release of 43.3 ML/d and the Penrith Weir pool is evident with a significant reduction in total nitrogen concentrations between the confluence of the Warragamba River and Penrith Weir under existing conditions. Downstream of Penrith Weir the influence of the Penrith STP on total nitrogen concentrations is evident while further downstream the influence of Winmalee STP and South Creek are pronounced under existing conditions.

Run 11 shows the combined influence of the Replacement Flows Project, the 2009 river management changes and upgrade to West Camden STP on total nitrogen concentrations in the Hawkesbury-Nepean River. As can be seen the project leads to a significant improvement in water quality throughout the river system. Noteworthy is that the model predicts that there are no areas of deterioration in water quality with respect to total nitrogen. The combined effects of the 2009 river management changes and upgrade to West Camden are significant in the upper reaches while the project results in significant improvements downstream of Penrith STP and South Creek. The model predicts that the water quality improvements associated with the Replacement Flows Project (Run 11) persist with distance downstream of Penrith Weir to North Richmond and further downstream to Sackville where there are significant improvements in total nitrogen concentrations.

Noteworthy are the indicative total nitrogen concentrations shown in **Figure 4-2.** The trends for existing conditions are similar to those apparent in the monitoring data (see **Section 4.3.2**) the concentrations in the downstream reaches are significantly greater for the modelled scenario than those for the measured data during the sampling program for the period 2000-2006. This is most likely due to the difference in water quality from 1991 to 1996 used for the model set-up compared those post 2000 used here for the assessment of existing water quality. Nonetheless the model appears to be producing a reliable indication of trends for total nitrogen concentrations in the Hawkesbury-Nepean River if not for absolute concentrations.

Figure 4-3 shows similar information for total phosphorus concentrations in the river between Maldon Weir and immediately downstream of South Creek. As can be seen existing total phosphorus concentrations (Run 1a) are affected by the discharge from the West Camden STP. The upgrade to West Camden sewage treatment plant (Run 11) clearly results in a significant

reduction in total phosphorus concentrations at Sharpes Weir and downstream although there is a very slight increase in total phosphorus concentrations between 180 and 190 km from the ocean due to the "flushing" effects of the transparent/translucent environmental flow releases from the upper Nepean Dams compared to existing conditions. Between the confluence of the Warragamba River and Penrith Weir, total phosphorus concentrations remain low while immediately downstream of the discharge from Penrith STP a significant improvement in water quality is apparent for the project (Run 11). The model predicts that the water quality improvements associated with the project (Run 11) persist with distance downstream to North Richmond while downstream of South Creek the model predicts there are very marginal improvements in total phosphorus concentrations.

Figure 4-4 shows the longitudinal profile for chlorophyll-a concentrations commencing in the vicinity of Maldon Weir. Similarly to the total nitrogen profile, existing chlorophyll-a concentrations (Run 1a) are influenced by West Camden STP which causes an increase in concentrations immediately downstream of the discharge. The combined effects of the flow releases from Warragamba Dam and the Penrith Weir pool reduce chlorophyll-a concentrations between Warragamba confluence and Penrith Weir, although this reduction is not as significant as that observed for total nitrogen. Increases in chlorophyll-a concentrations as a result of nutrient loads contributed by Penrith STP, Winmallee STP and South Creek are also observed for the existing case, with the concentration rising to a maximum at Sackville.

Run 11 shows the combined influence of the Replacement Flows Project, the Water Sharing Plan and upgrade to West Camden sewage treatment plant on chlorophyll-a concentrations. As would be anticipated with a significant improvement in nutrient concentrations (shown in **Figure 4-2**) a decrease in chlorophyll-a concentrations can be seen, with the most significant changes observed downstream of West Camden STP, Penrith STP and at Sackville. The upgrade at West Camden significantly reduces chlorophyll-a concentrations downstream of the discharge point to the Warragamba River confluence (release). The AWTP reduces the loads of nutrients discharged by Penrith STP and consequently a decrease in chlorophyll-a concentrations is observable compared to the existing situation (Run 1a). Historically, Sackville is the section of the river most susceptible to algal blooms. As a result of the project it is predicted that the concentrations of chlorophyll-a at Sackville will reduce significantly compared to the existing concentrations, indicating that a decline in algae growth is expected in this reach of the river.

Figure 4-5 shows the influence of the various scenarios on the freshwater/saline interface. As can be seen the model predicts that there will be virtually no change in the salinity structure of the estuary associated with the project. Given that there are greater spatial fluctuations in salinity under existing conditions depending on flow in the river, the Replacement Flows Project is not predicted to impact on the salinity structure of the estuary in any way.

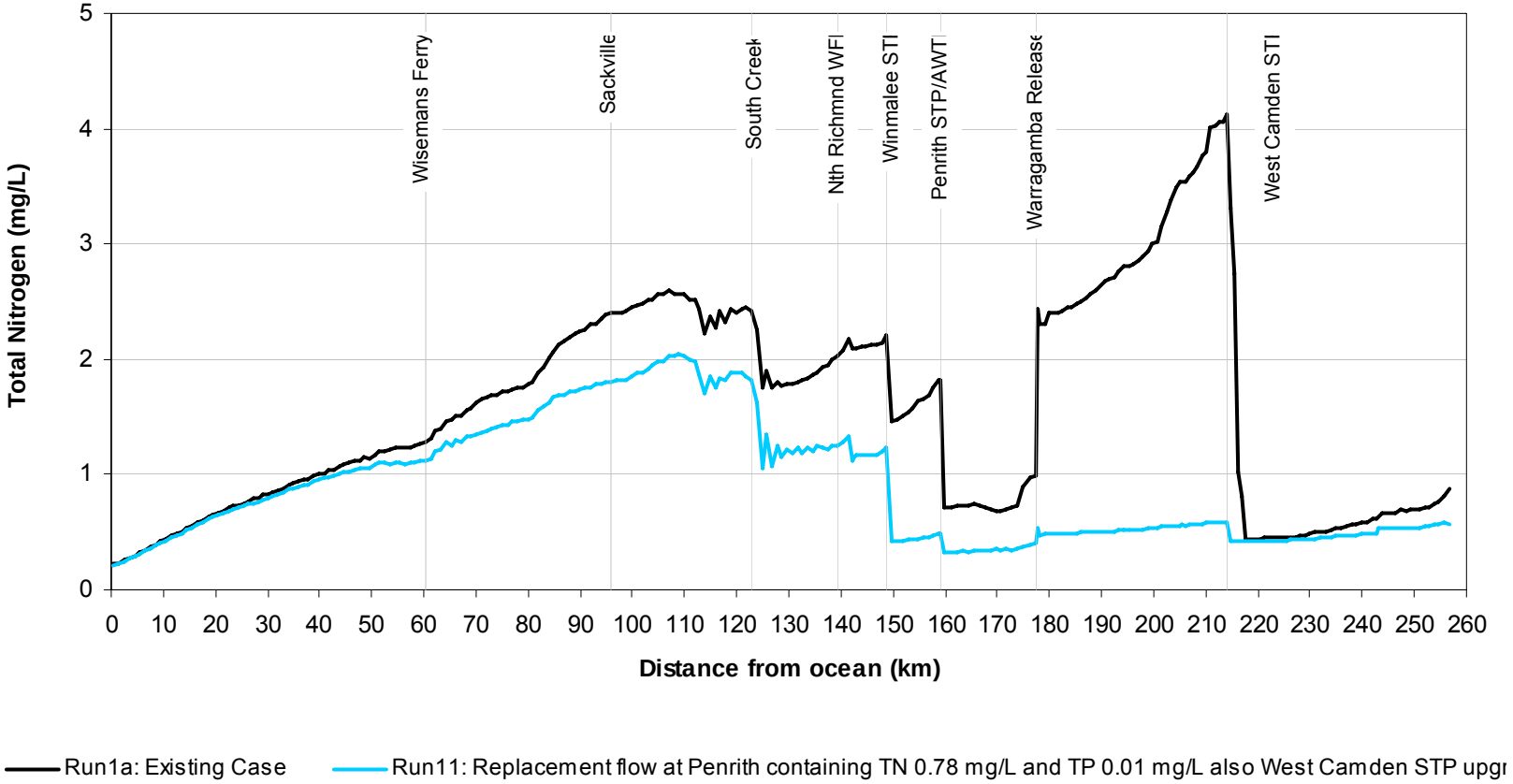


Figure 4-2: Modelled total nitrogen concentrations in the Hawkesbury-Nepean River for existing conditions the Replacement Flows Project

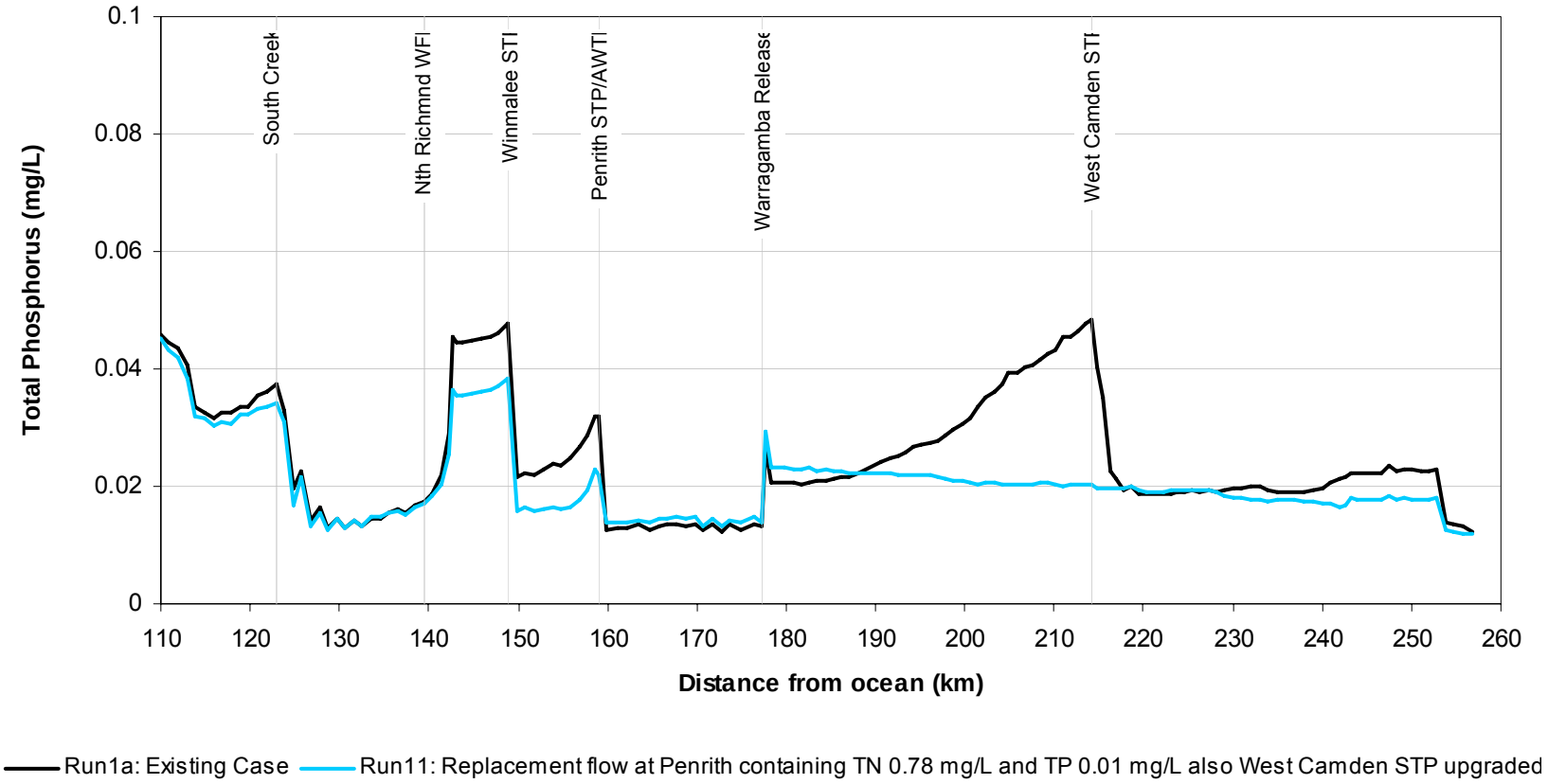


Figure 4-3: Modelled total phosphorus concentrations in the Hawkesbury-Nepean River for existing conditions and the Replacement Flows Project

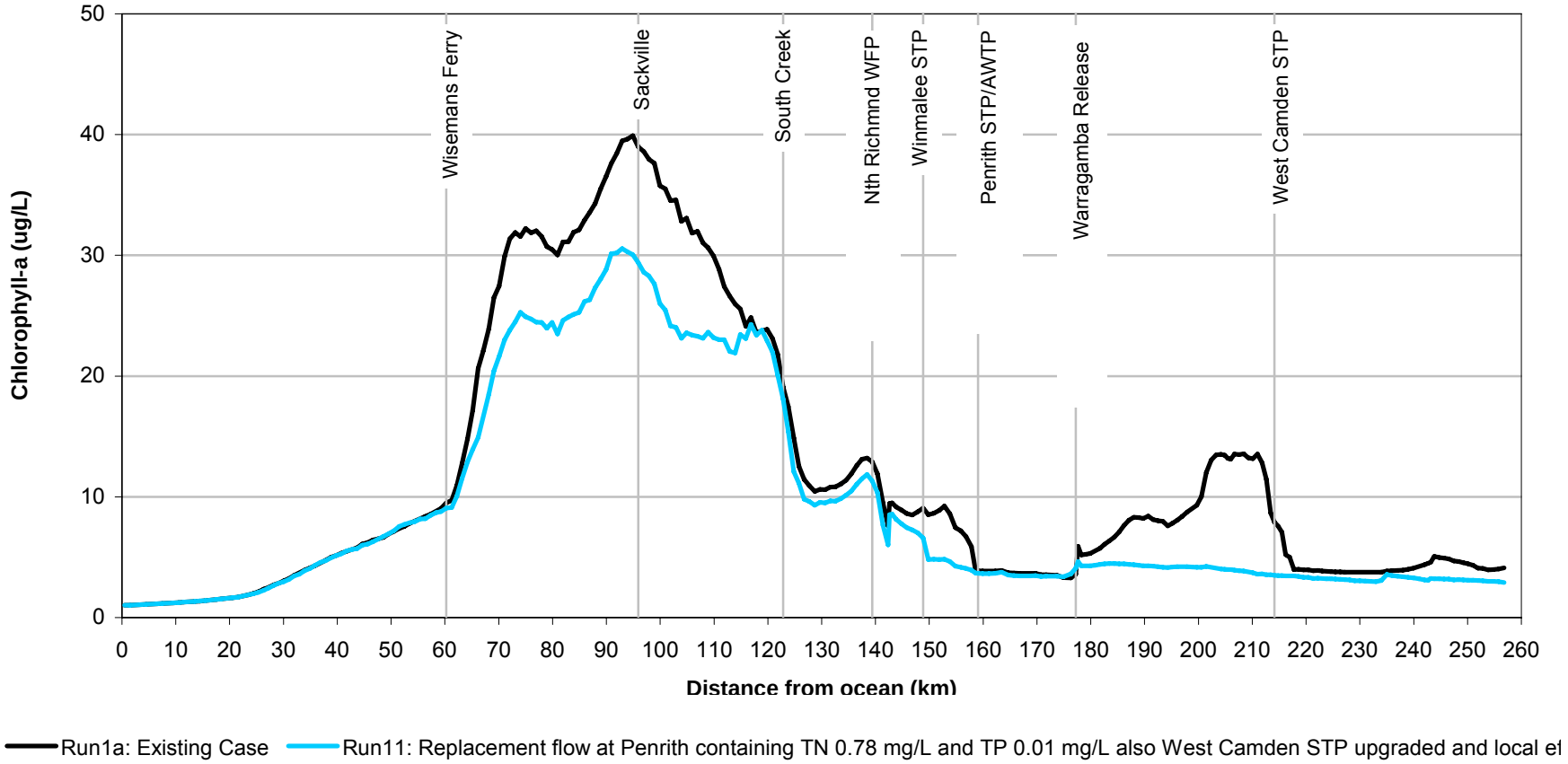


Figure 4-4: Modelled chlorophyll-a concentrations in the Hawkesbury-Nepean River for existing conditions and the Replacement Flows Project

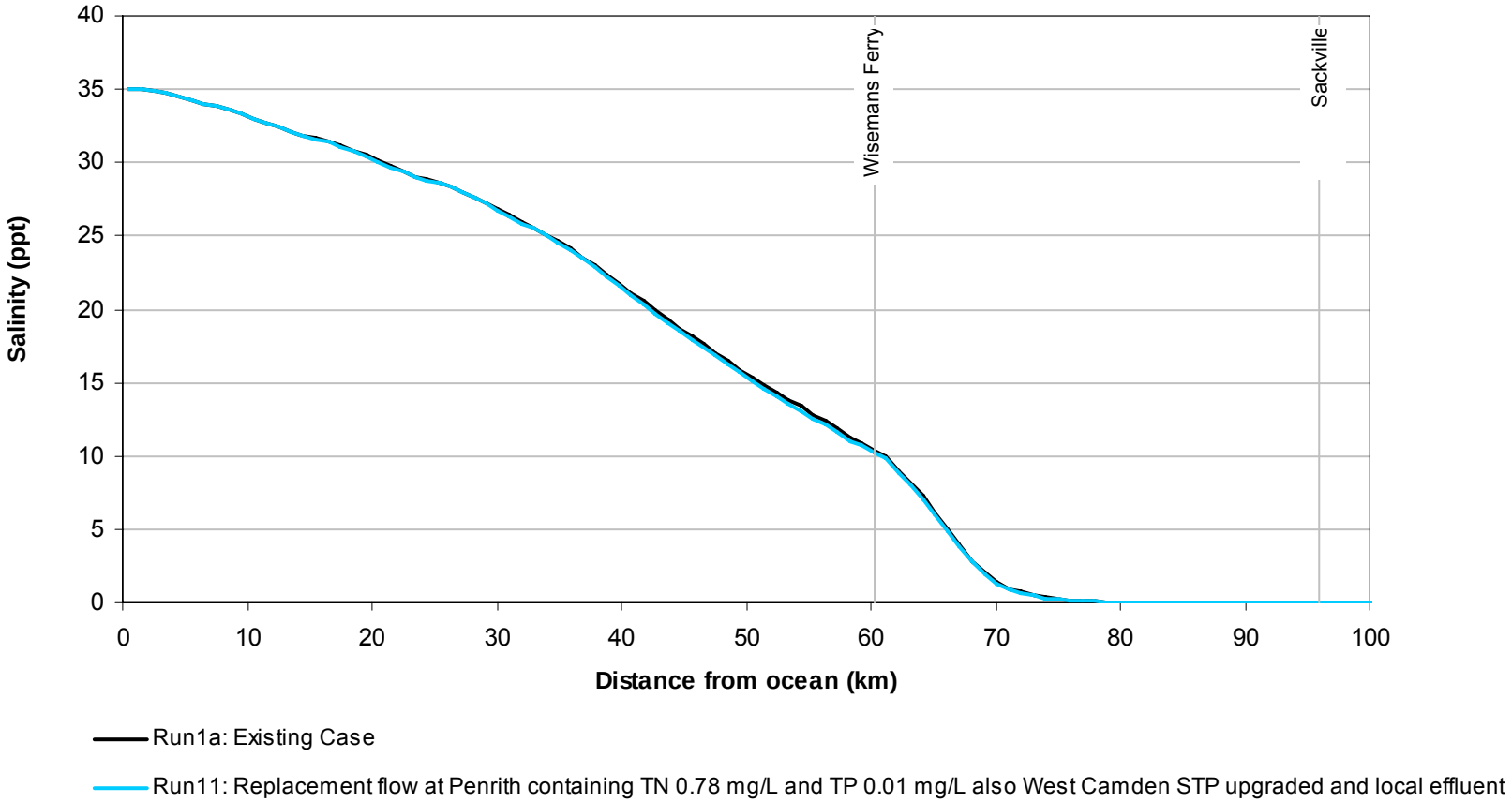


Figure 4-5: Modelled salinity structure of the estuary under existing conditions and the Replacement Flows Project

5. Aquatic Ecology

5.1 Introduction

In order to assess the impact of the Project on aquatic ecosystems appropriate biological indicators need to be evaluated which reflect the current impacts on the river system; namely catchment disturbance, stormwater runoff, the discharge of treated effluent and flow regulation and modification.

The ANZECC/ARMCANZ (2000) *Guidelines for Water Quality Monitoring and Reporting* lists a number of taxonomic groups that may be used to determine aquatic ecosystem condition including macrophytes, fish, macroinvertebrates, algae, bacteria, protozoa and fungi. The selection of which taxonomic groups should be investigated depends upon the purpose of the study (ANZECC/ARMCANZ, 2000).

Key taxonomic groups that respond rapidly to changes in river health are aquatic flora (including macrophytes and algae), fish and macroinvertebrates, which are ideal indicators for this project and have been used in the following assessment. Riparian vegetation has also been incorporated into the study as the structure and diversity of the riparian vegetation strongly depends upon the quality of river water, flow rates and disturbances occurring in the floodplain environment.

Macroinvertebrates

Aquatic invertebrates are sensitive to changes in flow regime, water quality and habitat condition. They are consequently frequently used as biological indicators of waterway health and to assess impacts on freshwater ecosystems. The diversity, composition and abundance of macroinvertebrate communities provide a general measure of the ecological health of waterways.

Macrophytes

Macrophytes are aquatic plants, growing in or near water that are either emergent, submergent, or floating. Macrophytes act as nutrient sinks and nutrient sources, stabilise sediments, and provide habitat for fish and other aquatic organisms. Macrophytes are excellent indicators of waterway health because they respond to nutrients, light, toxic contaminants, metals, herbicides, turbidity, water level change and salt. Introduced exotic macrophytes may also rapidly dominate aquatic ecosystems due to their ability to thrive in modified environments (eg. Polluted waters).

Riparian Vegetation

Riparian vegetation is vegetation on land that adjoins, directly influences or is influenced by, a body of water. Riparian vegetation forms an important part of a healthy functioning river and has a number of benefits including:

- provides shade and shelter, buffers temperature and creates habitat for fish;
- provides a source of woody debris, an essential habitat for native fish;
- constantly deposits fine organic materials in the river through leaf fall providing food for invertebrates and fish;
- provides food for fish through invertebrates falling into the stream from the riparian strip (it may form more than half their diet);
- stabilises riverbeds and banks, binds soil and protects against erosion and slumping;
- may act to lower the water table and help reduce the flow of salt into streams (particularly deep-rooted vegetation); and

- acts as a filter for sediments, phosphorous and organic nitrogen which improves the quality of water entering watercourses. This is especially important along smaller streams that feed into the main channels (NSW Fisheries, 2001).

Studies show greater numbers of fish and more species live in areas with healthy intact riparian vegetation.

Fish

A fish assemblage refers to the distribution and abundance of fish species within a particular area of a water body. The composition may include both native, translocated (introduced) and exotic species. Due to the high proportion of migratory species, native fish species are particularly vulnerable to changes in flow regulation and habitat disturbance and to a degree by poor water quality. Fish assemblage is used as an indicator of ecosystem health as exotic fish species generally have a higher tolerance of habitat disturbance and associated changes in water quality and flow rates than native species (Gehrke, 1996). Key factors identified by Gehrke (1996) affecting to fish communities in the Hawkesbury-Nepean River system include:

- river regulation, barriers and flow diversion devices;
- bank degradation and removal of riparian vegetation; and
- discharge of treated effluent.

The first two factors are listed as key threatening processes under Schedule 6 of the *Fisheries Management Act 1994*. River regulation is also listed as a key threatening process under the *Environmental Protection and Biodiversity Conservation Act 1999.*

River Regulation and Flow Diversion

Regulation of flows in the Hawkesbury-Nepean system has resulted from the construction of weirs and dams mainly along the Nepean River.

Weirs and dams are major barriers to fish passage in the Hawkesbury-Nepean River, affecting the movement of fish both upstream and downstream. The impacts associated with barriers to fish passage are perhaps the most influential and disruptive to fish lifecycles (Gehkre, 1996). Also, alterations to the natural flow regime caused by dams and weirs disrupt the environmental cues needed to initiate fish migration (Thorncraft and Harris, 2000; Ward and Stanford, 1989; Mallen-Cooper, 1996; Mallen-Cooper et al, 1995). Regulated flows also have the capacity to affect environmental cues necessary to instigate the reproductive cycle of a number of native freshwater fish species (Ward and Stanford, 1989).

There are currently 14 major barriers to fish passage in the Nepean River (DLWC, 1999) including 11 weirs between Penrith and Picton (Marsden and Gehrke, 1996; Hawkesbury-Nepean Catchment Management Trust, 1997). Four of the existing weirs are fitted with vertical fishways to allow the movement of native fish species upstream and downstream (Hawkesbury-Nepean Catchment Management Trust 1997). NSW Fisheries identified Penrith Weir as a major barrier to fish migration and spawning and was one of the four weirs that required a fishway to address this problem (HRC, 1998 and Hannan, 1998). The fishway at Penrith Weir has been successful in encouraging a greater abundance of native fish upstream including a 144% increase in Australian Bass following the installation of the fishway (Independent Expert Panel on Environmental Flows for the Hawkesbury Nepean, Shoalhaven and Woronora Catchments, 2002). The Hawkesbury River currently has no barriers to fish passage (DLWC, 1999).

Marsden and Gehrke (1996) identified principally migratory species that are affected by these barriers. Twenty-two migratory fish species were identified including those that migrate

downstream from freshwater to the sea to breed (catadromous), migrate between freshwater and the sea but not for breeding purposes (amphidromous) and fish that migrate within freshwater reaches (potamodromous). Affected species found in the Hawkesbury-Nepean River system are listed in **Table 5-1**. Migratory fish species included 8 catadromous species, 6 amphidromous species and 8 potamodromous species (Marsden and Gehrke, 1996).

Table 5-1: Migratory species present in the Hawkesbury-Nepean catchment

Catadromous	
Shortfinned Eel	*Anguilla australis*
Longfinned Eel	*Anguilla reinhardtii*
Common Jollytail	*Galaxias maculatus*
Estuary Perch	*Macquaria colonorum*
Australian Bass	*Macquaria novemaculeata*
Freshwater Mullet	*Myxus petardi*
Bullrout	*Notesthes robusta*
Freshwater Herring	*Potamalosa richmondia*
Amphidromous	
Climbing Galaxias	*Galaxias brevipinnis*
Striped Gadgeon	*Gabiomorphus australis*
Silver Batfish	*Monodactylus argenteus*
Striped Mullet	*Mugil cephalus*
Australian Grayling	*Prototroctes maraena*
Australian smelt	*Retropinna semoni*
Potamodromous	
Silver Perch	*Bidyana bidyanus*
Carp	*Cyprinus carpia* [I]
Coxs Gudgeon	*Gobiomorphus coxii*
Murray Cod	*Maccullochella peelii*
Macquarie Perch	*Macquaria australasica*
Rainbow Trout	*Oncorhynchus mykiss* [I]
Brown Trout	*Salma trutta* [I]
Brook Trout	*Salvelinus fontinalus* [I]

Source: Marden and Gehrke (1996). [I] indicates Alien (introduced) species.

Gehrke *et al* (1996) studied fish communities upstream of the major dams in the Hawkesbury-Nepean River system 1 km downstream and within the lower reaches of the catchment to examine the effects of river regulation on fish communities. An important finding of this study was the apparent abundance and diversity of fish communities upstream of the dams, whilst there was a signifincant decline in species diversity and abundance downstream of the impoundments (Gehrke *et al,* 1996). Two species that were notably affected were the Australian Bass and Freshwater Mullet.

Gehrke *et al* (1999) also examined the abundance and distribution of fish species in the regulated and unregulated sections of the Hawkesbury-Nepean river system. Species that were highly sensitive to flow regulation and included Common galaxia (*Galaxias maculates*), Empire gudgeon (*Hypseleotris compressa*), Striped mullet (*Mugil cephalus*), freshwater mullet (*Myxus petardi*) and Pacific blue-eye (*Pseudomugil signifier*) were absent from flow impacted sites.

The Department of Land and Water Conservation (now DNR) addressed the issues associated with barriers to fish passage through the development of the State Fishways Program which included the construction and maintenance of the vertical slot fishway at Penrith Weir (DLWC, 1999). However, the response of fish species to the fishway largely depends upon the structure and location of the fishway and unrelated processes such as reduced flows resulting from prolonged drought (Mallen-Cooper *et al,* 1995; Mallen-Cooper, 1996).

Clearing of Native Vegetation Along the Riparian Zone

Clearing of riparian vegetation is commonly associated with a decline in fish habitat. The process reduces available shelter and breeding grounds for both native and introduced fish species. Disturbance of native riparian vegetation and its effects on fish species distribution and abundance was investigated by Gehrke *et al* (1996) and Growns *et al (*1996; 2003).

Gehrke *et* al, (1996) concluded that smaller fish species such as gudgeons utilised the macrophyte stands adjacent to grassed banks for shelter and feeding, but this riparian vegetation community generally supported fewer fish species than well-vegetated riparian habitat.

Growns *et al* (1996) found that species richness and abundance was generally higher along the well-vegetated banks rather than degraded banks. The abundance of Australian Bass (*Macquaria novemaculeata)*, Carp (*Cyprius carpia)*, Empire gudgeon (*Hypseleotris compressa)*, Freshwater mullet (*Myxus petardi*) and Long-finned eel (*Anguilla reinhardtii*) was significantly higher near well-vegetated banks than along degraded banks (Growns *et al*, 1996). However, there was no relationship identified between the abundance and bank vegetation for Flathead gudgeon (*Philypnodon grandiceps*), Australian smelt (*Retropinna semoni)*, Freshwater herring (*Potamalosa richmondia)* and Striped mullet (*Mugil cephalus)* (Growns *et al*, 1996).

Growns *et al* (2003) also examined the affects of vegetation removal on fish communities in the Hawkesbury-Nepean River. Two habitats were selected for the study including well-vegetated banks supporting native trees and shrubs and grassed banks that have been colonised following the removal of native vegetation. Firetail, flathead and empire gudgeons were found to thrive in the vicinity of the grassed riverbanks, whereas freshwater mullet were much less abundant around the grassed banks (Growns *et al*, 2003). Growns *et al* (2003) inferred that the difference in species abundance was closely associated with the abundance of macrophyte species near the grassed banks. Therefore both macrophyte species and a diversity of riparian vegetation are considered essential to the maintenance of complex fish communities in the Hawkesbury-Nepean River system.

5.1.1 Objectives

This assessment has been prepared to assess the potential impacts of the Replacement Flows Project on native and exotic aquatic flora and fauna within the study area. The objectives of the assessment are to:

- describe the type, condition and distribution of aquatic flora and fauna species and fish habitat in the project area;
- evaluate the significance of aquatic flora and fauna and aquatic habitat in the local and regional context;
- assess the potential impact of the project on aquatic flora and fauna, including threatened species listed under the *Fisheries Management Act 1994* and *Commonwealth Environment Protection and Biodiversity Conservation Act 1999*, which occur in or in the general vicinity of the study area;

- provide management recommendations to ameliorate the identified direct or indirect impacts of the project on aquatic flora and fauna or their habitats.

5.1.2 Methodology

A desktop review was undertaken to assess the aquatic ecology and aquatic health of the local and regional area. Threatened species were a major focus of the aquatic ecology assessment. The investigation involved a search of relevant data sources to identify threatened species, endangered populations and endangered ecological communities in the receiving waters of the study area. It also involved a general assessment of the ecological health of the waterways. Data sources included:

- Department of Environment and Conservation Atlas of NSW Wildlife Database;
- Rare or Threatened Australian Plants (ROTAP) list developed by the CSIRO;
- Commonwealth Scientific and Industrial Research Organisation (CSIRO) - Australian National Insect Collection (ANIC) Database;
- Sydney Water Corporation Environmental Compliance Reports;
- records published in scientific journals, reports and general flora and fauna distribution text; and
- findings of local environmental studies, including studies prepared by consultants, local government authorities, universities and other sources.

5.2 Existing Environment

5.2.1 Warragamba River

Fish

Fish within the Warragamba River were studied by Gehrke *et al* (1996; 1999) as part of a larger study covering the Hawkesbury-Nepean River system. Gehrke *et al* (1996) conducted a detailed study of the effects of river regulation associated with dams in the Upper Nepean River catchment on downstream fish assemblages. Warragamba Dam (Lake Burragorang) was one of five dams subject of this investigation. Sites were selected upstream of the dam wall, 1 km downstream of the dam wall and in the lower reaches of the main channel of the Hawkesbury-Nepean River system at Menangle, Penrith and Yarramundi (Gehrke *et al, 1996;* 1999).

Distinct communities were identified in the lowland reaches of the Hawkesbury-Nepean River system, in the tributaries of the Upper Nepean River and parts of Lake Burragorang (Gehrke *et al*, 1996). The lake supports a heterogenous habitat with a more diverse community than other impoundments in the Hawkesbury-Nepean catchment (Gehrke *et al*, 1996).

Fish species sensitive to flow regulation including the Common galaxia (*Galaxia maculates*), Empire gudgeon (*Hypseoleotris compressa*), Striped mullet (*Mugil cephalus*) and Pacific blue-eye (*Pseudomugil signifier*) were generally absent from flow-impacted sites (Gehrke *et al*, 1999). The site downstream of Warragamba Dam was classed as a slope site due to its proximity to the dam wall, however it was grouped with sites in the lowland reaches of the Hawkesbury-Nepean River and the site shared the same characteristic species as the lowland reaches of the system (Gehrke *et al,* 1996.1999). Common species identified downstream of Warragamba Dam during the study included long-finned eel (*Anguilla reinhardtii*), Australian bass (*Macquaria novemaculeata*),

freshwater mullet (*Myxus petardi*), flathead gudgeon (*Philypnodon grandiceps*) and Australian smelt (*Retropinna semoni)* (Gehrke *et al*, 1999).

NSW Fisheries has also conducted fish surveys in the Warragamba River. **Table 5-2** provides a list of the fish catches between 1994 and 1995. Species caught include the Australian bass (*Macquaria novemaculeata*), Cox's gudgeon (*Gobiomorphus coxii*), eel-tail catfish (*Tandanus tandanus*), empire gudgeon (*Hypseleotris compressa*), firetail gudgeon (*Hypseleotris galii*), flathead gudgeon (*Philypnodon grandiceps*), freshwater mullet (*Myxus petardi*), long-finned eel (*Anguilla reinhardtii*), sea mullet (*Mugil cephalus*), smelt (*Retropinna semoni*), Bullrout (*Notesthes robusta*) and striped gudgeon (*Gobiomorphus australis*). The introduced Carp (*Cyprinus carpio*) was also recorded, in low numbers, during one survey.

Species abundance and composition varied considerably between sampling periods. The Australian Bass was the only species recorded during all eight sampling surveys, followed by the Sea Mullet, which was recorded during seven sampling surveys. The Bullrout, Eel-tail catfish and Firetail gudgeon were absent during the four 1994 surveys, while the Carp, Cox's gudgeon and Freshwater mullet were absent during the four 1995 surveys.

Table 5-2: Warragamba River fish catches 1994-1995 conducted by NSW Fisheries

Scientific Name	Common Name	Date of Survey							
		3/02/1994	10/03/1994	23/11/1994	5/12/1994	26/04/1995	31/05/1995	20/06/1995	28/09/1995
Macquaria novemaculeata	Australian Bass	3	154	36	90	148	3	91	20
Notesthes robusta	Bullrout					1		2	2
*Cyprinus carpio**	Carp			4					
Gobiomorphus coxii	Cox's Gudgeon	27							
Tandanus tandanus	Eel-tail Catfish							4	2
Hypseleotris compressa	Empire Gudgeon	6					3		
Hypseleotris galii	Firetail Gudgeon						1		
Philypnodon grandiceps	Flathead Gudgeon	273	33	16			18		
Myxus petardi	Freshwater Mullet			3					
Anguilla reinhardtii	Long-finned Eel	54	54	11			3		
Mugil cephalus	Sea Mullet		9	4	20	19	3	13	15
Retropinna semoni	Smelt		18	2			13		
Gobiomorphus australis	Striped Gudgeon	288		3			4	1	

Note: * - Introduced Species

Macroinvertebrates

Limited data is available to describe macroinvertebrate communities of the Warragamba River. A study undertaken as part of the Mulgoa Wallacia Silverdale Priority Sewerage Scheme (PPK, 2003) provides an assessment of the ecological health of macroinvertebrate communities in the Warragamba River between 1998 and 2002. Macroinvertebrates were surveyed from three sites in the Warragamba River and one site in the Nepean River at Wallacia Bridge. Records for 1998 and 2002 when the dam did not spill were analysed. The data was assessed at the Genus level using a rapid biological assessment methods (Stream Invertebrate Grade Number Average Level (SIGNAL) biotic index). The abundance and diversity of macroinvertebrate communities was analysed and a SIGNAL score calculated to infer the ecological health of macroinvertebrate communities. **Figure 5-1** shows the SIGNAL Values for each of the sites described in **Table 5-3**.

Immediately below the dam wall SIGNAL Values were in the range of 'possible organic pollution' whereas immediately downstream of the Warragamba STP discharge point, the SIGNAL Value displayed 'moderate organic pollution' (PPK, 2003). Further downstream, the SIGNAL Value improved to a level of 'possible organic pollution' (PPK, 2003).

Table 5-3: Warragamba River Site Descriptions

Site Code	Site Description	Distance from Dam Wall (m)
N643	Warragamba River below dam wall	200
N642	Warragamba River downstream of STP	1457
N641	Warragamba River at Norton basin	3287

Source: PPK (2003, p.6).

Note: Data derived from PPK (2003, p.16).

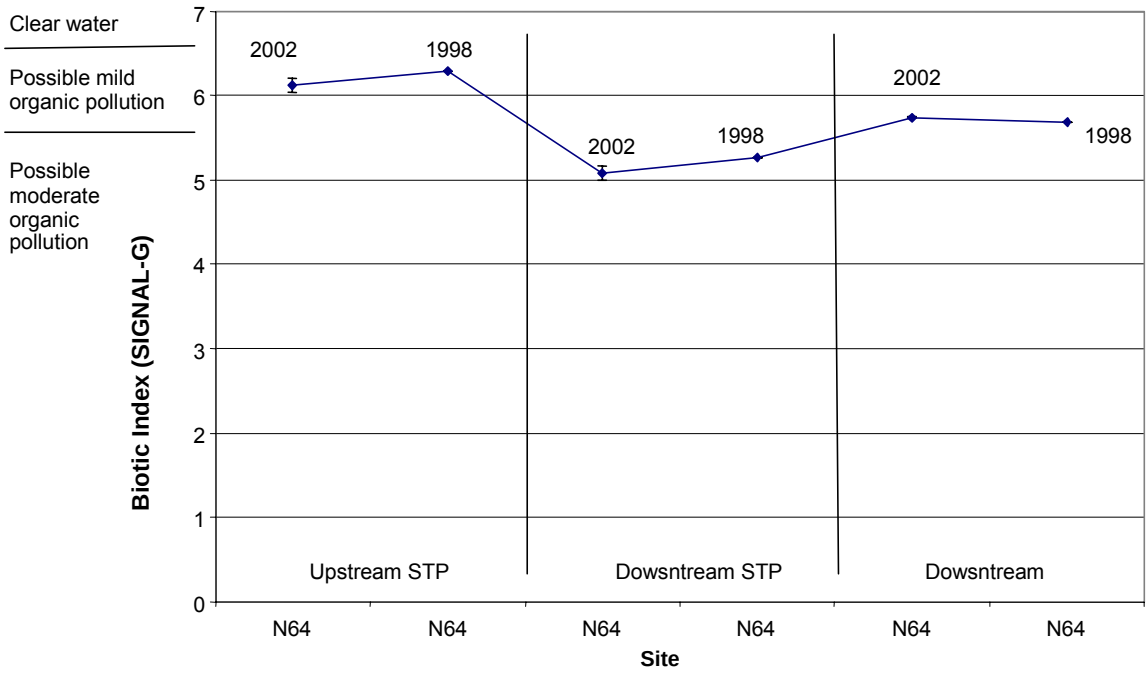


Figure 5-1: Existing Ecological Health of Warragamba River based on macroinvertebrate community composition

Based on the macroinvertebrate data available, Warragamba STP effluent discharge had an effect on the Warragamba River between the STP release point and the dam environmental flow release point. The SIGNAL Index score indicates a decline in ecosystem health immediately below the STP discharge and improvement downstream of the environmental flow release point near Site N641. However, flood water released from Lake Burragorang in 1998 improved water quality (SIGNAL Values) due to flushing pollutants associated with the effluent discharge from the STP out of the Warragamba River and into the Nepean River.

Dominant macroinvertebrates found in the Warragamba River include Chironomidae (Biting Midge Larvae), Pyraiidae (Aquatic Caterpillar) and Ecnomidae (Caddisfly Larvae), which are commonly associated with macrophyte species including Ribbonweed (*Vallisneria gigantea*) and Water Thyme (*Hydrilla verticillata*) (Cummins *et al*, 1997). A well studied order is the Odonata- dragonfly species, has three rare and potentially threatened species have been found in the catchment (*Sims et al,* 2001*)*. Species include the Giant Dragonfly (*Petalura gigantea*), Sydney Hawk Dragonfly (*Austrocordulia leonardi*) and the Adams Emerald Dragonfly (*Archaeophya adamsi*) (Sims *et al*. 2001). These species are discussed in more detailed in the following section.

Other Fauna

The Platypus (*Ornithorhynchus anatinus*) has been sighted infrequently in the Warragamba River below the dam wall (Grant, 1998). This species is most common in the headwaters of rivers and streams and prefers steep earth banks (Scott & Grant, 1997), which are characteristic of the Warragamba River. The Platypus has a timid nature and is rarely witnessed which could account for the infrequent nature of recorded sightings.

The native Water Rat (*Hydromys chrysogaster*), Eastern Snake-neck Turtle (*Chelodina longicollis*), Eastern Water Skink (*Eulamprus quoyii*) and numerous frog species are also likely to occur in the Warragamba River downstream of Warragamba Dam.

Macrophytes

Macrophyte species occurring in the Warragamba River have not been studied in detail due to their patchy distribution (Williams and Roberts, 2001). Dominant species include Ribbonweed (*Vaillisneria gigantean)* and Water thyme (*Hydrilla verticillata)* (Cummins *et al,* 1997). Regionally significant emergent species Lilaeopsis (*Lilaeopsis polyantha)* and *Marsilea spp*. (*Marsilea drummondii* and *Marsilea mutica*) were not identified in the areas surveyed (Williams and Roberts, 2001). More recently Egera and Salvinia have been observed in the river (pers. comm., DEC 2006).

Riparian Vegetation

Riparian vegetation in the Warragamba River catchment primarily consists of Sydney Coastal Riverflat Forest (AMBS, 1999) and Riparian Sandstone Scrub (ERM Mitchell McCotter, 1996). The river below the dam forms a steep gorge, known as Warragamba Gorge. River Oak (*Casuarina cunninghamiana*), Water Gum (*Tristaniopsis laurina*), Lemon-scented Tea Tree (*Leptospermum polygalifolium*) were once common in the gorge (ERM Mitchell McCotter, 1996). Their distribution has since been affected by land clearing associated with catchment development. Areas protected from land clearing and modification are inhabited by Gossamer Wattle (*Acacia floribunda*), Red Spider Flower (*Grevillea oleoides*), Native Daphne (*Eriostemon myoporoides*), Black Wattle (*Callicoma serratifolia*), Mat Rush (*Lomandra longifolia*) and (*Lomandra fluviatilis*) which are listed as a threatened species under the Rare or Threatened Australian Plants (ROTAP) developed by the CSIRO (ERM Mitchell McCotter, 1996).

Along Megarritys Creek, a tributary of the Warragamba River, the dominant riparian vegetation community is Sydney Sandstone Gully Forest (AMBS, 1999). Species include Red Bloodwood (*Corymbia gummifera*), Smooth-barked Apple (*Angophora castata*) and Sydney Peppermint (*Eucalyptus piperita*) (AMBS, 1999).

5.2.2 Hawkesbury-Nepean River - Wallacia Weir to Sackville

Fish

Fish species in the Hawkesbury-Nepean River system have been studied in both the freshwater and estuarine reaches. Pollard and Growns (1993) identified 164 species in these environments of which only a small portion exist in the middle and upper freshwater reaches of the Nepean River. Species identified during the study comprise native species, translocated species from other Australian catchments (namely the Murray-Darling system) and exotic species (Pollard and Growns 1993). Gehrke (1996) has identified four of these species listed as threatened, vulnerable or protected under the *Fisheries Management Act 1994* including Trout Cod, Macquarie Perch, Australian Grayling and Silver Perch (Gehrke, 1996).

Fish species in the Hawkesbury-Nepean catchment also surveyed as part of the NSW Rivers Survey (NSW Fisheries and the CRC for Freshwater Ecology 1997). Three sites were surveyed during 1983 and 1996. These sites included the Nepean River at Wallacia, Coxs River in Lithgow and Mangrove Creek at Mangrove Mountain. The most relevant of these sites in the context of this investigation is the location along the Nepean River at Wallacia.

Table 5-4 shows changes in the composition of fish species of the Nepean River between 1983 and 1996. A total of 5 introduced fish species were identified of which two appeared between 1983 and 1996 (Carp and Rainbow Trout). Twelve species of native fish were found of which several were not identified in the 1996 survey including the Macquarie Perch, Murray Cod, Common Jollytail, Mountain Galaxia, Empire Fish, Bullrout and Freshwater Herring. The absence of a number of native species in the 1996 fish survey was potentially due to the survey method however it was considered more likely that this was associated with an increase in exotic species and a decline in water quality and quantity (NSW Fisheries and the CRC for Freshwater Ecology, 1997).

Table 5-4: Changes in the Assemblage of Fish Species of the Hawkesbury- Nepean River System Between 1983 and 1996

Common Name	Scientific Name	Status	1983	1996
Shortfinned Eel	*Anguilla australis*	Native	R	R
Longfinned Eel	*Anguilla reinhardtii*	Native	R	R
Goldfish	*Carassian auratus*	Introduced	R	R
Carp	*Cyprius carpia*	Introduced	NR	R
Common Jollytail	*Galaxias maculatus*	Native	R	NR
Mountain Galaxias	*Galaxias olidus*	Native	R	NR
'Mosquito Fish'	*Gambusia holbrooki*	Introduced	R	R
Striped Gudgeon	*Gobiomorphus australis*	Native	R	R
Coxs Gudgeon	*Gobiomorphus coxii*	Native	R	R
Empire Gudgeon	*Hypseleotris compressa*	Native	R	NR
Firetailed Gudgeon	*Hypseleotris galii*	Native	NR	R
Murray Cod	*Maccullochella peelii*	Native	R	NR
Macquarie Perch	*Macquaria australasica*	Native	R	NR
Australian Bass	*Macquaria*	Native	R	R

Common Name	Scientific Name	Status	1983	1996
	novemaculeata			
Freshwater Mullet	*Myxus petardi*	Native	R	R
Bullrout	*Notesthes robusta*	Native	R	NR
Rainbow Trout	*Oncorhynchus mykiss*	Introduced	NR	R
Flathead Gudgeon	*Philypnodon grandiceps*	Native	R	R
Dwarf Flathead Gudgeon	*Philypnodon sp.*	Native	R	R
Freshwater Herring	*Potamalosa richmondia*	Native	R	NR
Australian Smelt	*Retropinna semoni*	Native	R	R
Brown Trout	*Salmo trutta*	Introduced	R	R
Freshwater Catfish	*Tandanus tandanus*	Native	R	R

Source: NSW Fisheries and the CRC for Freshwater Ecology (1997) Note: R – recorded, NR – Not Recorded

Pollard et al (1993; 1996), Pollard (1994) and Gehrke and Harris (1996) investigated the effects of STP discharge on fish communities in the freshwater reaches of the Hawkesbury-Nepean catchment. These studies concluded that the poorer water quality from STPs resulting from discharge of treated effluent adversely affects native fish species. Some species were more susceptible than others including the Australian Bass, an important recreational fishing species (Pollard et al, 1996). Introduced species such as Carp were much more tolerant of poor water quality (Gehrke and Harris, 1996).

Pollard *et al* (1994) examined the distribution and abundance of fish species in the freshwater reaches of the Hawkesbury-Nepean catchment in the vicinity of STP discharge points. Sites situated upstream and downstream of the discharge points at Camden, Penrith and Windsor STPs were studied. Of most relevance to this study were the fish communities examined in the vicinity of Penrith STP, which discharges to Boundary Creek. Pollard *et al* (1994) concluded that the species with higher environmental tolerances for nutrient rich waters occurred downstream of effluent discharge points. **Table 5-5** shows the distribution of species upstream, downstream and within the Penrith STP discharge.

Table 5-5: Fish species identified in the vicinity of the Penrith STP discharge point

Common Name	Scientific Name	Upstream	Within	Downstream
Firetailed Gudgeon	*Hypseleotris galii*	•		
Goldfish	*Carassian auratus**	•	•	
Freshwater Catfish	*Tandanus tandanus*	•		•
'Mosquito Fish'	*Gambusia holbrooki**	•	•	•
Long-finned Eel	*Anguilla reinhardtii*	•	•	•
Australian Bass	*Macquaria novemaculeata*	•	•	•
Flathead Gudgeon, Dwarf Flathead Gudgeon	*Philypnodon spp.*	• •	• •	• •
Australian Smelt	*Retropinna semoni*	•	•	•
Striped Gudgeon, Coxs Gudgeon	*Gobiomorphus spp.*	• •	• •	• •
Carp	*Cyprius carpia**	•	•	•
Freshwater Herring	*Potamalosa richmondia*	•	•	•
Freshwater Mullet	*Myxus petardi*	•	•	•

Common Name	Scientific Name	Upstream	Within	Downstream
Sea Mullet	*Mugil cephalus*	•	•	•
Bullrout	*Notesthes robusta*	•	•	•
Empire Fish	*Hypseleotris compressa*		•	•
Southern Blue Eye	*Pseudomugil signifer*			•

Source: Pollard *et al* (1994) * Indicates an exotic species.

Macroinvertebrates

Williams and Besley (1995) studied the distribution of macroinvertebrate species in the Hawkesbury-Nepean River system, including sites upstream and downstream of STP effluent discharge sites.

The diversity of macroinvertebrate communities was generally higher in the upper reaches of the Nepean River and its tributaries, whilst sites in the lower freshwater reaches and along tributaries displayed a lower species diversity (Williams and Besley, 1995). Sites at both Boundary and South Creek that receive effluent from Penrith STP and Quakers Hill, St Marys and Riverstone STPs respectively had the lowest macroinvertebrate diversity compared to other sites indicating the impact of poor water quality found in Boundary and South Creek as a result of habitat degradation, effluent discharge and pollutants entering the creeks via runoff. Williams and Besley (1995) also found that the introduced snail (*Physa acuta*) was the most commonly recorded species in the study area. This species and other exotic snails and worms thrive in eutrophic environments such as areas downstream of the STP effluent discharge points (Williams and Besley, 1995).

Since this study of macroinvertebrate species was undertaken each of the STPs discussed in the report have been upgraded to improve the quality of effluent. However the regulation of flows in the river system has not changed significantly over this time period.

Sydney Water has undertaken regular monitoring of macroinvertebrate abundance and distribution in this river reach. Analysis of macroinvertebrate data using the SIGNAL-G biotic index indicates that the operation of West Camden, Penrith, Winmalee and North Richmond STPs have had no net impact on macroinvertebrates in the main channel of the Hawkesbury-Nepean River with one exception for Penrith in the 1999-2000 period of the 11 year study period (SWC, 2005a).

In general, sites on the Hawkesbury-Nepean River fall into two distinct spatial zones with different levels of ecosystem health (**Figure 5-2).** The Upper-Nepean zone had relatively higher ecosystem health than the study reaches downstream of Penrith Weir. The Upper-Nepean zone extended from the upper-most sites sampled on the Bargo River at Rockford Bridge and on the mod to lower Nepean River at Maldon Bridge to the Nepean River at Wallacia Bridge. Sites were situated along the Nepean River from the confluence of the Warragamba River to the Hawkesbury River at Sackville Ferry, the most downstream site sampled.

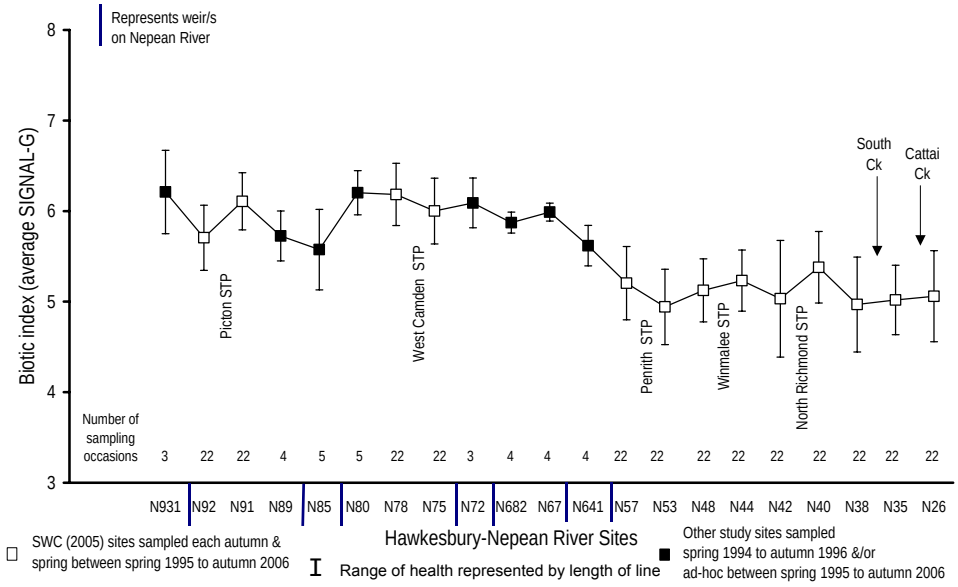


Figure 5-2: Ecosystem Health in the Receiving Waters of the Hawkesbury-Nepean River according to macroinvertebrate data

Other Fauna

The native Water Rat (*Hydromys chrysogaster*), Eastern Snake-neck Turtle (*Chelodina longicollis*), Eastern Water Skink (*Eulamprus quoyii*) and numerous frog species are likely to occur in the Hawkesbury-Nepean River, between Wallacia Weir and Wisemans Ferry.

Macrophytes

Macrophyte species occurring in the Hawkesbury-Nepean River include both native and exotic species. The abundance and distribution of macrophyte species has changed considerably as a result of eutrophication, habitat disturbance and alterations to the flow regime of the river (Recher *et al,* 1993). **Table 5-6** lists the common species that currently inhabit the Hawkesbury-Nepean River. The most abundant of the listed species includes the exotic weed Egeria (*Egeria densa*) and the native Ribbonweed (*Vallisneria gigantea*). Both are submerged species and their distribution in the river system has been examined in previous studies including Roberts *et al,* (1999), AMBS (1999), AMBS (2000) and Taylor-Woods (2002). The distribution and abundance of these species has changed considerably over the course of these studies. Both species are common downstream of Penrith Weir. Egeria has dominated over Ribbonweed, however Egeria is rarely found downstream of the Colo River as it has a low salt tolerance unlike the native Ribbonweed (Taylor-Wood, 2002).

Egeria is perhaps the most invasive exotic macrophyte inhabiting the Hawkesbury-Nepean River system. Roberts, *et al* (1999) conducted a detailed mapping survey of the distribution of Egeria and Ribbonweed as part of an investigation into the distribution of aquatic macrophytes inhabiting the river between Warragamba Dam and Wisemans Ferry. In 1994, Egeria covered an area of approximately 1.1 km^2 of the river and dominated the river reaches between Penrith Weir and Yarramundi. During this time the estimated fresh weight of Egeria was 9,500,000 kg (Roberts *et al*, 1999). Survey results for 1996 estimated that Egeria cover had increased to an area of approximately 2.1 km^2 below Penrith Weir and had an estimated fresh weight of 19,000,000 kg.

However, Egeria was not found upstream of Penrith Weir in the 1994 or 1996 surveys. Egeria was first recorded above Penrith Weir in 1998 (AMBS, 1999). Subsequent studies by AMBS (2000) and Taylor-Woods (2002) also identified *Egeria* upstream of Penrith Weir (refer **Table 5-6)**.

Since the introduction of Egeria into the Hawkesbury-Nepean catchment the native species Ribbonweed has been rapidly displaced (Roberts *et al,* 1999). In 1994, Ribbonweed was observed to be the dominant macrophyte species between Yarramundi and Windsor, and Windsor and Wisemans Ferry, but by April 1996 Egeria had infiltrated Vallisneria beds and in some areas totally displaced the native species (Roberts *et al* 1999).

Elodea (*Elodea Canadensis*) and Hydrilla (*Hydrilla verticillata*) are also common species found in the river system (AMBS, 2000). Elodea is a noxious weed that survives in faster flowing waters however, it is currently only found in low abundance in the Hawkesbury-Nepean River and is not yet considered to be a pest (AMBS, 2000). Both Egeria and Hydrilla thrive in nutrient laden water that promotes rapid growth of these plants (AMBS, 2000). The native Ribbonweed is intolerant of high nutrient waters and is generally absent in the river immediately downstream of the STPs.

Several factors have been attributed to the distribution of macrophyte species occurring in the Hawkesbury-Nepean River system including flow rates, habitat availability, temporal variations and water quality (Independent Expert Panel on Environmental Flows for the Hawkesbury-Nepean, Shoalhaven and Woronora Catchments, 2002). Perhaps the most influential factors are changes to flow rates caused by river regulation and changes to water quality resulting from discharge of effluent from STPs and runoff from urban and agricultural land. The distribution of invasive exotic macrophyte species reflects the impacts of both river regulation and eutrophication. In fact conditions have favoured the establishment of exotic species to the point that monospecific beds of Egeria have developed upstream of Penrith Weir (AMBS, 2000).

Table 5-6: Macrophyte Composition of the Hawkesbury-Nepean River System

River Reach	Macrophyte Species
Wallacia Weir to Penrith Weir (Nepean River)	At Wallacia common species found include: ◗ Large beds of Ribbonweed (*Vallisneria gigantean)* and Water Thyme (*Hydrilla verticillata)*; ◗ *Floating Pondweed (Potamogeton* tricarinatus) and Blunt Pondweed (*Potamogeton ochreatus)*; and; ◗ Floating macrophytes including Duck Weed, Pacific *Azolla (Azolla filiculoides) and* Salvinia *(Salvinia molesta)*. Downstream of the Wallacia Weir in the pool and riffle section of the gorge to Nortons Basin. ◗ Macrophyte species occurring in the pools include Alligator Weed (*Alternanthera philoxeroides*)and Egeria (*Egeria densa)*; and ◗ Reeds and sedges are also located in this river reach around the edge of pools. Near the confluence with the Warragamba River: ◗ Mixed beds of macrophtyes dominated by Ribbonweed (*Vallisneria gigantean)* and Water thyme (*Hydrilla verticullata*); and ◗ *Sage pondweed (Potamogeton pectinatus),*Blunt pondweed *(Potamogeton ochreatus,* Floating pondweed (*Potamogeton tricarinatus), Chara sp.* and Egeria (*Egeria densa)*. At Penrith Weir flows slow to support a mix of native and exotic macrophyte species including: ◗ Monospecific beds of Egeria (*Egeria densa*) along the river banks; ◗ Mixed beds of Ribbonweed (*Vallisneria gigantea*) and Water thyme (*Hydrilla verticillata*); and ◗ Reeds and sedges in shallow water.

River Reach	Macrophyte Species
Penrith Weir to Yarramundi Brdige (Nepean River)	◗ Egeria *(Egeria densa*) and Ribbonweed (*Vaillsneria gigantean*) are the dominant species; ◗ Alligator Weed (*Alternanthera philoxeroides*) infestations; and ◗ Mixed beds of Salvinia (*Salvinia molesta)*, Pacific *azolla (Azolla filiculoides*), Duck Weed and Water Hyacinth *(Azolla filiculoides*).
Yarramundi Bridge to South Creek (Hawkesbury River)	◗ Egeria (*Egeria densa*) dominates over native Ribbonweed (*Vallisneria gigantea*).
South Creek to Wisemans Ferry (Hawkesbury River)	Estuarine environment: ◗ Egeria *(Egeria densa*) is less common due to its salt intolerance; ◗ Ribbonweed (*Vallisneria gigantea*) is still common as far downstream as Webbs Creek; and ◗ River mangroves (*Aegiceras corniculatum*) and the Grey Mangrove (*Avicennia marina*) are present.

Data extracted from Taylor-Wood (2002) and Independent Expert Panel on Environmental Flows for the Hawkesbury-Nepean, Shoalhaven and Woronora Catchments (2002).

Riparian Vegetation

Riparian vegetation along the Hawkesbury-Nepean system is crucial to a number of aquatic species and provides shelter and important breeding habitat for aquatic fauna including fish and macroinvertebrates. Trees provide snags and shade, which lowers the water temperature and provides suitable habitat for sensitive species such as the threatened Macquarie Perch (Hannan, 1998). However, the existing distribution and abundance of riparian vegetation is sparse and highly modified along stretches of the river system where farming and urban development have occurred.

The section of the Hawkesbury-Nepean displaying the highest disturbance of riparian habitat lies along a 215 km stretch between the Nepean Dam and Wisemans Ferry (Benson and Howell, 1997). According to the *Stressed Rivers Assessment Report: Hawkesbury-Nepean Catchment* (DLWC, 1999), the Nepean River exhibits a moderate degree of environmental stress placed on riparian vegetation, whilst the riparian vegetation of the Hawkesbury River has been classified as highly stressed (DLWC, 1999). More than 50% of riparian vegetation has been removed from the banks of the Hawkesbury River and subsequent disturbance of shallow water ecosystems associated with the removal of riparian vegetation has resulted in a decline in aquatic fauna in these areas (DLWC, 1999). The importance of riparian vegetation to the assemblage of fish species occurring in the Hawkesbury-Nepean systems is discussed later.

Many weed species inhabit the riparian environment. AMBS (2000), Howell and Benson (2000), HRC (1998) and Hunt and Higgins (1996) have studied the disturbance of remnant vegetation by exotic weed species. Common species identified include Serrated Tussock (*Nasselia trichotoma*), Blackberry (*Rubus ulmifolius*), Lantana (*Lantana camara*), Scotch Broom (*Cytisus scaparius*), Balloon Vine (*Cardiospermum grandiflorim*), Blue Water Speedwell (*Veronica anagolia-aquatica*), Senegal Tea Plant (*Gymnocornis spilanthoides*), Hawthorn (*Crataegus monogyna*) (Benson and Howell, 1993; Expert Panel, 2003). Problematic species include Privet (*Ligustrum lucidum* and *L. sinense*), Honey Suckle (*Lonicera japonica*), Willows (*Salix sp.*), Honey Locust (*Gleditsia tricanthos*) and African Lovegrass (*Eragrostis curvula*) (AMBS 2000; Expert Panel 2003).

5.2.3 South Creek catchment

South Creek catchment is highly modified as a result of agriculture and urban development. Past and ongoing landuse practices have resulted in a decline in water quality and the health of the aquatic environment. Poor water quality is reflected by the state of the aquatic ecology including the presence of aquatic weeds and algal blooms.

Eastern Creek is a major tributary of South Creek and it contains tertiary treated effluent from Riverstone STP and Quakers Hill STP after it is discharged into Breakfast Creek, an important tributary of Eastern Creek.

The combined wastewater discharges entering South Creek via Eastern Creek and the discharge from St Marys STP has led to high nutrient loads which have been implicated in causing persistent algal blooms downstream of the STPs (SWC, 2005a). However algal blooms have also been recorded upstream of the STPs indicating that other sources upstream are adversely affecting water quality and the health of the aquatic environment SWC (2005a). Upstream sources of nutrient pollution are mainly runoff from urban, agricultural and industrial areas.

Overall, there is limited information on the aquatic ecosystems of South Creek.

Fish

As Eastern and South Creek are highly disturbed systems, larger fish species that depend on intact native riparian vegetation are absent in the middle and upper reaches of the creeks. Introduced species dominate both Eastern and South Creek due to the degraded aquatic environment. The Mosquito Fish (*Gambusia holbrooki*) is a common introduced species (Roberts, 2003).

There is one major barrier to fish passage in South Creek, Badgerys Creek Dam (DLWC, 1999). A number of other smaller barriers to fish passage impact the creek, primarily road crossings and culverts (Roberts, 2003).

Macroinvertebrates

Macroinvertebrate communities in South and Eastern Creeks have been regularly monitored to assess the impact of effluent discharge from St Marys, Quakers Hill and Riverstone STPs on aquatic ecosystem health (SWC 2005a). Monitoring upstream and downstream of the STPs indicates that the system is moderately to highly disturbed (SWC, 2005a). According to an assessment undertaken by SWC (2005a), effluent discharges from St Marys STP have a significant negative impact while effluent discharges from Quakers Hill STP have an intermittent negative impact, while discharges from Riverstone STP had no impact (SWC, 2005a).

Overall ecosystem health in the South Creek catchment was poorer than in the Hawkesbury-Nepean River with the exception of sites above St Marys STP (refer **Figure 5-2** and **Figure 5-3**).

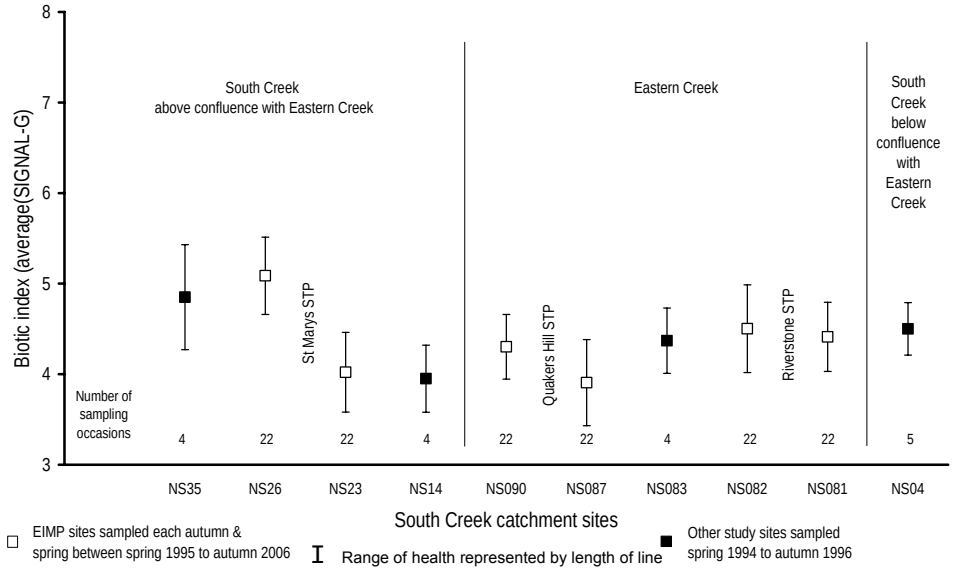


Figure 5-3: Ecosystem health in the receiving waters of the South and Eastern Creek catchments according to macroinvertebtrae data.

Other Fauna

Numerous frog species, the native Water Rat (*Hydromys chrysogaster*), Eastern Snake-neck Turtle (*Chelodina longicollis*) and Eastern Water Skink (*Eulamprus quoyii*) are likely to occur in the South Creek catchment.

Macrophytes

Macrophyte species in South Creek and its tributaries include both native and exotic species, although the latter dominate the waterway due to their tolerance of poor water quality.

Roberts (2003) examined macrophytes in South Creek as part of an investigation into the aquatic ecology of the South Creek catchment. In dry weather the upper reaches do not flow however pools supporting emergent macrophytes have formed in these areas.

Along the more stagnant and low flow zones of the creek, filamentous green algae, *Enteromorphis sp*. and aquatic weeds were common including Salvinia (*Salvinia molesta*) and Alligator Weed (*Alternanthera philoxeroides)* (Roberts, 2003). A weed control program to eradicate Salvinia and Alligator Weed has been developed by Penrith City Council (2003).

The most common native macrophyte found in South Creek is Ribbonweed (*Vallisneria gigantea*), however this species only occurs in reaches with less disturbed catchments.

Riparian Vegetation

The quality and coverage of riparian vegetation along Eastern Creek and South Creek has declined since European settlement. In 2002, the National Parks and Wildlife Service mapped riparian vegetation along South Creek as the endangered ecological community, Sydney Coastal River Flat Forest (Penrith City Council, 2003). Scattered remnants of the endangered ecological community (listed under the *TSC Act 1995)* form a corridor between the riparian zone and the transitional zone to Cumberland Plain Woodland, which has declined dramatically due to land clearing for agriculture and urban development (Penrith City Council, 2003). The River-Flat Forest community provides an important habitat for aquatic and amphibious species that inhabit riverbanks and adjacent waters.

Although the riparian zone is fragmented and highly disturbed, remnant native species such as Cabbage Gum (*Eucalyptus ampliflora*), Swamp Oak (*Casuarina glauca*) and Black Wattle (*Acacia decurrens)* still occur in the area (Penrith City Council, 2003). These trees overhang the creek and provide shelter and food for native and introduced aquatic fauna.

Much of the riparian zone is dominated by woody weed species, reflecting past and current landuse activities. Introduced species including Small-leaved Privet (*Ligustrum sinense*), Broad-leaved Privet (*Ligustrum ludicum),* African Olive *(Olea europea.)*, Bridal Creeper (*Asparagus asparagoides*)*,* Blackberry *(Rubus fructicosus)* and Wandering jew (*Tradescantia fluminensis*) dominate the understorey of the riparian zone.

5.3 Assessment of Impacts

5.3.1 Warragamba River

As identified in **Section 4.4.2** low flow conditions within Warragamba River would have an effect on the water quality conditions. Operation of the project would result in a further reduction in flows for the Warragamba River, which would cause further deterioration in water quality conditions. This predicted change would create favourable conditions for the growth of exotic macrophytes and could impact on the health of aquatic native species. Sydney Water is preparing a strategy to reduce the impacts of the discharge of the recently commissioned Wallacia STP to acceptable levels. This would result in a reduced nutrient load into the river to offset the impacts of reduced flows from the Warragamba Dam. Provided this is undertaken, excessive growth of exotic macrophytes would be limited.

Decommissioning of the old Warragamba STP should result in removal of the intermittent impact observed in drier periods in the Warragamba River above the existing environmental flow release point and would be beneficial to this reach of the Warragamba River. Recovery in macroinvertebrate assemblages following the decommissioning of STPs has been observed in the Blue Mountains, particularly Wentworth Falls STP (SWC 2003).

Provided appropriate measures to reduce the potential impact of the discharge from the Wallacia STP are implemented, the project is not expected to have any additional impact on fish or other components of the aquatic ecosystem.

5.3.2 Hawkesbury-Nepean River - Wallacia Weir to Sackville

Growns & Growns (2001) from a study of environmental flow releases concluded the principle effect of management of the water supply system in the Hawkesbury-Nepean River was changed hydrology rather than altered water quality. Future flow releases from the Upper Nepean storages under the Upper Nepean Dam releases are envisaged to only marginally raise the river level through the Upper Nepean zone. This increased level is unlikely to change the existing process of toe scarp retreat (bank erosion) within these weir-impounded reaches. Hubble (2004) describes the existing process of toe scarp retreat in this zone. The undercut bank areas provide macroinvertebrate edge habitat with extensive vegetation root growth and habitat complexity for juvenile fish. Given the existing process of toe scarp retreat will continue and maintain undercut bank habitat the existing macroinvertebrate assemblages should persist in this zone yielding SIGNAL-G scores similar to those recorded over the last 10 years at long term SWC (2005a) monitoring sites. Future flow releases are anticipated to have a neutral impact on fish assemblages, macrophyte composition or riparian vegetation. That is, neutral effect is envisaged from flow releases in the Upper Nepean zone.

The relatively long residence time of water in the Warragamba to Penrith Weir reach is predicted to only marginally shorten as a result of the 39 ML/day from the Upper Nepean Dam releases under the proposed Water Sharing Plan, which will enter the upper section of this reach. With the proposed reduction in flow from the Warragamba River a predicted increase of 4.5 ML/day at Penrith Weir is expected in the lower section of this reach. Under long spells of dry weather semi-lentic conditions are expected to continue and the river level is predicted to only marginally rise from these changes in flow and as such existing macroinvertrebate, fish, macrophyte and riparian assemblages should persist in this reach. That is, neutral effect is envisaged in the 'Warragamba to Penrith Weir reach'.

River level in the Penrith Weir to Yarramundi reach is expected to marginally rise from the predicted replacement flow release from 87 ML/day just below Penrith Weir to 116 ML/day. This flow is expected to continue to support flowing water macroinvertebrate, fish and macrophyte assemblages. The discharge from Winmalee STP in the lower section of this reach will also continue. As such, neutral effect is envisaged in the Penrith Weir to Yarramundi reach.

Most of the reach below Yarramundi is subject to bi-directional flow and is a freshwater tidal zone. Changes in flow upstream of this point are not expected to influence macroinvertebrates, fish or macrophytes in this reach. That is, neutral effect is envisaged in the 'Yarramundi to South Creek' reach.

The South Creek to Sackville reach is tidal. Overall flow into this reach will reduce from South Creek. After tidal mixing in this reach, concentrations from effluent discharges down South Creek are expected to be slightly lower in the receiving waters under dry weather conditions. A neutral effect is envisaged in the 'South Creek to Sackville' reach on aquatic life.

5.3.3 South Creek catchment

In dry weather conditions in South Creek the bulk of flow will originate from St Marys STP and in the Eastern Creek sub catchment the bulk of flow will originate from Quakers Hill STP. Despite reductions in flow from these plants, these treated discharges will still produce flowing water conditions downstream of these STPs and the constituents of the effluent will be similar. As such, no change in macroinvertebrate, fish or macrophyte assemblages is expected below these STPs. That is, neutral effect is envisaged in South Creek and in the Eastern Creek sub catchment.

5.3.4 Other Relevant Areas

Boundary Creek

As discussed in **Section 3.3.3**, approximately 22 ML/day of tertiary treated effluent from Penrith STP is currently discharged into the creek approximately 500 m upstream of its junction with the Hawkesbury-Nepean River. It is proposed that discharge from Penrith STP would cease, except in wet weather or as a consequence of a shutdown on the AWTP, and up to 50 ML/day of highly treated recycled water would be discharged as replacement flows via Boundary Creek.

An increase in flow volume and potentially velocity could lead to a change in the composition of macroinvertebrate taxa in Boundary Creek, favouring species adapted to faster flowing water. Water quality is expected to improve as a result of the advanced water treatment (reverse osmosis) and as such the project would have a neutral or beneficial effect on macroinvertebrate community composition.

In regard to fin-fish assemblages, increased flows from Boundary Creek have the potential to effect fish migration at Penrith Weir and the functioning of the fishway. The upstream migration of fish in the Nepean River is stimulated mainly by rising water temperatures and flow. Fish appear to

respond to either stable low flows or to increases in flow (Mallen-Cooper, 2006). Downstream migration is either stimulated by falling temperatures or falling temperatures combined with significant increases in flows. Downstream migration is unlikely to be impacted by the project as the flows that stimulate downstream migration would not be affected (Mallen-Cooper, 2006).

The potential affect of the project which is of most concern would be on fish species during upstream migration at low flows, which are mainly small-bodied fishes. Those species that are stimulated to migrate by high flows would not be impacted, as the project would only contribute a small percentage of the total river flow (Mallen-Cooper, 2006).

To gauge the impact there are three hydrological scenarios to consider: i) current non-drought flows, ii) predicted flows without the project, and iii) predicted flows with the project (Mallen-Cooper, 2006).

Current non-drought flows

Under present conditions the low flows (95^{th} percentile) passing Penrith Weir (including the fishway) is 62 ML/d, compared with 22 ML/d from Boundary Creek. Boundary Creek might be attracting some fish in these conditions but the extent would depend on water quality, particularly water temperature. Fish that are migrating upstream in spring and summer in lowland coastal rivers of NSW are attracted to warmer water if there is a choice. Limited data for Boundary Creek suggest it may be warmer than the Nepean River. The migratory response of fish to streams of differing water quality or the interaction of temperature and water quality is not well known but it would be reasonable to assume that fish would prefer higher water quality (Mallen-Cooper, 2006).

Predicted 2009 flows

In this predicted flow regime Penrith Weir passes low flows of 67 ML/d and Boundary Creek passes 50 ML/d with improved water quality. If all water quality parameters were similar in these two streams the migratory biomass could be expected to be proportional to flow. The diversity of habitat features in the Nepean River compared with Boundary Creek might increase the proportion of fish using the Nepean River, which would have greater riparian and instream cover for small fish and greater depth for large fish. However, with similar water quality in both streams a significant biomass of migratory fish could be expected to enter Boundary Creek (Mallen-Cooper, 2006).

If water quality is different in the two streams the response for migratory fish would likely differ. The water quality from the project is expected to be improved and if it is assumed that it will be similar to the Nepean River passing Penrith Weir then water temperature will be the main factor influencing the extent the project impacts on fish migration. If the water temperature from the project is more than three degrees cooler it is likely that most fish would avoid Boundary Creek and migrate up the Nepean River. However, it is unknown if this generalisation applies to all species and life stages present near Penrith Weir and it would need to be monitored in the field (Mallen-Cooper, 2006).

In summary, the Replacement Flows Project discharge from Boundary Creek could affect fish migration but the extent of this impact depends on the water quality and particularly the water temperature.

Recommendations

A study should be undertaken in consultation with Department of Primary Industries (Fisheries) to determine whether the discharge of the replacement flow would result in changes to the natural fish migration over Penrith Weir. Based on outcomes of this study appropriate design and other mitigation measures would be developed.

5.4 Threatened Species

Species listed as 'threatened' are at risk of becoming extinct and therefore require protection. In NSW, threatened aquatic species are protected by the *Fisheries Management Act 1994*. The Act lists endangered (Schedule 4) and vulnerable (Schedule 5) fish and aquatic invertebrate species, populations and ecological communities. The *Fisheries Management Act 1994* receives listings according to recommendations by the Fisheries Scientific Committee. They are also responsible for assessing and listing key threatening processes. There are currently seven key threatening processes listed under Schedule 6 of the Act.

Threatened aquatic species are also listed under the *Environmental Protection and Biodiversity Conservation Act 1999*. The *Environment Protection and Biodiversity Conservation Act 1999* covers matters of National Environmental Significance including the conservation and protection of threatened species, endangered communities and ecological populations. It also lists key threatening processes.

Threatened species, their conservation status and likely presence within the study area are presented in **Table 5-7**.

Table 5-7: Aquatic threatened species

Scientific Name / Common Name	Status	Likely presence in study area
Petalura gigantean Giant Dragonfly	Endangered (TSC Act)	The Giant Dragonfly is an extremely large, and unusual species of dragonfly, which is considered to be largely terrestrial throughout its life cycle. The larvae occupy permanent long chambered burrows, built under swamps. Larvae are not known to swim and avoid open water. The dragonfly lives in permanent wetlands and swamps with open vegetation. The Giant Dragonfly is found along the east coast of NSW from the Victorian border to northern NSW. The Giant Dragonfly is not known to occur within the study area, however, potential habitat may exist within a freshwater wetland located adjacent Penrith STP. The proposed pipeline is to be located on an existing cleared track adjacent the southern perimeter of this wetland. Implementation of appropriate sediment and erosion controls will ensure the proposed development does not impact upon the wetland. No other suitable habitat has been identified within the project area. Further assessment is not required.
Austrocordulia leonardi Sydney Hawk Dragonfly	Endangered (FM Act)	The Sydney Hawk Dragonfly is a black and yellow dragonfly with clear wings. Its known distribution is extremely limited, being found in only three locations in a small area south of Sydney, from Audley to Picton. The Dragonfly has specific habitat requirements including deep riverine pools with slow-flowing cooler water in rocky rivers with steep sides that provide shady rest areas. The study area provides potential habitat for this species. Further assessment is provided below.
Archaeophya adamsi Adams Emerald Dragonfly	Vulnerable (FM Act) Vulnerable (TSC Act)	The Adams Emerald Dragonfly is a moderately large, robust dragonfly. The dragonfly is known to occur at only four localities in the greater Sydney region and its estimated potential distribution encompasses the Hawkesbury-Nepean catchment. Larvae are only known to occur in small creeks with gravel or sandy bottoms, in narrow, shaded, riffle zones and intact riparian vegetation. This species is considered very unlikely to occur within the project area due to a lack of suitable habitat. Further assessment is not required.
Macquaria australias Macquarie Perch	Vulnerable (FM Act) Endangered (EPBC Act)	The Macquarie Perch is a large freshwater fish endemic to the Murray-Darling Basin and part of southeastern coastal NSW, including the Hawkesbury-Nepean catchment. Macquarie Perch are found in both river and lake habitats, especially in the upper reaches of rivers and their tributaries. Macquarie Perch are known to occur in the upper reaches of the Nepean River. They have not been recorded within the project area however the project area provides potential habitat for this species. Further assessment is provided below.
Prototroctes maraena Australian Grayling	Vulnerable (EPBC Act) Protected (FM Act)	The Australian Grayling is a moderate to large freshwater fish which occurs in streams and rivers of southeastern NSW and Victoria. The Australian Grayling needs to migrate to and from the sea to complete their life cycle and are therefore not found upstream of physical barriers such as dams. The Australian Grayling is known to occur within the Grose River a tributary of the Hawkesbury-Nepean River. This population would utilise the Hawkesbury-Nepean River downstream of the Grose River confluence for migration to and from the sea. The project area provides potential habitat for this species. Further assessment is provided below.
Maccullochella macquariensis Trout Cod	Endangered (FM Act) Endangered (EPBC Act)	The Trout Cod is a large freshwater fish endemic to inland waters of the southeastern Australia region. The Trout Cod was translocated to the Hawkesbury-Nepean in 1915 and survives in Lake Cataract. This translocated population is thought to have hybridised with Murray Cod (Gehrke, 1996) and as such have no conservation value as a natural population. Furthermore it is highly unlikely that the Cod survives below Cataract Dam due to the physical barrier created by the dam wall. The Trout Cod is unlikely to occur within the study area due to the presence of a physical barrier upstream. Further assessment is not required.
Bidyamus bidyanus Silver Perch	Vulnerable (FM Act)	The Silver Perch is a moderate to large freshwater fish native to the Murray-Darling river system. Along with the Trout Cod it was introduced to Lake Cataract in 1915. It is highly unlikely that the Perch survives below Cataract Dam due to the physical barrier created by the dam wall. The Silver Perch is unlikely to occur within the project area due to the presence of a physical barrier upstream. Further assessment is not required.

Three threatened species, including the Macquarie Perch, Australian Grayling and Sydney Hawk Dragonfly were identified as having potential habitat within the project area. An assessment of significance was prepared for each of the species likely to occur in the study area in accordance with the *Environmental Planning and Assessment Act 1979*, *Fisheries Management Act 1994* and *Environmental Protection and Biodiversity Act 1999* (**section 5.4.1**). The threatened species tests concluded that the Replacement Flows Project is unlikely to disrupt a local viable population of the species, such that the species is likely to be placed at risk of extinction. A significant area of known habitat for these species would not be modified or removed, or isolated from currently interconnecting or proximate areas as a result of the Replacement Flows Project. The project would not have a significant impact on threatened species known to occur within the Hawkesbury-Nepean catchment.

5.4.1 Assessment of Significance - *Fisheries Management Act 1994*

Sydney Hawk Dragonfly (*Austrocordulia leonardi*)

The Sydney Hawk Dragonfly is a black and yellow dragonfly with clear wings. It was first discovered along the Woronora and Kangaroo Rivers in 1968 and has since been identified in the Nepean River at Maldon Bridge. Its known distribution is extremely limited.

The Dragonfly appears to have specific habitat requirements, including slow-flowing water in rocky rivers with steep sides that provide shady resting areas (FSC, 2004). All specimens collected came from deep riverine pools with cooler water.

The Sydney Hawk Dragonfly has not been previously identified within the project area.

(a) in the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction,

The mid Nepean River generally provides poor quality potential habitat for the Sydney Hawk Dragonfly due to existing riverine and catchment impacts such as sedimentation of rocky pools, flow reduction and regulation, reduced water quality, catchment development, clearance of riparian vegetation and encroachment of exotic weeds.

As a result of the Project, other river management changes and wastewater management improvement, flows would generally increase in the Hawkesbury-Nepean River, with the exception of during very low flows for the reach above Penrith Weir and Warragamba River. Nitrogen concentrations and loads in the Hawkesbury-Nepean River between Wallacia Weir and Sackville are predicted to decrease. Other key water quality parameters are not predicted to change significantly as a result of the Project.

The proposed Project would not result in the direct loss of potential habitat for the Sydney Hawk Dragonfly. In addition, the proposed increase in flows and equivalent or improved water quality would potentially improve habitat for this species in the Nepean River. Flows would be reduced within the Warragamba River, however the river currently provides poor quality habitat for this species due to siltation and disturbance of preferred habitat areas (eg rocky rivers with intact riparian vegetation).

As potential habitat for this species within the Project area would be retained and potentially improved in the Nepean River, it is considered that the Project would not disrupt the lifecycle of this species such that a viable population is likely to be placed at risk of extinction.

(b) in the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction,

N/A

(c) in the case of an endangered ecological community or critically endangered ecological community, whether the action proposed:

- *is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or*
- *is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction,*

N/A

(d) in relation to the habitat of a threatened species, population or ecological community:

- *the extent to which habitat is likely to be removed or modified as a result of the action proposed, and*
- *whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action, and*
- *the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality,*

The proposed Project would not result in the direct loss of potential habitat for the Sydney Hawk Dragonfly. In addition, the proposed increase in flows and equivalent or improved water quality would potentially improve habitat for this species in the Nepean River. Flows would be reduced within the Warragamba River, however the river currently provides poor quality habitat for this species due to siltation and disturbance of preferred habitat areas (eg rocky rivers with intact riparian vegetation).

A significant area of known habitat for this species will not be modified or removed, or isolated from currently interconnecting or proximate areas as a result of the Replacement Flows Project.

(e) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly),

Critical habitat for the Sydney Hawk Dragonfly has not been defined under the *Fisheries Management Act 1994*. The Sydney Hawk Dragonfly has not been previously identified within the project area. Nonetheless, key habitats of the Sydney Hawk Dragonfly including deep riverine pools with slow-flowing water would not be adversely affected by the proposal.

(f) whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan,

There is currently no recovery plan or threat abatement plan prepared for the Sydney Hawk Dragonfly. The Sydney Hawk Dragonfly has not been previously identified within the project area. However, as potential habitat for this species within the Project area would be retained and potentially improved in the Nepean River, it is considered that the Project would not disrupt the lifecycle of this species such that a viable population is likely to be placed at risk of extinction.

(g) whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.

The Replacement Flows Project would result in alteration of existing flow regimes within the highly regulated Hawkesbury-Nepean River downstream of the confluence with Warragamba River. The installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams is a key threatening process listed under the *Fisheries Management Act 1994*.

The Project is unlikely to disrupt a local viable population of the species, through alteration of flow regimes and is considered unlikely to increase the impact of a key threatening process as the Project other river management changes and wastewater management improvement would improve natural flow variability and water quality.

Macquarie Perch (*Macquaria australias*)

The Macquarie Perch (*Macquaria australias*) is listed as Vulnerable on Schedule 5 of the *Fisheries Management Act 1994* and *Endangered on the Environment Protection and Biodiversity Conservation Act 1999*.

The Macquarie Perch is a schooling species that prefers deep, rocky holes with considerable cover. Spawning occurs just above riffles. Macquarie Perch undertake an upstream breeding migration in late spring, depositing small adhesive demersal eggs above riffles and at the tail of pools.

The eastern population of Macquarie Perch are known to occur in the upper reaches and dams of the Nepean River, Glenbrook Creek and the Colo River in the Hawkesbury-Nepean catchment and the upper Shoalhaven River. The eastern population appears to be genetically distinct from the Murray Darling basin population.

(a) in the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction,

The Macquarie Perch is known to occur in the upper reaches of the Hawkesbury-Nepean River including Glenbrook Creek (approximately 6km upstream of Penrith Weir). The mid Nepean River generally provides poor quality potential habitat for the Macquarie Perch due to existing impacts such as sedimentation of deep pools and riffles, flow reduction and regulation, reduced water quality, catchment development and encroachment of exotic weeds.

As a result of the Project, other river management changes and wastewater management improvement, flows would generally increase in the Hawkesbury-Nepean River, with the exception of during very low flows for the reach above Penrith Weir and Warragamba River. Nitrogen concentrations and loads in the Hawkesbury-Nepean River between Wallacia Weir and Sackville are predicted to decrease. Other key water quality parameters are not predicted to change significantly as a result of the Project.

The proposed Project would not result in the direct loss of potential habitat for this species. In addition, the proposed increase in flows and equivalent or improved water quality would potentially improve habitat for this species in the Nepean River. Flows would be reduced within the Warragamba River, however the river currently provides poor quality habitat for this species due to siltation of preferred habitat areas (eg deep pools and riffles).

As potential habitat for this species within the Project area would be retained and potentially improved in the Nepean River, it is considered that the Project would not disrupt the lifecycle of this species such that a viable population is likely to be placed at risk of extinction.

(b) in the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction,

N/A

(c) in the case of an endangered ecological community or critically endangered ecological community, whether the action proposed:

- *is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or*
- *is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction,*

N/A

(d) in relation to the habitat of a threatened species, population or ecological community:

- *the extent to which habitat is likely to be removed or modified as a result of the action proposed, and*
- *whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action, and*
- *the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality,*

The proposed Project would not result in the direct loss of potential habitat for this species. In addition, the proposed increase in flows and equivalent or improved water quality would potentially improve habitat for this species in the Nepean River. Flows would be reduced within the Warragamba River, however the river currently provides poor quality habitat for this species due to siltation of preferred habitat areas (eg deep pools and riffles).

A significant area of known habitat for this species will not be modified or removed, or isolated from currently interconnecting or proximate areas as a result of the Project.

(e) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly),

Critical habitat for the Macquarie Perch has not been defined under the FM Act 1994. Nonetheless, key habitats of the Macquarie Perch including deep pool and riffle systems would not be adversely affected by the proposal.

(f) whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan,

There is currently no recovery plan or threat abatement plan prepared for the Macquarie Perch. However, as potential habitat for this species within the Project area would be retained and potentially improved in the Nepean River, it is considered that the Project would not disrupt the lifecycle of this species such that a viable population is likely to be placed at risk of extinction.

(g) whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.

The Replacement Flows Project would result in alteration of existing flow regimes within the highly regulated Hawkesbury-Nepean River downstream of the confluence with Warragamba River. The installation and operation of instream structures and other mechanisms that alter natural flow

regimes of rivers and streams is a key threatening process listed under the *Fisheries Management Act 1994*.

The Project is unlikely to disrupt a local viable population of the species, through alteration of flow regimes and is considered unlikely to increase the impact of a key threatening process as the Project other river management changes and wastewater management improvement would improve natural flow variability and water quality.

5.4.2 Assessment of Significance - *Environment Protection and Biodiversity Conservation Act 1999*

Macquarie Perch - *Macquaria australasica*

1. Lead to a long-term decrease in the size of an important population of a species.

Impacts on fish may potentially result from the alteration of flows within Warragamba River (associated with the cessation of environmental flows from Warragamba Dam), the Hawkesbury-Nepean River (associated with the release of replacement flows and increased flows from the Upper Nepean Dams), South Creek and Eastern Creek (associated with reduced tertiary wastewater discharges).

The Macquarie Perch is a schooling species that prefers deep, rocky holes with considerable cover. Spawning occurs just above riffles. Riffle and pool habitat has been dramatically altered and in-filled within the Warragamba River due to construction of Warragamba Dam and alteration of the natural flow regime and in the Hawkesbury-Nepean River downstream of the Warragamba River.

The proposed Project would not result in the direct loss of potential habitat for this species. In addition, the proposed increase in flows and equivalent or improved water quality would potentially improve habitat for this species in the Nepean River. Flows would be reduced within the Warragamba River, however the river currently provides poor quality habitat for this species due to siltation of preferred habitat areas (eg deep pools and riffles).

As potential habitat for this species within the Project area would be retained and potentially improved in the Nepean River, it is considered that the Project would not lead to a long-term decrease in the size of an important population of this species.

2. Reduce the area of occupancy of an important population

The proposed Project would not result in the direct loss of potential habitat for this species. In addition, the proposed increase in flows and equivalent or improved water quality would potentially improve habitat for this species in the Nepean River. Flows would be reduced within the Warragamba River, however the river currently provides poor quality habitat for this species due to siltation of preferred habitat areas (eg deep pools and riffles).

3. Will the action adversely affect habitat critical to the survival of the species?

Critical habitat for the Macquarie Perch has not been defined under the *Environmental Protection and Biodiversity Conservation Act 1999.*

Key habitat of the Macquarie Perch includes pool and riffle sequences. The replacement flows project will not modify, isolate or damage the quality of habitat required by Macquarie Perch.

4. Modify, remove, or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline.

Key habitat of the Macquarie Perch includes pool and riffle sequences. The Project will not modify, isolate or damage the quality of habitat required by Macquarie Perch.

5. Result in invasive species that are harmful to a vulnerable species becoming established in the threatened species habitat.

Introduced and exotic species would not increase as a result of the proposal and therefore would not establish in areas known to be inhabited by Macquarie Perch.

6. Interferes substantially with the recovery of the species

The proposal would not interfere with the recovery of the species as it would not result in the direct loss of potential habitat for this species or reduce water quality in the Hawkesbury-Nepean River.

Australian grayling - *Prototroctes maraena*

1. Lead to a long-term decrease in the size of an important population of a species.

The Australian Grayling is known to occur in the Grose River, with converges on the Hawkesbury-Nepean River approximately 18 km downstream of Penrith Weir.

The proposed Project would not result in the direct loss of potential habitat for this species. In addition, the proposed increase in flows and equivalent or improved water quality would potentially improve habitat for this species in the Nepean River. Flows would be reduced within the Warragamba River, however the Australian Grayling is not known to occur in the River and the River currently provides poor quality habitat for this species.

As potential habitat for this species within the Project area would be retained and potentially improved in the Nepean River, it is considered that the Project would not lead to a long-term decrease in the size of an important population of this species.

2. Reduce the area of occupancy of an important population

It is unlikely that the replacement flows project will reduce the area of occupancy of Australian Grayling. The proposed Project would not result in the direct loss of potential habitat for this species. In addition, the proposed increase in flows and equivalent or improved water quality would potentially improve habitat for this species in the Nepean River.

3. Will the action adversely affect habitat critical to the survival of the species?

Critical habitat for the Australian Grayling has not been defined under the *Environmental Protection and Biodiversity Conservation Act 1999.*

Key habitat of the Australian Grayling will not be adversely affected by the proposal as it will result in a reduction of nutrients discharged downstream of Penrith Weir.

4. Modify, remove, or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline.

The replacement flows project is likely to improve the habitat of the Australian Grayling through reduction in nutrients discharged and will not modify or damage the quality of habitat downstream of Penrith Weir.

5. Result in invasive species that are harmful to a vulnerable species becoming established in the threatened species habitat.

The Project is not expected to increase the abundance of introduced and alien species and therefore will not adversely lead to invasion of established Australian Grayling habitat.

6. Interferes substantially with the recovery of the species.

The proposal will not interfere with the recovery of the Australian Grayling as it would not result in the direct loss of potential habitat for this species or would improve water quality in the Hawkesbury-Nepean River downstream of Penrith Weir.

5.5 Mitigation Measures

Management measures to reduce the impact of the proposed Replacement Flows Project on aquatic flora and fauna species and habitat include:

- a strategy to minimise the impacts of the discharge of Warragamba STP on water quality in the Warragamba River with the cessation of interim flow releases from Warragamba to acceptable levels would be developed;
- monitoring of the predicted affects of the project will be conducted; and
- a study would be undertaken in consultation with Department of Primary Industries (Fisheries) to determine whether the discharge of the Replacement Flows Project would result in changes to the natural fish migration over Penrith Weir. Based on outcomes of this study appropriate design and other mitigation measures would be developed
- restricting removal of riparian vegetation and disturbance to the natural banks and bed of the South and Eastern Creeks during construction of the pipelines by employing underground boring techniques; and
- implementation of appropriate sediment and erosion control measures during construction and stabilisation of the proposed construction works to ensure that downstream impacts are minimised.

If a problem is detected from the above mentioned monitoring adaptive management strategies would be implemented to minimise the detected affect of the operation of the project.

6. Recreation

6.1 Introduction

The Hawkesbury-Nepean river system provides a considerable recreational resource for the local population and for tourists. The data on recreation facilities, usage and revenue is very sporadic. An estimated 900 'cultural and recreational services' businesses employed over 4,000 people in the Hawkesbury-Nepean catchment in 1997. Due to the population growth in the region the number of visits to the river each year is estimated to increase to 20 million in 2020, from 10 million in 1992 (HNRMF, 2004).

As well as providing opportunities for water based activities the weir pools and many of the main river stretches have retained their scenic qualities which attract visitors who come to enjoy the natural surroundings. A rough estimate of general recreation expenditure was in the order of $300 million per year (1992). In 1993 the gross revenue to caravan and ski parks alone was about $5.1 million (HNRMF, 2004).

Table 6-1 provides details of the range of recreational activities that occur on and around the river. These include both passive and active recreation types.

Table 6-1: Recreational activities undertaken within the Hawkesbury-Nepean

Medium	Details
Water based	
Waterskiing	The Hawkesbury River has been regarded as the 'home of water skiing in Australia'. The stretch between Windsor and Wisemans Ferry supports around 25 ski parks.
Boating	Hire of houseboats is a popular tourist activity as is sailing, speed or motor boating. Ferries and tour boats also operate along various stretches of the river. In 1993 there were over 40,000 boat licenses issued to people who use the Hawkesbury-Nepean (UTS, 2002).
Rowing	There are many rowing opportunities within the river and neighbouring recreational facilities such as the Penrith Lakes Scheme. The stretch of River between the Western Motorway bridge and Victoria Bridge is used as a championship rowing course and rowing and kayak sprint course
Kayaking	Kayak hiring businesses operate in the area, providing individual kayak hire or guided kayak tours.
Recreational fishing	Recreational fishing occurs in both saline and freshwater stretches with over 43,000 recreational fishers visiting the Hawkesbury Nepean river system every year (NSW Fisheries & Tasmania Aquaculture and Fisheries Institute, 2003). They are thought to spend $3.5-5.2 million dollars and land 87 tonnes of fish annually. NSW has the highest number of recreational fishers in Australia (NSW Fisheries & Tasmania Aquaculture and Fisheries Institute, 2003). There are a number of local fishing clubs who use the river including the Hawkesbury-Nepean Bass Anglers Association.
Swimming	Swimming and paddling occurs along the length of the Hawkesbury Nepean river and within the weir pools. As it is a primary contact recreational activity it is dependent upon water quality as well as presence of algae and macrophytes.
Land based	
Picnicking	Formal picnic sites are provided within national parks, reserves and recreation areas at various locations along the length of the river.
Camping/caravanning	The stretch between South Creek and Wisemans Ferry has the highest concentration of caravan sites.
Eco tours/bushwalking	Walking is a popular activity along the banks of the Hawkesbury Nepean and also within adjacent National Parks and Recreation Areas. Guided nature walks and other ecotourism activities are provided.
Scenery	There are several lookouts along the length of the river which provide scenic viewing points mostly within the national parks. There are accessed by car or by foot.
Horse riding	Horse riding is permitted in various locations including the Yarramundi Reserve.
Retreats/spas	In addition to hotels and motels the natural surroundings within the Hawkesbury Nepean River provide a popular environment for health retreats and spa facilities.
Adventure	Motor biking, bicycling and other adventure activities are available within designated areas along the river.

The recreational use of the river is based on a number of factors including width and depth of the water body, access, land ownership, degree of development and water quality. The culmination of these factors in particular locations, results in the recreational use of the river being concentrated at a number of nodes (MWS&DB, 1986).

The area of the Hawkesbury-Nepean River potentially affected by the proposed replacement flows project has been separated into seven distinct reaches. These reaches have been described separately and are shown in **Figure 2-1**. **Figure 6-1** shows the location of parks, reserves and other important recreation areas along the river.

6.2 Existing Recreational Uses

6.2.1 Warragamba River

This section covers the area from the Warragamba Dam wall to the confluence with the Hawkesbury Nepean river. This 3km stretch of river has picnic facilities located within Haviland Park on the east side of the dam and at Warragamba Park at the confluence with the Nepean River. There are no boat ramps or camping facilities provided along this short stretch.

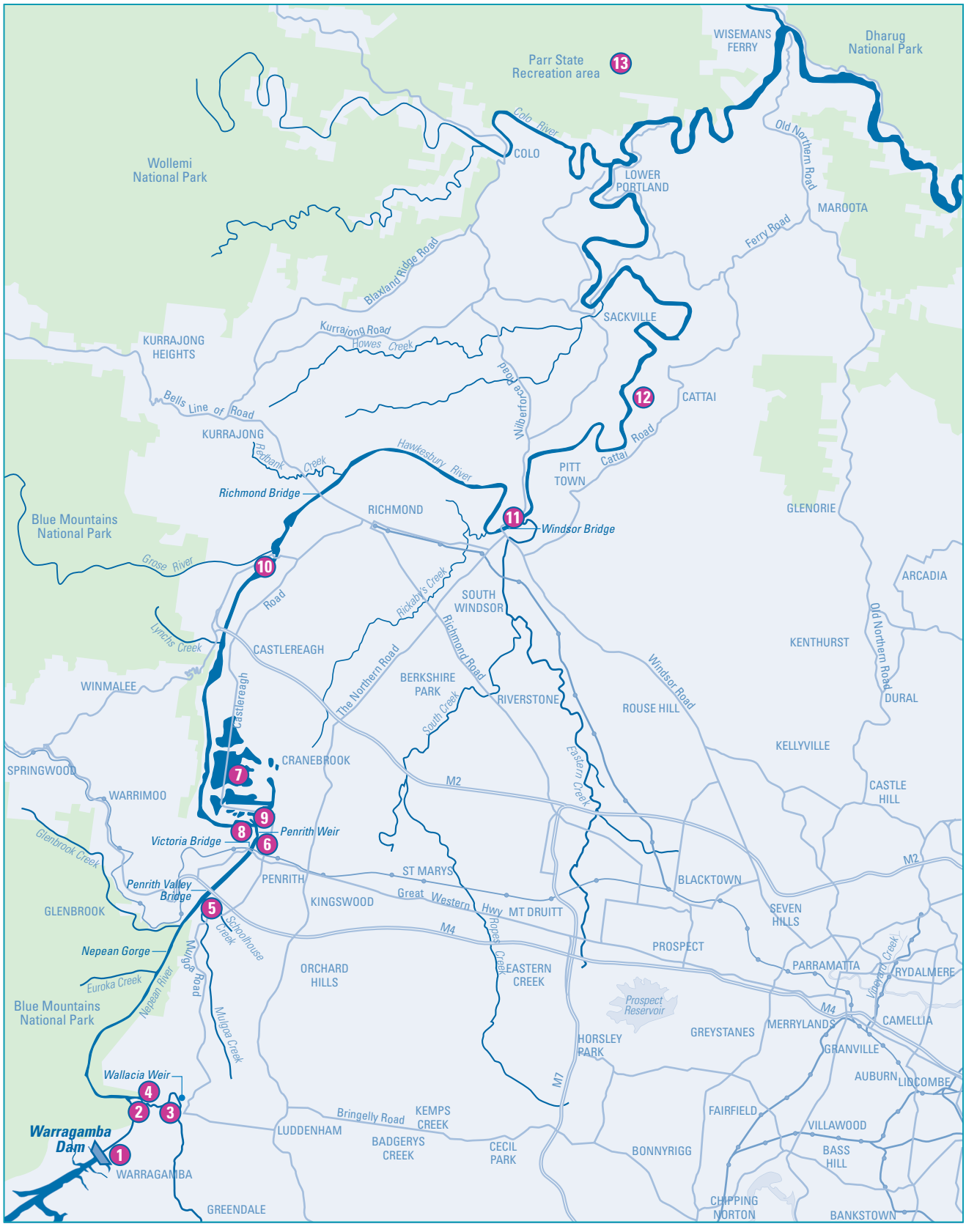
6.2.2 Nepean River - Wallacia Weir to Penrith Weir

Wallacia was a renowned holiday resort from the late 1800s to the 1940s and is still popular (www.penrithcity.nsw.gov.au). There are a few recreational facilities around Wallacia including Blaxlands Crossing reserve with associated caravan park, picnic area and barbecue facilities and Wallacia golf course. Wallacia weir is located approximately 1.75km downstream of Wallacia. The stretch of river from the weir to the confluence with the Warragamba River includes rapids which are navigable by canoe. Norton's Basin is a large calm pool with rocky cliffs around, and is a popular swimming area (www.penrithcity.nsw.gov.au).

From the confluence with the Warragamba the river enters the Nepean Gorge. Most of this gorge is located within the Blue Mountains National Park and access is only possible by boat or walking trail. The gorge is bounded by scenic cliffs and there are a number of large exposed and submerged rocks in this area which makes navigation by some craft difficult. Euroka Creek runs through the Blue Mountains National Park and joins the Nepean around the Nepean Gorge. There are walking tracks alongside the creek and camping is available within the National Park at Euroka Clearing.

Where Glenbrook Creek joins the Nepean River the river returns to floodplain. From this point onwards the river becomes wide and deep and there are high levels of public access. Tench Reserve lies on the eastern bank of the Nepean at Regentville. It commences around the point of the confluence of Mulgoa and School House Creeks extending north beyond the Western Motorway bridge to the Cable Water Ski Park at Penrith. The reserve has a boat ramp on the north side of the bridge. The Nepean Belle paddle steamer also operates from Tench Reserve, taking passengers on trips through the scenic Nepean Gorge. The stretch of River between the reserve and Victoria Bridge at Penrith is used as a Championship Rowing Course and rowing and kayak sprint course.

Figure 6.1 Recreation reserves



1. Haviland Park
2. Warragamba Park
3. Blaxlands Crossing Reserve
4. Norton's Basin
5. Tench Reserve
6. Cable Water Ski Park
7. Penrith Lakes Scheme
8. Regatta Park
9. Weir Reserve
10. Yarramundi Reserve
11. Governor Phillip Park
12. Cattai National park
13. Parr State Recreation Park

This stretch is used to be the region's main rowing venue, until the Sydney International Regatta Centre at Penrith Lakes opened.

There are parks on either side of the river around Victoria Bridge. Regatta Park and adjacent reserve on the western bank is mainly used for passive recreational pursuits such as picnicking, informal ball games and walking. This site is a popular spectator spot. The Weir Reserve is located on the eastern bank. This park has picnic areas, public amenities and a caravan park. It is also popular for picnicking, walking and fishing, as well as providing a scenic backdrop for wedding photographs at the pagoda overlooking the river (UTS, 2002). The Nepean Rowing Club, located in the reserve, provides a boat shed and licensed club facilities.

The Cable Water Ski Park, Nepean Shores Riverside Resort and Conference Centre, playgrounds, Jamieson Golf Resort, hotels, motels and log cabins are concentrated in the area just south of Victoria Bridge.

A number of annual water based events are held at Penrith, including the following:

- Australia day committee bridge to bridge swimming race;
- triathlon;
- Nepean River festival;
- 100 mile canoe race; and
- Penrith swimming club's annual swimathon.

6.2.3 Nepean River - Penrith Weir to Yarramundi

The navigability of the river in this section has been decreasing due to siltation and a number of beaches and sand banks have built up around the Jackson Falls area. The area to the north of Penrith has been transformed through extensive sand and gravel extraction. This has now been restored and forms the Penrith Lakes Scheme, International Regatta Centre and Whitewater Stadium. The scheme includes a series of lakes covering 700 hectares providing facilities for rowing and canoeing, whitewater rafting and picnicking (www.penrithlakes.com.au).

Further north into Castlereagh, the river passes alongside the Yellow Rock Reserve and Yellow Rock Recreation Reserve. Further north, around Lynch Creek, is the Lynch Creek Reserve, River Park Christian Youth Camp and Yarrawood Teachers College Camp, all located on the western bank of the Nepean.

Yarramundi is another major zone for in-stream gravel extraction. Significant extraction occurred between 1927 and 1989 at the confluence of the Grose and Nepean Rivers. This has now been transformed into the Yarramundi Reserve. This reserve lies to the west of Agnes Banks and Yarramundi Lagoon and provides local and regional recreation opportunities such as fishing, canoeing, swimming, nature-based study, bird watching, educational activities, walking, mountain-bike riding, jogging, dog walking and horse riding (www.hawkesbury.nsw.gov.au).

6.2.4 Hawkesbury River - Yarramundi to South Creek

Recreational fishing is popular at Richmond Bridge, as well as some commercial fishing, motor boating, canoeing and raft races. There are a number of parks providing land based recreation activities and access to the riverbank between Yarramundi and Windsor. These include Hawkesbury Park, Hanna Park, Terrace Park and the Breakaway.

Tourist and recreation facilities are concentrated around Windsor, with hotels and motels present within the town and public mooring available around Windsor Bridge. There are parks on both sides of the river including Deerubbin Park and Howe Park on the southern bank. Macquarie Park is positioned alongside Windsor Bridge and has parking, amenities, playgrounds and picknicking. The Power Boat Club, which has parking and boat ramps, is located within Governor Phillip Park alongside the confluence with South Creek. The most popular recreation activity at Windsor is picnicking, followed by speed boating, swimming and motor boating. There are only low levels of sailing, bushwalking and sightseeing (HNRMF, 2004).

6.2.5 Hawkesbury River - South Creek to Sackville

The most popular recreation activities identified at Windsor and Wisemans Ferry are picnicking, speed boating, waterskiing and swimming. This stretch of river has the greatest number of riverside recreational facilities of all of the sections discussed. There are around twenty five water ski resorts, around twenty of which are associated with caravan parks. Further recreation and camping facilities are present within the surrounding areas including Cattai National Park and Parr State Recreation Area. This area is the site of the annual bridge-to-bridge water ski classic. This is the world's longest water skiing race held annually from Dangar Island in Broken Bay to Windsor drawing up to 20,000 spectators (www.waterskinsw.com.au).

Canoeing is also a popular activity along these reaches. The Hawkesbury Canoe Classic, an annual canoe race held at night obtains exclusive use of the river from Windsor to Brooklyn once a year (www.caneoclassic.asn.au). Other recreation facilities in this stretch include the Riverside Oaks Golf Course which is present along the river bank at Maroota South accessed from Wisemans Ferry Road.

There are significant permanent boat moorings at Sackville and a few at Gronos Point, Ebenzer, Portland, Colo and Wisemans Ferry. A number of cruise hire companies operate out of Wisemans Ferry and there are ferry services at Wisemans Ferry and at Webbs Creek.

Due to the high level of use within this stretch of river there have historically been conflicts between recreational activities, with boating and water skiing generating the most problems.

6.2.6 South Creek catchment

Dunheved Golf course is located a short distance from St Marys STP. South Creek flows through Shanes Park, and alongside Berkshire Park Racehorse Education Centre. A reserve runs alongside the western bank in the Windsor Downs area. Besides a boat ramp near the confluence with the Hawkesbury, the waters of South Creek are not used extensively for recreation purposes.

From Quakers Hill STP Eastern Creek flows northwards. With the exception of Knudsen Reserve there are no official parklands alongside the creek up to its confluence with South Creek.

6.3 Assessment of Impacts

The replacement flows project would result in greater flows in all stretches of the Hawkesbury-Nepean River upstream of the South Creek confluence in 2009, for all but very low flows. The replacement flows, which have been treated through reverse osmosis to remove pathogens and nutrients, will significantly reduce the nutrient loads discharged to the Nepean River at Penrith. Removal of a portion of current sewage treatment plant releases at South Creek will also reduce nutrient loads in this watercourse.

Aquatic plant growth is responsive to nutrient inputs. Previously blue-green algae and macrophytes, in particular exotic species, have bloomed in stretches of the Hawkesbury-Nepean due to high nutrient concentrations. These blooms reduce the clarity and attractiveness of the river for primary contact users such as swimmers and water skiers. There are also safety implications where algae or weeds reduce visibility in the water.

The predicted flows at the confluence of the Warragamba River and Hawkesbury-Nepean River will be lower during very low flow conditions as a result of the Replacement Flows Project. This has the potential to have minor negative recreational impacts, however, this stretch is not used extensively for recreation purposes. The overall increase in flows through the system will have benefits for recreational users through a reduced flushing time and higher water levels.

6.3.1 Warragamba River

Due to the decrease in flow and potential impacts on water quality from the Wallacia STP and dam seepage water, recreational amenity of this reach of the river may decrease with the operation of the Replacement Flows Project. However, as this reach of the river is not a popular or accessible area for recreation, the overall impact upon recreational values of the Hawkesbury-Nepean River system is minor.

6.3.2 Nepean River - Wallacia Weir to Penrith Weir

The Replacement Flows Project (in conjunction with the other changes to river management) would result in greater flows in this river reach, for all but very low flows. There would be no change in water quality associated with the Replacement Flows Project, however it should be noted that the planned upgrade of West Camden STP would result in improvements in water quality in the upper sections of this river reach.

The recreational amenity of this section of the river would remain relatively unchanged and would not deteriorate as a result of the Replacement Flows Project.

6.3.3 Nepean River - Penrith Weir to Yarramundi

The current discharge of approximately 22 ML/day of highly treated tertiary effluent from Penrith STP would cease and would be replaced with 50 ML/day of highly treated recycled water with the operation of the project.

The replacement flows, which have been treated through reverse osmosis to remove pathogens and nutrients, would significantly reduce the nutrient loads discharged to the Nepean River at Penrith. Lowering the levels of total nitrogen and total phosphorous entering the river system would reduce the potential for excessive growth of algae and weeds, as such, would be expected to increase the appeal of the river for recreational purposes. Increased water clarity would also enhance the scenic qualities of the water resource, whilst the overall improvements in river health resulting from the scheme would potentially be beneficial to recreational fishers.

6.3.4 Hawkesbury River - Yarramundi to South Creek

There would be little change in water quality and flows in this river reach associated with the Replacement Flows Project. There may be some reduction in nutrient loads from the South Creek inflow, however, the benefits of this are more likely to be observed in the downstream river reach. Consequently the recreational amenity and suitability of this river reach would not change as a result of the project.

6.3.5 Hawkesbury River - South Creek to Sackville

There will be a significant reduction in the load of nutrients entering this river reach from the South Creek inflow. Lowering the levels of total nitrogen and total phosphorous entering the river system would reduce the potential for excessive growth of algae and weeds, as such, the project is expected to increase the appeal and suitability of the river for recreational purposes. Increased water clarity would also enhance the scenic qualities of the water resource, whilst the overall improvements in river health resulting from the scheme would potentially be beneficial to recreational fishers.

6.3.6 South Creeks catchment

There would a substantial reduction in flows and load of nutrients impacting upon the South Creek catchment with the operation of the project. This may result in an improvement in water quality and health of aquatic ecosystems in the catchment, however, this is unlikely to affect the relatively low recreational values and uses of the creek.

7. Primary Industry

7.1 Introduction

Primary industries that are dependent on the Hawkesbury-Nepean River system consists predominantly of agriculture, horticulture and commercial fisheries. This Section describes the primary industry values of the river system and assess the affects of the predicted changes to flow and water quality conditions that would result from the implementation of the project and other 2009 water management activities.

7.2 Existing Environment

7.2.1 Agriculture and Horticulture

In the Hawkesbury-Nepean catchment, agricultural and horticultural water extraction may be up to 100 billion litres per year. The rate of extraction is highly variable and it is only in extended dry periods that most irrigators take their full allocation of river water. In many years, irrigators may well use less than 40 percent of their allocation (HNRMF, 2004).

The economic value of agriculture and horticulture in the Hawkesbury-Nepean catchment is reported to be approximately $1.07 billion per year, of which $600 million per year is derived from irrigated agriculture. Industries are mainly horticultural and animal production, with an estimated gross value of 12 percent of all New South Wales agricultural production. Agricultural industries also provide numerous community benefits to the greater Sydney water supply region, including employment diversity, rural amenity and tourism, agri-tourism and heritage values. Agriculture in the Sydney Basin faces challenges such as encroaching urban development, increasing effects of aquatic weeds, and the impact of poor water quality on the viability of irrigated horticulture in some areas (HNRMF, 2004).

Primary production activities which extract water from Hawkesbury-Nepean River system include:

- stock drinking water supply
- pasture (both perennial and annual) growth
- lucerne production
- turf farming
- vegetable production
- citrus and other orchard products
- nursery watering.

The volumes of water entitlements for extraction for agricultural and horticultural uses under licenses issued by Department of Natural Resources in the different reaches of the river are described in detail in **Table 7-1.** The reach of the river from Yarramundi to the Colo River has the highest allocation of water for agricultural and horticultural use (36,391 ML/year). Water users in this reach extract from the freshwater tidal pool downstream of the Yarramundi. Licensed water extraction for agriculture and horticultural uses also occurs in South Creek (7,997 ML/year) and between Warragamba River and Yarramundi on the Nepean River (7,768 ML/year). Although water extraction for agriculture and horticultural uses occurs in other areas of the Hawkesbury-Nepean River, these areas would not be affected by the project and are not further discussed.

Table 7-1: Current irrigation entitlements within the study area

Catchment	Number of extraction licences	Total volumetric entitlement	Main Purpose
Upper Nepean	68	2,293 ML/year	Irrigation - 2064 ML/year Stock - 38 ML/year Other- 191 ML/year
Lower Nepean to Warragamba River	271	23,782 ML/year	Irrigation - 22,506.5 ML/year Stock - 352 ML/year Other- 923 ML/year
Warragamba River to Yarramundi Bridge	106	7,769 ML/year *	Irrigation – 6,937 ML/year Stock – 60 ML/year Other - 772 ML/year
Yarramundi to Colo River	431	36,392 ML/year	Irrigation - 35,546 ML/year Stock - 150 ML/year Other- 696 ML/year
South Creek	200	7,997 ML/year**	Not available

(Source: DIPNR – Draft Water Sharing in the Hawkesbury-Nepean, Summary Information for Surface Water Zones)

* 45% of volumetric entitlements are held by Penrith Lakes – these will be surrendered before 2015 and alternative water harvesting arrangement for the Lakes will be implemented

** All of South Creek entitlements including entitlements above STP discharges locations. Below the STP discharge locations entitlements are estimated to be approximately 1,925 ML/year

7.2.2 Fisheries

Existing Conditions

There are between 75 and 100 commercial fishing licences held for the Hawkesbury-Nepean River system. These licences are administered and regulated by the Department of Primary Industry - NSW Fisheries. The licence holders catch a diverse range of finfish, crustaceans and molluscs using a wide range of fishing methods such as meshing, hauling, trawling and trapping. It should be noted that the vast majority of commercial fishing activities are undertaken in the saline estuarine and marine reaches of the Hawkesbury River, downstream of the study area for the project.

In 2004, the Hawkesbury-Nepean River was reported to support New South Wales' second largest commercial coastal fishery of prawns, oysters and fish with a wholesale value of $6.3m per year (HNRMF, 2004).

7.3 Assessment of Impacts

At the same time the project would become operational in 2009, other changes to river management would be implemented, namely increased environmental flow releases from the Upper Nepean Dams and protection of low flows from extraction. The cumulative effects of these changes on river flows at relevant locations in the study area are discussed in detail in Section 3.3.

7.3.1 Agriculture and horticulture

Nepean River - Warragamba River to Penrith Weir

Apart from very low flows (>95th percentile), the volume of water in this reach of the river across all flow categories would increase compared to the existing situation primarily due to the increase in environmental flow releases from the Upper Nepean Dams. For very low flows, there would be a slight decrease in flow volumes at the junction of the Nepean River with Warragamba River. Consequently, there would be no significant adverse impact on water availability for extraction in this river reach due to the project.

Hawkesbury-Nepean River - Penrith Weir to Sackville

Flow volumes downstream of Penrith Weir would increase substantially for all flows (ie. very low to high flows) compared to the existing situation. This would result in a greater volume of water entering the freshwater tidal pool (ie.Yarramundi to the Colo River) from the Nepean River. However, flow volumes from the South Creek inflow would be reduced. The cumulative effect of these changes would result in increased flows into the freshwater tidal pool downstream of Yarramundi, primarily due to higher environmental flow releases from the Upper Nepean Dams. Consequently the volume of water available for extraction for agriculture and horticulture uses in the freshwater tidal pool would not be adversely impacted.

South Creek catchment

Although water licences in the South Creek catchment allow 7997 ML/year to be extracted, most of the licensed extraction points are located upstream of the Quakers Hill and St Marys STP discharge locations – and therefore would not be impacted by the project. However, licensed extractions downstream of the STPs (1,925 ML/year) may potentially be affected due to the significant decrease in discharge volumes from the STPs as tertiary treated effluent is diverted to the AWTP. Based on flow gauging information it is estimated that approximately 5 ML/day on average and a peak demand of 9.3 ML/day, is extracted from the creeks downstream of the STPs.

Although effluent discharges from STPs are currently not recognised as a source of water by the Draft Water Sharing Plan (and therefore Sydney Water has no statutory requirement to ensure flows in the creeks are maintained for downstream water users), Sydney Water recognises that these effluent discharges are used as a source of water for agriculture and horticulture. Consequently in developing the project, the water requirements of extractors downstream of the STPs were considered and sufficient volumes of effluent were allocated for continuing discharge to South and Eastern Creeks. These releases are sufficient to meet both the average and peak demands for current water extraction and therefore there would be no adverse impact on agricultural and horticultural water users downstream of the STPs.

7.3.2 Fisheries

Operation of the project would affect river flow and water quality between Warragamba River and Sackville along the Hawkesbury-Nepean River and within South Creek. As noted in above, the major commercial fisheries in the Hawkesbury-Nepean River are located in the saline estuarine and marine areas downstream of the study area. These downstream areas would not be affected by the project, therefore commercial fisheries would not be affected. Some of the species targeted by the commercial fisheries may spend part of their lifecycle in the freshwater reaches of the Hawkesbury-Nepean River. The impact of the Replacement Flows Project on these reaches is described in detail for flow, water quality and aquatic ecology. These impacts have been assessed to have a neutral impact on flows and a neutral to potentially beneficial impact on water

quality of the receiving waterways, except for the Warragamba River. Mitigation measures would be implemented to maintain acceptable water quality within Warragamba River, which are discussed in the main document.

As there would be no significant adverse impacts on flow, water quality and aquatic ecosystems in the freshwater reaches, commercially important fish and crustaceans, which spend part of their lifecycle in the freshwater reaches, would also not be affected. Consequently there would be no indirect impacts on commercial fisheries from the Replacement Flows Project.

8. Conclusions

The operation of the Replacement Flows Project under the 2009 flow and water quality conditions resulting from the activities outlined in Section 1.2 would have a neutral or positive effect on the aquatic ecology, primary industries and recreational water users within the Hawkesbury-Nepean River system, including the South Creek catchment area. The only exception to this is the Warragamba River, where a strategy to reduce the impact of tertiary treated effluent discharged from Wallacia STP to acceptable levels would need to be delevoped. Listed below are the general conclusions for the study area:

- the AWTP will treat up to approximately 60ML/day of highly treated effluent from St Marys, Quakers Hill and Penrith Sewage treatment plants. Up to 50ML/day will be discharged as replacement flows below Penrith Weir, which will increase flows at this location within the Nepean River but will reduce the increased variability introduced by the Upper Nepean Dam releases;
- the AWTP will generate a concentrate volume of approximately 8ML/day, which will be discharged to the Northern Suburbs Ocean Outfall Sewer (NSOOS). This discharge will not affect the operation of the North Head sewage treatment plant. The discharge of the concentrate will not increase the occurrence of sewage overflow within the NSOOS;
- the small volume of concentrate compared to daily discharges at North Head sewage treatment plant will not affect water quality or ecological communities located at the deep ocean outfall;
- there will be an approximate 70% reduction in flow within the South Creek catchment due to reduced discharges from St Marys and Quakers Hill sewage treatment plants;
- the combination of the project and the 2009 river and water cycle management initiatives will result in an increase in flow within the upper reaches of the Hawkesbury River and the Nepean River;
- there will be a general reduction in nutrient concentrations and loads within the Hawkesbury-Nepean River system;
- the combination of increased flow downstream of Penrith Weir and improved water quality from the implementation of the 2009 river management initiatives and operation of the project would create environmental conditions less conducive for the growth of exotic aquatic weed species.
- it is anticipated that the improved flow and water quality conditions could result in improvements in the distribution of the native Ribbonweed (*Vallisneria giganetea*)which would be beneficial to the diversity, abundance and growth of native fish species;
- no threatened aquatic species would be impacted by the project;
- the major commercial fisheries are located in the downstream estuarine reaches of the Hawkesbury-Nepean River system. This area will be unaffected by the operation of the project, therefore there will be no adverse affect of the project on commercial fisheries;
- there would be no significant adverse impacts on water quality, flows and aquatic ecosystems in the freshwater reaches of the Hawkesbury-Nepean River affected by the project. Therefore, commercially important fish species, which spend part of their lifecycle in the freshwater, would not be affected by the project;
- the recreational amenity of the Hawkesbury-Nepean River and the South Creek catchment would remain unchanged and would not deteriorate as a result of the project. Lowering the

levels of total nitrogen and total phosphorous entering the river system would reduce the potential for excessive growth of algae and weeds, as such, would be expected to increase the appeal and suitability of the river for recreational purposes. Increased water clarity would also enhance the scenic qualities of the water resource, whilst the overall improvements in river health resulting from the project would potentially be beneficial to recreational fishers; and

- water extraction for agriculture and horticulture purposes would not be impacted by the project. Except for the South Creek catchment, additional flows would be made available with the implementation of the project and 2009 river management activities.

Other specific changes to conditions within each of the study reaches of the Hawkesbury-Nepean River system and South Creek catchment are discussed below.

Warragamba River

Warragamba River would experience long periods without effective flows, although the Penrith Weir pool would ensure that it does not run dry. With the affect of the Penrith Weir pool on the hydrology of Warragamba River, it is anticipated that the project would result in minimal change to flow conditions within Warragamba River, which would have a neutral affect on the assemblage of macroinvertebrates. In addition there will not be a significant effect on riparian vegetation.

Without any water releases from the dam, Warragamba River would be dominated by effluent discharged from the new Warragamba sewage treatment plant. The resulting nutrient concentration would be approximately 6.7 mg/L total nitrogen and 0.14 mg/L total phosphorus which reflects the characteristics of the Wallacia sewage treatment plant effluent. Given that the volume of the Warragamba River is 108 ML and the effluent flow is 1.35 ML/d, with some rainwater runoff, the expected detention time in the Warragamba River is greater than 50 days. This would be likely to provide significant potential for aquatic plant/algae growth and exotic macrophytes in Warragamba River.

Options will be developed to ensure that discharge from the Wallacia STP does not have unacceptable environmental impacts. Provided the discharge from Wallacia STP does not have unacceptable environmental impacts, the project is not expected to have any additional impact on fish or other components of the aquatic ecosystem.

Warragamba River is not a popular or accessible area for recreation, therefore the affects of reduced flows would not impact upon the general recreational values of the Hawkesbury-Nepean River system.

Wallacia Weir to Penrith Weir

There would be a significant reduction in flow from Warragamba River as a result of the operation of the project. However, flow over Wallacia Weir would increase with the implementation of the 2009 river management changes, which would ensure that an adequate volume of water is made available within this reach of the Nepean River. Therefore the operation of the project is not likely to adversely affect the extraction of water for primary industry use.

The improvements to West Camden STP and the implementation of the recycled water scheme at Camden will significantly reduce nutrients discharged to this reach of the Nepean River. These initiatives will have a greater influence on water quality within this reach of the river. Total nitrogen concentrations will improve compared to current conditions in this reach while total phosphorus remains relatively unchanged. Neutral affects on macroinvertebrates, fish, macrophytes and riparian assemblages are anticipated as a result of the project.

Penrith Weir to Yarramundi

Flow volume (under low flow conditions) downstream of Penrith Weir would be higher than the existing conditions (87ML/day) with the operation of the project (117ML/day). This is also the case for median flows. Due to this increase in flows, agriculture and horticulture industries within this reach will not be adversely affected by the operation of the project.

The project would result in a 14% reduction in total nitrogen and 75% reduction in total phosphorus loads downstream of Penrith Weir compared to the current Penrith STP discharge. Oxidised nitrogen loads discharged downstream of Penrith Weir would be reduced by approximately 25% with the implementation of the project.

All nutrients except oxidised nitrogen will comply with water quality guidelines downstream of Penrith Weir. This is an improvement over the existing situation where water quality immediately downstream of Penrith Weir does not meet for any of the nitrogen species.

In the lower sections of this reach water quality is dominated by inflows from Winmalee sewage treatment plant, but the integrated model predicts that despite this, improvements in total nitrogen and phosphorus concentrations would be maintained through to the lower sections of this reach.

Increased flows in this reach would continue to support flowing water macroinvertebrates, fish and macrophyte assemblages. However, due to the influence of Winmallee STP the overall effect of the project on macroinvertebrates will be neutral.

Yarramundi to South Creek

The operation of the project would not affect flow conditions within this tidal reach of the Hawkesbury River. Operation of the project would result in a significant improvement in total nitrogen and a marginal improvement in total phosphorus concentrations within this reach.

Most of the reach below Yarramundi to South Creek is subject to bi-directional flow and is a freshwater tidal zone. Changes in flow upstream of this point are expected to have a neutral affect on macroinvertebrates in this reach. Also, recreational amenity and suitability would not change.

South Creek to Sackville

The project would reduce flows (under dry weather conditions) within South Creek by approximately 70% but since the freshwater tidal pool is not dependant on dry weather flows the project would not affect water levels in this reach. Reduced discharges from South Creek STPs would consequently reduce the impact of nutrient loads discharged to the Hawkesbury River downstream of the South Creek confluence. There is a significant improvement in total nitrogen concentrations and there would be a marginal improvement in phosphorus concentrations. Nonetheless, it is likely there will be a reduced potential for algal blooms to occur during periods of low flow which will increase the appeal and suitability of the river for recreation purposes.

After tidal mixing, nutrient concentrations from effluent discharges down South Creek are expected to be slightly lower in this reach under dry weather conditions. Therefore it is anticipated that the project would have a neutral effect on macroinvertebrates.

There are very few extraction licences operating within this reach of the Hawkesbury River due to the tidal affected waters. The volume of water available for extraction in this reach of the river is not likely to change, therefore there would be no adverse affect on agriculture and horticulture industries resulting from the operation of the project.

South Creek catchment

There will be a reduction in flow of approximately 43ML/day within the South Creek catchment. Approximately 39% of effluent from Quakers Hill and 76% of effluent from St Marys sewage treatment plants will be transferred to the AWTP. This reduction in flow from would still dominant flows, under dry weather conditions, within the South Creek catchment.

This reduction in flow will result in a significant decrease in nutrient loads discharged to South and Eastern creeks. With the exception of ammonia, nutrient loads discharged to the South Creek catchment would be reduce by approximately 70%. Ammonia loads will be reduced by approximately 57%.

Concentration of forms of all nitrogen would decrease in both low and median flows whilst total phosphorus concentrations would increase. The increase in phosphorus concentrations is due to the affect of reduced dilution resulting from the proposed reduction discharge volumes from the sewage treatment plants (which currently discharge phosphourus at very low levels).

It is anticipated that the project would overall have a neutral affect on native fish, macroinvertebrate and macrophyte species within the South Creek catchment. Despite reductions in flow resulting from the proposed operation of the project no change in macroinvertebrate assemblages is expected below St Marys and Quakers Hill sewage treatment plants.

The requirements of water extractors downstream of St Marys and Quakers Hill sewage treatment plants were considered for the design and operation of the AWTP. Between 16 and 21ML/day would be discharged from the sewage treatment plants to meet both the average and peak demands for water downstream agriculture and horticulture industries.

Existing low recreational values and uses of South Creek would remain unaffected by the project.

Recommendations

The following recommendations are proposed to minimise impacts from the operation of the project:

- Sydney Water would continue investigations to establish a sustainable solution to manage the effluent produced by the new Wallacia STP
- a study would be undertaken in consultation with Department of Primary Industries (Fisheries) to determine whether the discharge of the Replacement Flows Project would result in changes to the natural fish migration over Penrith Weir. Based on outcomes of this study appropriate design and other mitigation measures would be developed
- a suitable volume of effluent would continue to be released from the St Marys and Quakers Hill sewage treatment plants to ensure that current irrigation users downstream of these plants are not disadvantaged by the operation of the project
- management of the concentrate, including the AWTP and storages, would ensure there is no discharge of concentrate to the Hawkesbury-Nepean River including South Creek catchment, unless there is a significant incident or emergency or as otherwise agreed with DEC; and to ensure that there is no increase in overflow frequencies from the NSOOS.

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Attachment A

Water quality

A.1 Hawkesbury-Nepean River

Table A - 1: Sharpes Weir to Penrith Weir

Site	Data type	Statistic	Conductivity (ms/m	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Temperature	pH	Tubidity (NTU)	Ammonia (mg/L)	Oxidised Nitrogen (mg/L)	Total Nitrogen (mg/L)	Filterable Phosphorus (mg/L)	Total Phosphorus (mg/L)	Faecal Coliforms (cfu/100mL)	Enterococci (cfu/100mL	Chlorophyll-a (ug/L)
N75 - Nepean River at Sharpes Weir	Low flow	N	**8**	**ND**	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**ND**	**8**	**8**	**8**	**8**
		Median	**660**	**ND**	**9.7**	**20.4**	**8.2**	**2.3**	**0.050**	**3.68**	**4.43**	**ND**	**0.0190**	**13**	**9**	**8.2**
	All flow conditions	N	**142**	**ND**	**142**	**142**	**142**	**142**	**137**	**137**	**137**	**ND**	**137**	**137**	**137**	**154**
		Median	**528**	**ND**	**ND**	**20.5**	**7.8**	**3.1**	**0.020**	**1.84**	**2.42**	**ND**	**0.0210**	**24**	**20**	**8.5**
N67 - Nepean River at Wallacia	Low flow	N	**6**	**ND**	**6**	**6**	**6**	**6**	**12**	**12**	**12**	**ND**	**12**	**12**	**12**	**12**
		Median	**631**	**ND**	**8**	**20.2**	**7.9**	**3.0**	**0.030**	**0.07**	**0.70**	**ND**	**0.0200**	**22**	**20**	**5.0**
	All flow conditions	N	**141**	**ND**	**141**	**141**	**141**	**141**	**151**	**151**	**151**	**ND**	**151**	**151**	**150**	**150**
		Median	**498**	**ND**	**8.6**	**20.9**	**7.7**	**4.9**	**0.020**	**0.33**	**0.73**	**ND**	**0.0200**	**26**	**31**	**6.4**
N57 - Nepean River at Penrith Weir upstream Boundary Creek and Penrith STP	Low flow	N	**8**	**8**	**8**	**8**	**8**	**8**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
		Median	**25**	**82**	**7.5**	**22.3**	**7.7**	**1.6**	**0.010**	**0.01**	**0.27**	**0.004**	**0.0095**	**21**	**31.5**	**3.0**
	All flow conditions	N	**125**	**125**	**62**	**125**	**86**	**86**	**171**	**171**	**171**	**171**	**171**	**171**	**171**	**157**
		Median	**28**	**93**	**8.2**	**21.0**	**7.7**	**1.7**	**0.010**	**0.02**	**0.33**	**0.004**	**0.0110**	**42**	**52**	**2.8**

Note: Shaded values exceed relevant guideline value.

Table A - 2: Downstream Penrith Weir to Yarramundi Bridge

Site	Data type	Statistic	Conductivity (ms/m	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Temperature	pH	Tubidity (NTU)	Ammonia (mg/L)	Oxidised Nitrogen (mg/L)	Total Nitrogen (mg/L)	Filterable Phosphorus (mg/L)	Total Phosphorus (mg/L)	Faecal Coliforms (cfu/100mL)	Enterococci (cfu/100mL	Chlorophyll-a (ug/L)
N53 - Nepean River at BMG Causeway, 700m downstream Boundary Creek and Penrith STP	Low flow	N	**7**	**7**	**7**	**7**	**7**	**7**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**
		Median	**46**	**74**	**6.5**	**19.0**	**7.5**	**2.7**	**0.050**	**0.92**	**1.23**	**0.019**	**0.0340**	**79**	**41**	**2.7**
	All flow conditions	N	**85**	**85**	**59**	**85**	**85**	**85**	**170**	**170**	**170**	**170**	**170**	**170**	**170**	**156**
		Median	**36**	**88**	**7.7**	**20.9**	**7.6**	**3.5**	**0.030**	**0.57**	**0.99**	**0.020**	**0.0380**	**68**	**85**	**2.7**
N48 - Nepean River at Smith Road, 8.7km downstream Boundary Creek and Penrith STP	Low flow	N	**7**	**7**	**7**	**7**	**7**	**7**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**
		Median	**39**	**102**	**9.1**	**21.7**	**8.2**	**3.0**	**0.020**	**0.06**	**0.82**	**0.013**	**0.0250**	**13**	**22**	**41.2***
	All flow conditions	N	**85**	**85**	**59**	**85**	**85**	**85**	**170**	**170**	**170**	**170**	**170**	**170**	**170**	**156**
		Median	**35**	**100**	**8.8**	**21.7**	**7.9**	**2.6**	**0.020**	**0.28**	**0.70**	**0.010**	**0.0255**	**14**	**48**	**5.0**
N44 - Nepean River at Yarramundi Bridge	Low flow	N	**10**	**0**	**ND**	**10**	**10**	**10**	**10**	**10**	**10**	**ND**	**10**	**10**	**10**	**10**
		Median	**354**	**ND**	**ND**	**18.9**	**7.6**	**2.4**	**0.020**	**0.43**	**0.71**	**ND**	**0.0200**	**45**	**50**	**5.1**
	All flow conditions	N	**146**	**0**	**ND**	**147**	**147**	**147**	**158**	**158**	**158**	**ND**	**158**	**158**	**158**	**158**
		Median	**344**	**ND**	**ND**	**20.2**	**7.5**	**2.7**	**0.030**	**0.53**	**0.91**	**ND**	**0.0260**	**56**	**56**	**5.5**

Note: Shaded values exceed relevant guideline value.

* Some samples contaminated with macroalgae causing abnormally high result

Table A - 3: Downstream Yarramundi Bridge to South Creek

Site	Data type	Statistic	Conductivity (ms/m	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Temperature	pH	Tubidity (NTU)	Ammonia (mg/L)	Oxidised Nitrogen (mg/L)	Total Nitrogen (mg/L)	Filterable Phosphorus (mg/L)	Total Phosphorus (mg/L)	Faecal Coliforms (cfu/100mL)	Enterococci (cfu/100mL	Chlorophyll-a (ug/L)
N42 - Hawkesbury River at North Richmond, downstream Grose River and upstream Redbank Creek and North Richmond STP	Low flow	N	**7**	**7**	**7**	**7**	**7**	**7**	**14**	**14**	**14**	**14**	**14**	**14**	**14**	**14**
		Median	**27**	**100**	**8.8**	**20.3**	**7.6**	**1.5**	**0.010**	**0.26**	**0.46**	**0.004**	**0.0100**	**5**	**4**	**2.5**
	All flow conditions	N	**85**	**85**	**59**	**85**	**85**	**85**	**170**	**170**	**170**	**170**	**170**	**170**	**170**	**156**
		Median	**27**	**100**	**8.8**	**21.8**	**7.6**	**2.4**	**0.013**	**0.28**	**0.58**	**0.005**	**0.0160**	**11**	**18**	**3.9**
N39 - Hawkesbury River at Freemans Reach	Low flow	N	**6**	**6**	**6**	**6**	**6**	**6**	**12**	**12**	**12**	**12**	**12**	**12**	**12**	**12**
		Median	**29**	**107**	**10.1**	**21.2**	**7.8**	**2.5**	**0.010**	**0.17**	**0.52**	**0.006**	**0.0195**	**33**	**28**	**7.0**
	All flow conditions	N	**83**	**83**	**57**	**83**	**83**	**83**	**166**	**166**	**166**	**166**	**166**	**166**	**166**	**152**
		Median	**27**	**106**	**9.6**	**22.7**	**7.8**	**2.9**	**0.014**	**0.22**	**0.54**	**0.006**	**0.0170**	**34**	**78**	**4.7**
N38 - Hawkesbury River at Winsdor Bridge	Low flow	N	**18**	**18**	**18**	**18**	**18**	**6**	**12**	**12**	**12**	**12**	**12**	**12**	**11**	**12**
		Median	**51**	**89**	**8.0**	**22.1**	**7.6**	**8.4**	**0.020**	**0.49**	**0.94**	**0.009**	**0.0330**	**26**	**34**	**12.9**
	All flow conditions	N	**250**	**250**	**172**	**250**	**184**	**84**	**168**	**168**	**168**	**168**	**168**	**168**	**167**	**154**
		Median	**40**	**88**	**8.1**	**22.0**	**7.5**	**8.6**	**0.020**	**0.49**	**0.91**	**0.008**	**0.0340**	**53**	**45**	**8.8**

Note: Shaded values exceed relevant guideline value.

Table A - 4: Downstream South Creek to Wisemans Ferry

Site	Data type	Statistic	Conductivity (ms/m	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Temperature	pH	Tubidity (NTU)	Ammonia (mg/L)	Oxidised Nitrogen (mg/L)	Total Nitrogen (mg/L)	Filterable Phosphorus (mg/L)	Total Phosphorus (mg/L)	Faecal Coliforms (cfu/100mL)	Enterococci (cfu/100mL	Chlorophyll-a (ug/L)
N35 - Hawkesbury River at Wilberforce downstream South Creek	Low flow	N	18	18	18	18	18	6	12	12	12	12	12	11	11	12
		Median	47	97	8.4	21.9	7.8	11.0	0.010	0.29	0.79	0.008	0.0455	19	22	27.6
	All flow conditions	N	253	253	175	253	187	85	170	170	170	170	170	169	169	156
		Median	42	89	8.1	21.8	7.6	12.5	0.030	0.52	1.00	0.009	0.0480	24	28	16.7
N26 - Hawkesbury River at Sackville Ferry	Low flow	N	18	18	18	18	18	6	12	12	12	12	12	11	11	12
		Median	44	99	8.5	22.5	8.0	8.4	0.010	0.01	0.55	0.006	0.0390	10	6	31.1
	All flow conditions	N	255	255	177	255	189	85	170	170	170	170	170	169	169	156
		Median	40	101	8.9	22.0	8.0	10.0	0.010	0.19	0.78	0.006	0.0420	8	6	25.5
N21 - Hawkesbury River at Lower Portland	Low flow	N	10	ND	10	10	10	10	3	10	10	ND	10	10	10	10
		Median	1145	ND	9.0	18.8	7.8	5.7	0.010	0.01	0.31	ND	0.0230	3	3	14.9
	All flow conditions	N	102	ND	103	103	103	103	86	110	108	ND	110	110	110	110
		Median	397	ND	8.3	21.0	7.8	7.9	0.010	0.05	0.45	ND	0.0285	5	5	16.1
N18 - Hawkesbury River at Leetsvale	Low flow	N	9	18	18	18	18	ND	12	12	12	12	12	12	12	12
		Median	950	89	7.3	22.3	7.6	ND	0.010	0.07	0.34	0.007	0.0175	1	1	6.9
	All flow conditions	N	234	255	177	255	189	18	170	170	170	170	170	170	170	156
		Median	373	89	7.8	21.5	7.5	9.0	0.010	0.11	0.40	0.007	0.0260	3	3	7.6
N14 - Hawkesbury River at Wisemans Ferry, downstream Macdonald River	Low flow	N	9	18	18	18	18	ND	12	12	12	12	12	12	12	12
		Median	1740	92	7.5	22.3	7.6	ND	0.010	0.10	0.36	0.009	0.0210	6	2	4.8
	All flow conditions	N	234	255	177	255	189	ND	169	169	169	169	169	169	169	155
		Median	1310	89	7.5	21.9	7.6	ND	0.010	0.12	0.38	0.008	0.0210	6	4	5.1

Note: Shaded values exceed relevant guideline value.

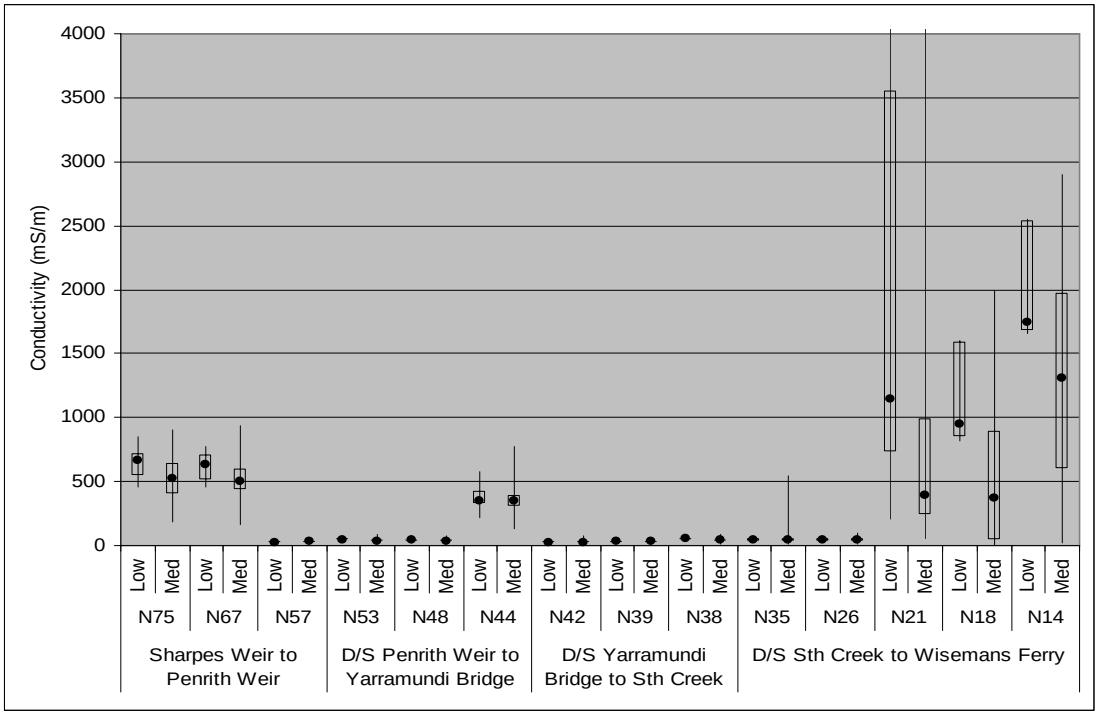


Figure A - 1: Hawkesbury-Nepean River Conductivity

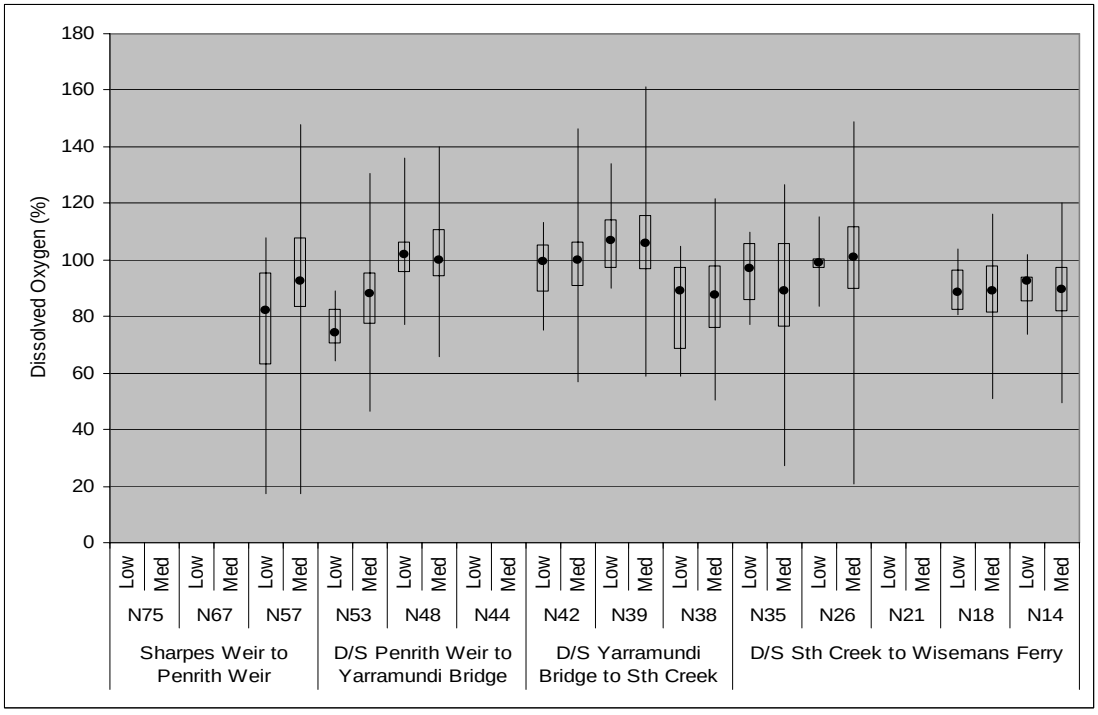


Figure A - 2: Hawkesbury-Nepean River Dissolved Oxygen (% saturation)

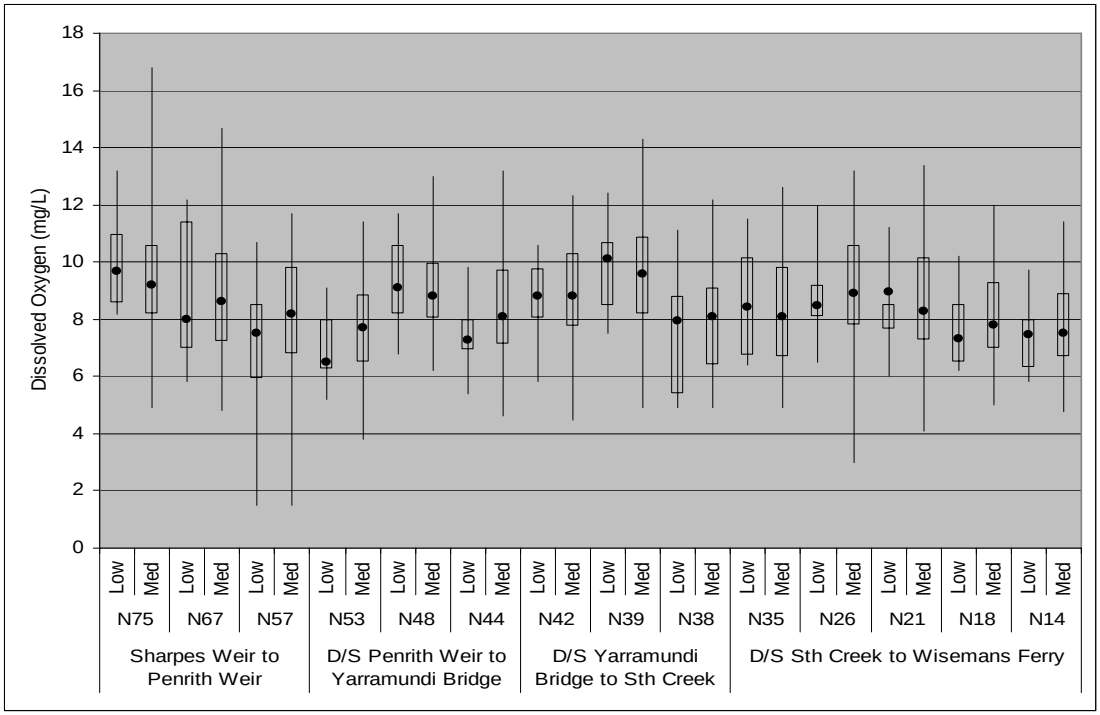


Figure A - 3: Hawkesbury-Nepean River Dissolved Oxygen (mg/L)

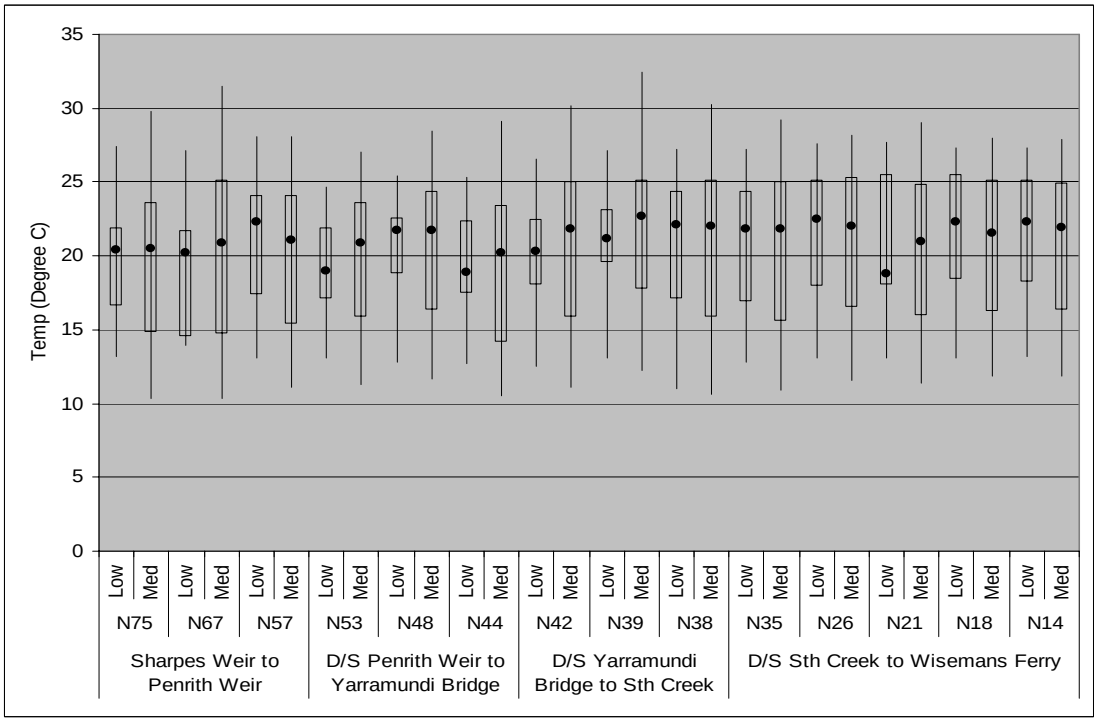


Figure A - 4: Hawkesbury-Nepean River Temperature

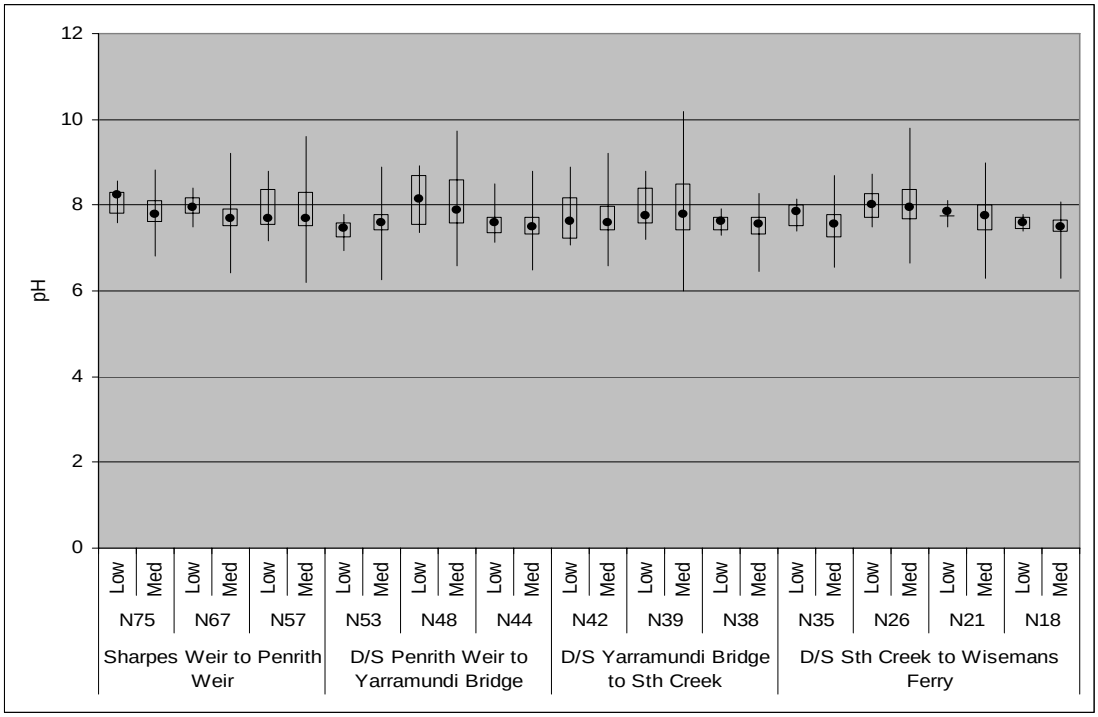


Figure A - 5: Hawkesbury-Nepean River pH

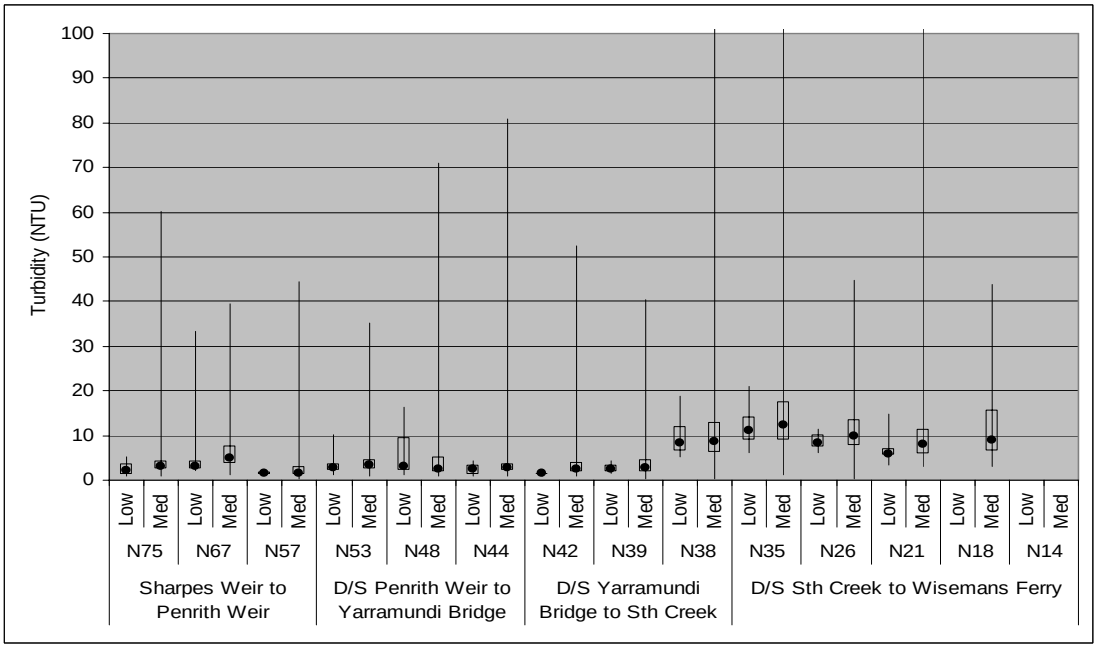


Figure A - 6: Hawkesbury-Nepean River Turbidity

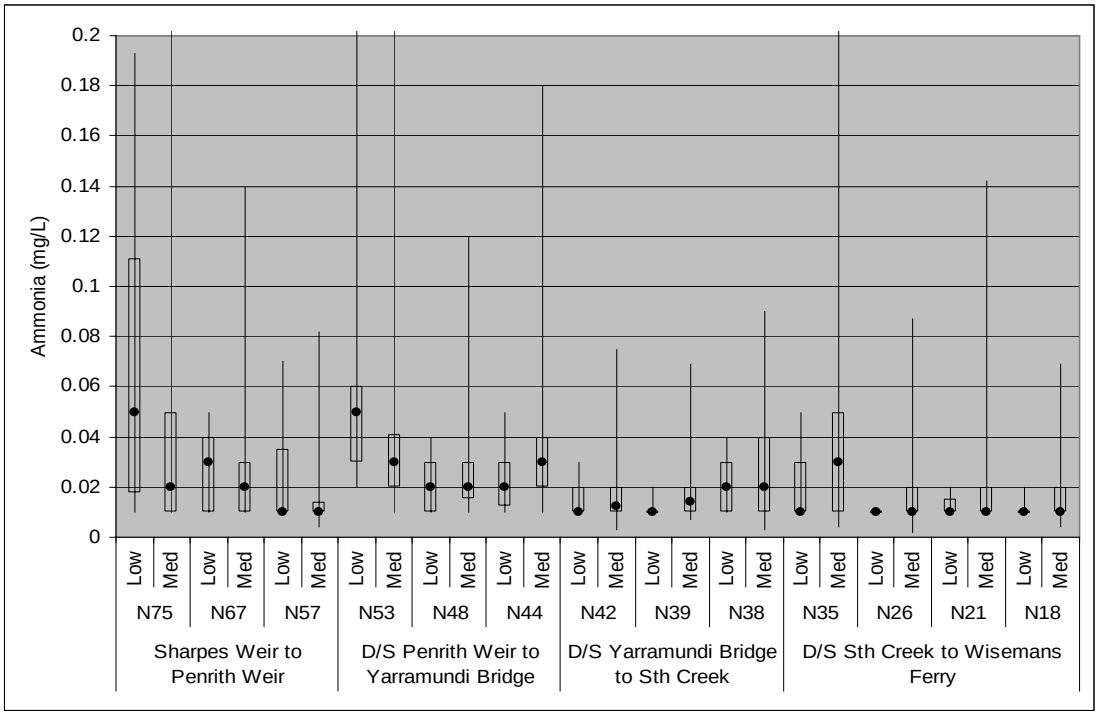


Figure A - 7: Hawkesbury-Nepean River Ammonia

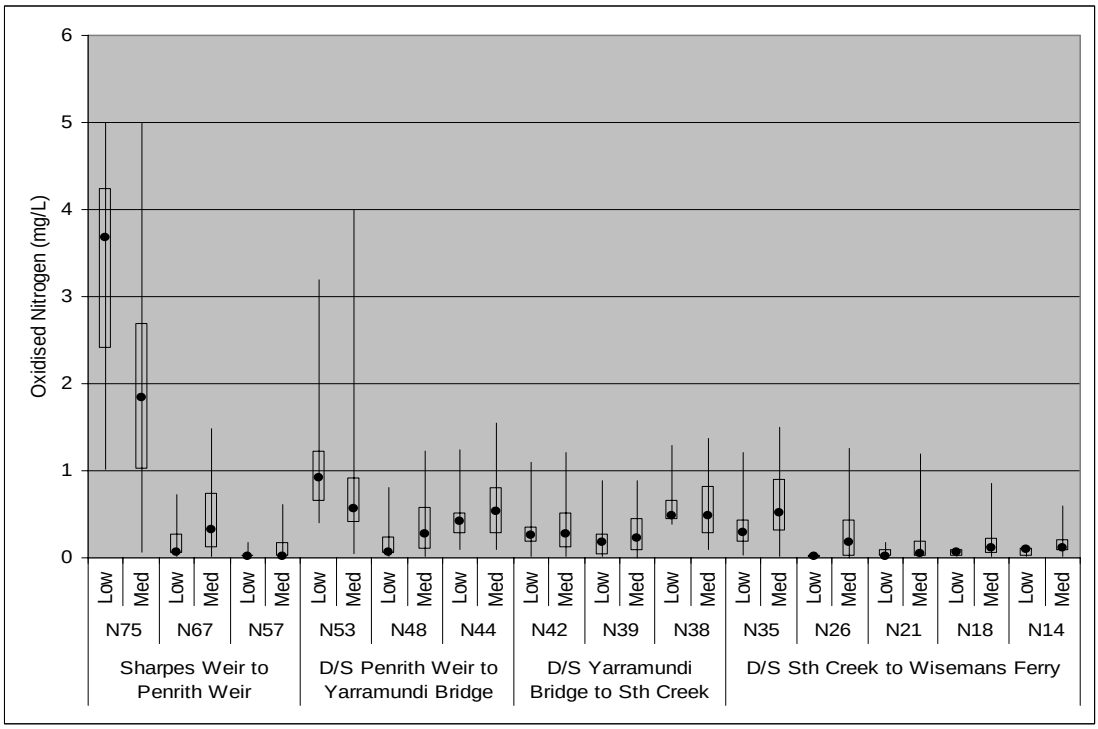


Figure A - 8: Hawkesbury-Nepean River Oxidised Nitrogen

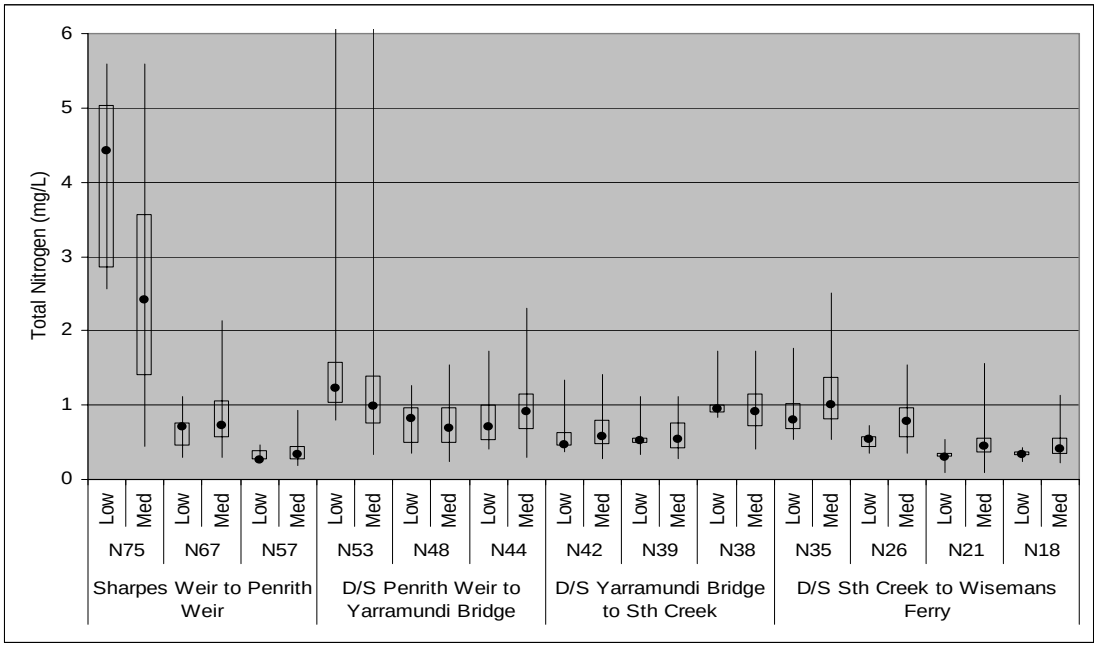


Figure A - 9: Hawkesbury-Nepean River Total Nitrogen

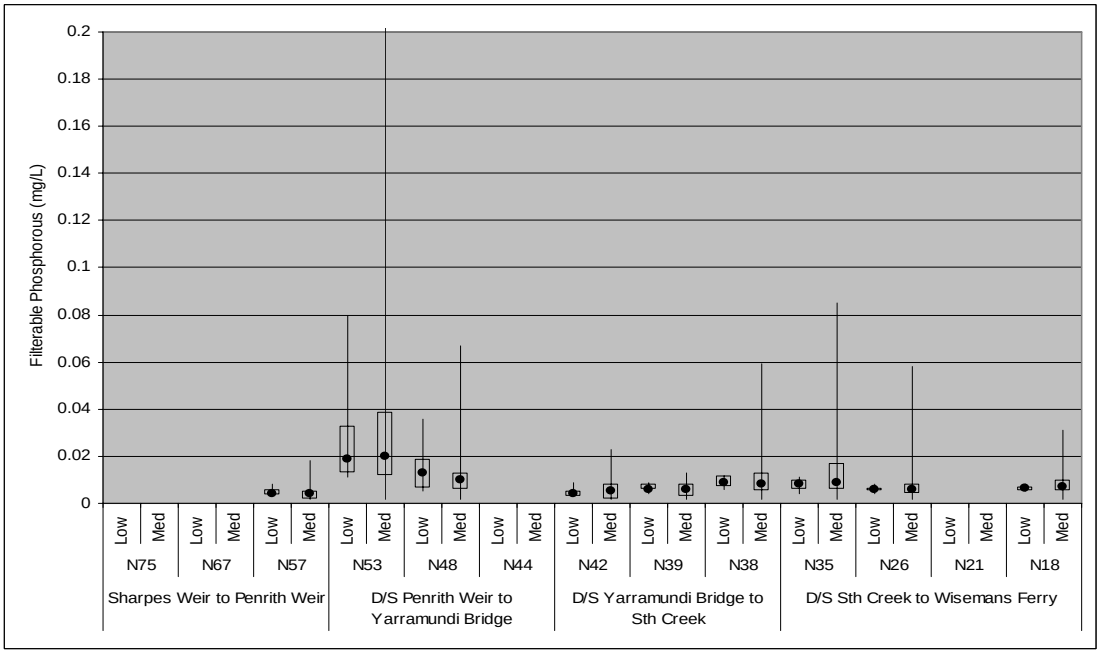


Figure A - 10: Hawkesbury-Nepean River Filterable Phosphorus

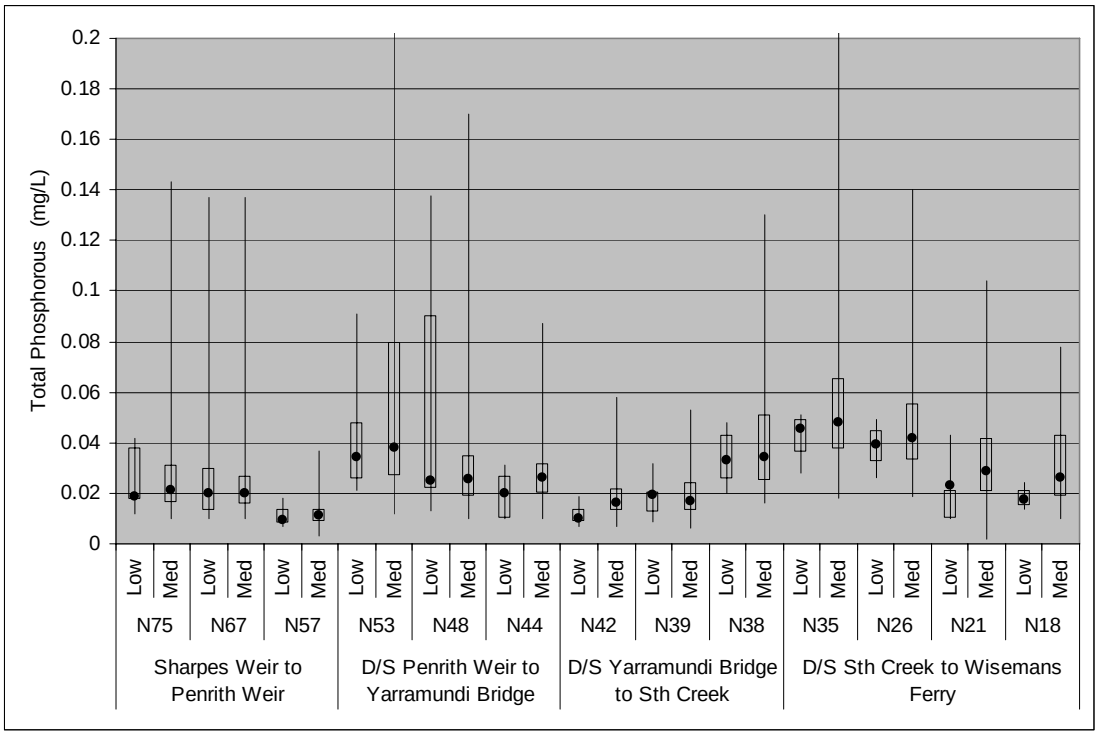


Figure A - 11: Hawkesbury-Nepean River Total Phosphorus

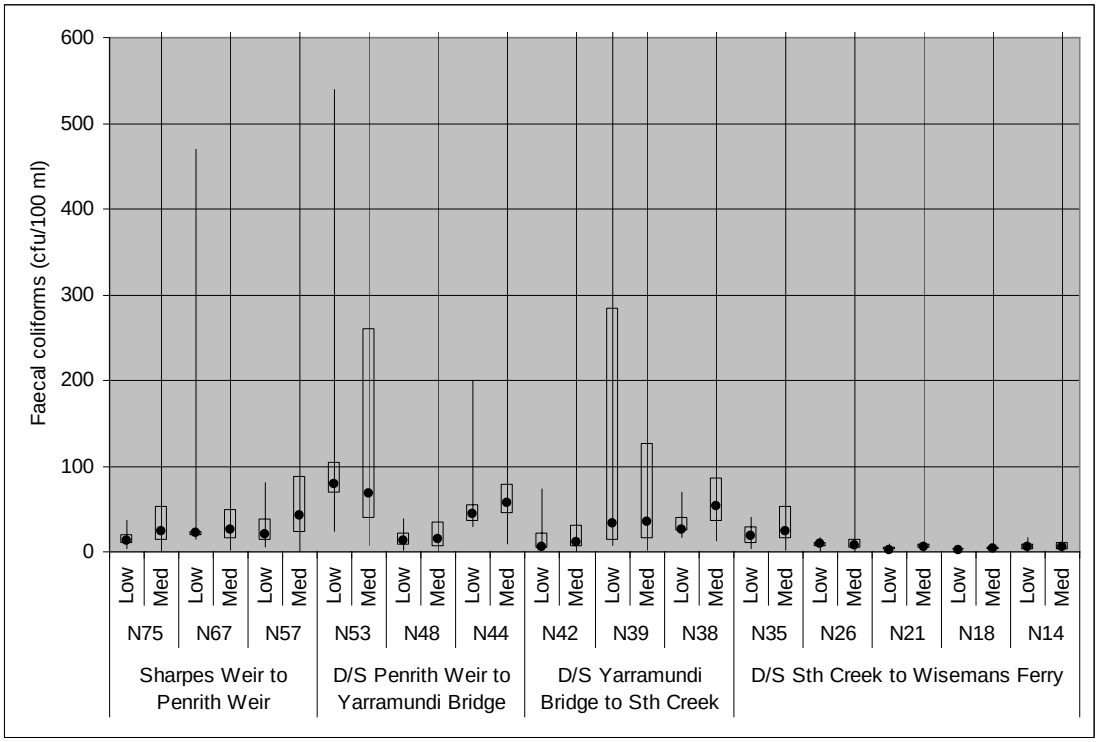


Figure A - 12: Hawkesbury-Nepean River Faecal Coliforms

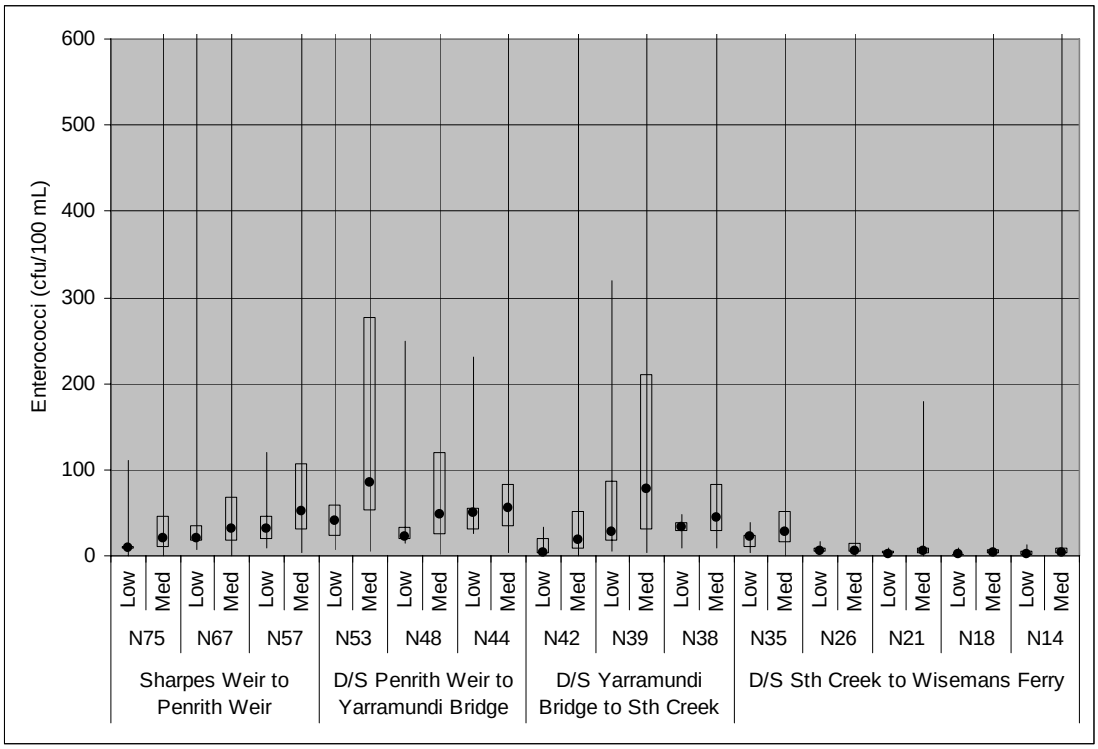


Figure A - 13: Hawkesbury-Nepean River Enterococci

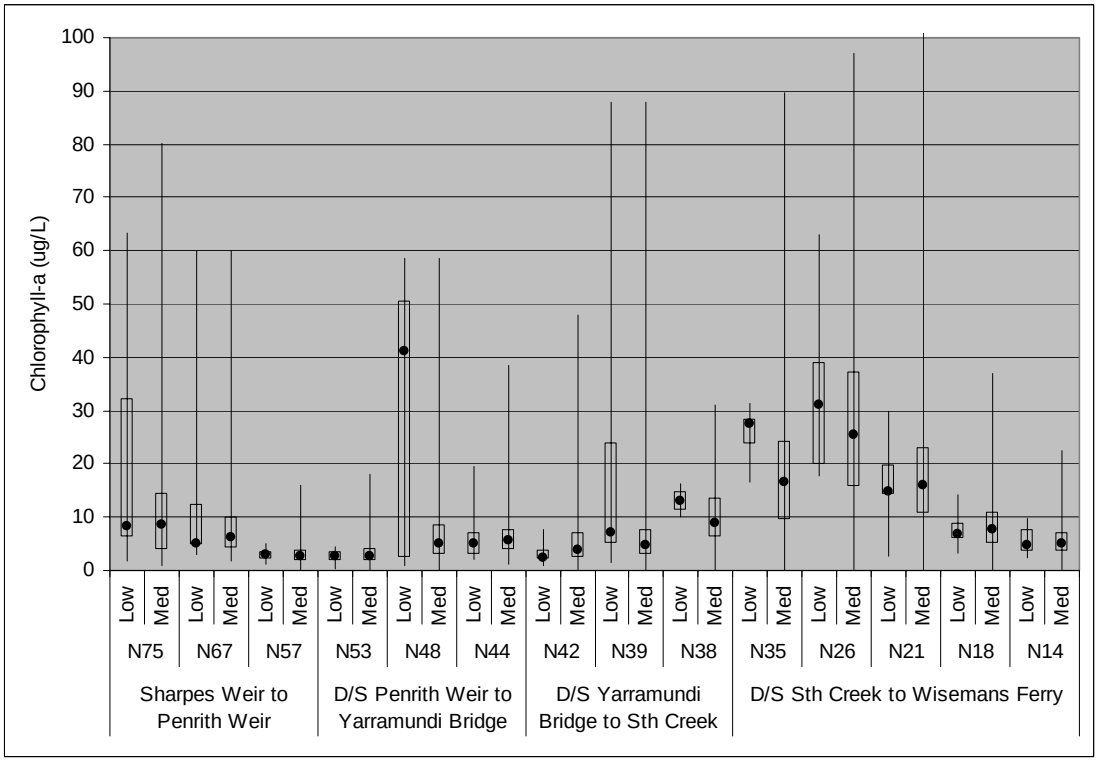


Figure A - 14: Hawkesbury-Nepean River Chlorophyll-a

* Some samples from N48 contaminated with macroalgae causing abnormally high result

A.2 Eastern Creek

Table A - 5: Eastern Creek

Site	Data type	Statistic	Conductivity (ms/m	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Temperature	pH	Tubidity (NTU)	Ammonia (mg/L)	Oxidised Nitrogen (mg/L)	Total Nitrogen (mg/L)	Filterable Phosphorus (mg/L)	Total Phosphorus (mg/L)	Faecal Coliforms (cfu/100mL)	Enterococci (cfu/100mL	Chlorophyll-a (ug/L)
NS094 - Eastern Creek at Richmond Road upstream Breakfast Creek	Low flow	N	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Median Concentrations	N	36	33	33	33	36	36	79	79	79	79	79	73	73	37
		Median	98	72	7.0	17.9	7.4	36.7	0.040	0.42	1.31	0.075	0.2020	2100	1200	5.3
NS085 - Eastern Creek at Douglas Road downstream Breakfast Creek	Low flow	N	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Median Concentrations	N	33	33	33	32	33	33	37	37	37	37	37	37	37	37
		Median	90	89	8	19.6	7.4	11.6	0.060	1.96	3.16	0.049	0.0970	170	70	2.4
NS083 - Eastern Creek at Garfield Road Bridge downstream Breakfast Creek	Low flow	N	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Median Concentrations	N	55	33	33	33	55	55	75	75	75	75	75	71	71	37
		Median	77	80	7.4	19.9	7.5	53.1	0.040	1.57	2.80	0.070	0.2130	4200	1500	4.1
NS082 - Eastern Creek upstream Riverstone STP, upstream confluence with South Creek	Low flow	N	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Median Concentrations	N	88	88	62	88	88	88	176	176	176	176	176	174	176	160
		Median	84	92	8.4	20.4	7.6	40.6	0.062	1.91	2.76	0.027	0.0960	180	95	6.2
NS081 - Eastern Creek downstream Riverstone STP, upstream confluence with South Creek	Low flow	N	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Median Concentrations	N	88	88	62	88	88	88	176	176	176	176	176	176	176	160
		Median	86	92	8.2	20.6	7.7	36	0.060	2.85	3.94	0.025	0.0845	140	120	5.5

Note: Shaded values exceed relevant guideline value.

Table A - 6: Breakfast Creek

Site	Data type	Statistic	Conductivity (ms/m	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Temperature	pH	Tubidity (NTU)	Ammonia (mg/L)	Oxidised Nitrogen (mg/L)	Total Nitrogen (mg/L)	Filterable Phosphorus (mg/L)	Total Phosphorus (mg/L)	Faecal Coliforms (cfu/100mL)	Enterococci (cfu/100mL	Chlorophyll-a (ug/L)
NS090 - Breakfast Creek at Falmouth Road, upstream Quakers Hill STP	Low flow	N	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
		Median	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Median Concentrations	N	**88**	**88**	**62**	**88**	**88**	**88**	**176**	**176**	**176**	**176**	**176**	**176**	**176**	**160**
		Median	**96**	**65**	**6.2**	**19.3**	**7.5**	**11.8**	**0.030**	**0.05**	**0.70**	**0.034**	**0.0885**	**445**	**285**	**6.0**
NS087 - Breakfast Creek at Station Road, downstream Quakers Hill STP	Low flow	N	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
		Median	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Median Concentrations	N	**88**	**88**	**62**	**88**	**88**	**88**	**176**	**176**	**176**	**176**	**176**	**176**	**176**	**160**
		Median	**85**	**92**	**8.0**	**21.7**	**7.5**	**3.3**	**0.031**	**2.55**	**3.63**	**0.029**	**0.0495**	**230**	**85**	**1.5**

Note: Shaded values exceed relevant guideline value.

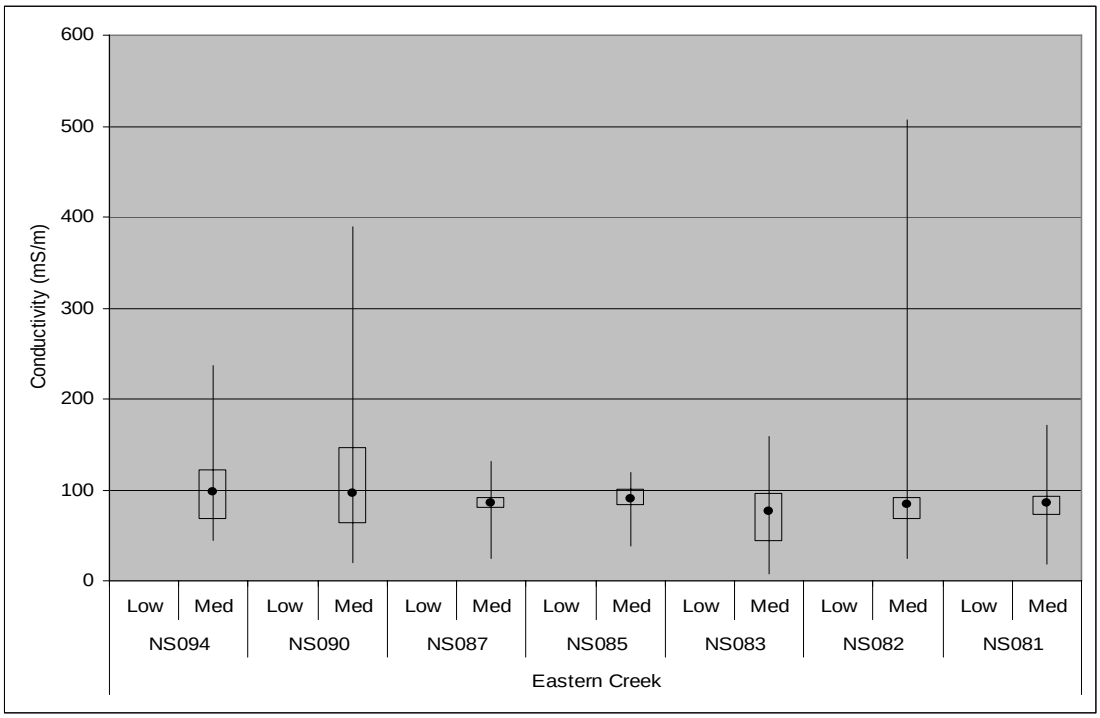


Figure A - 15: Eastern Creek Conductivity

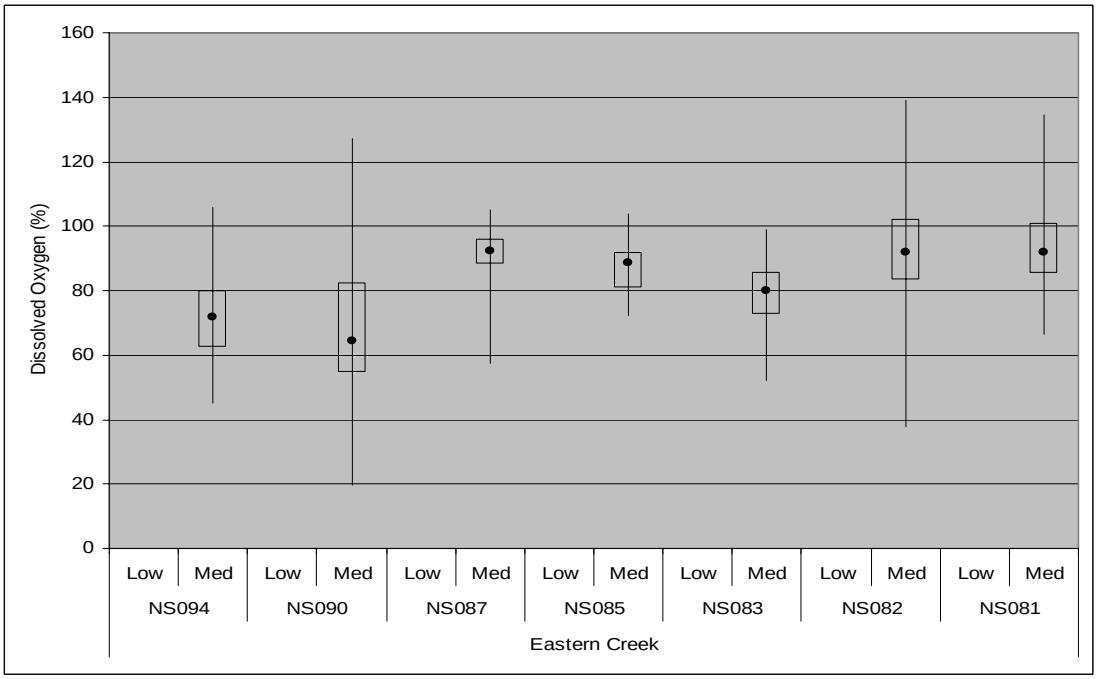


Figure A - 16: Eastern Creek Dissolved Oxygen (% saturation)

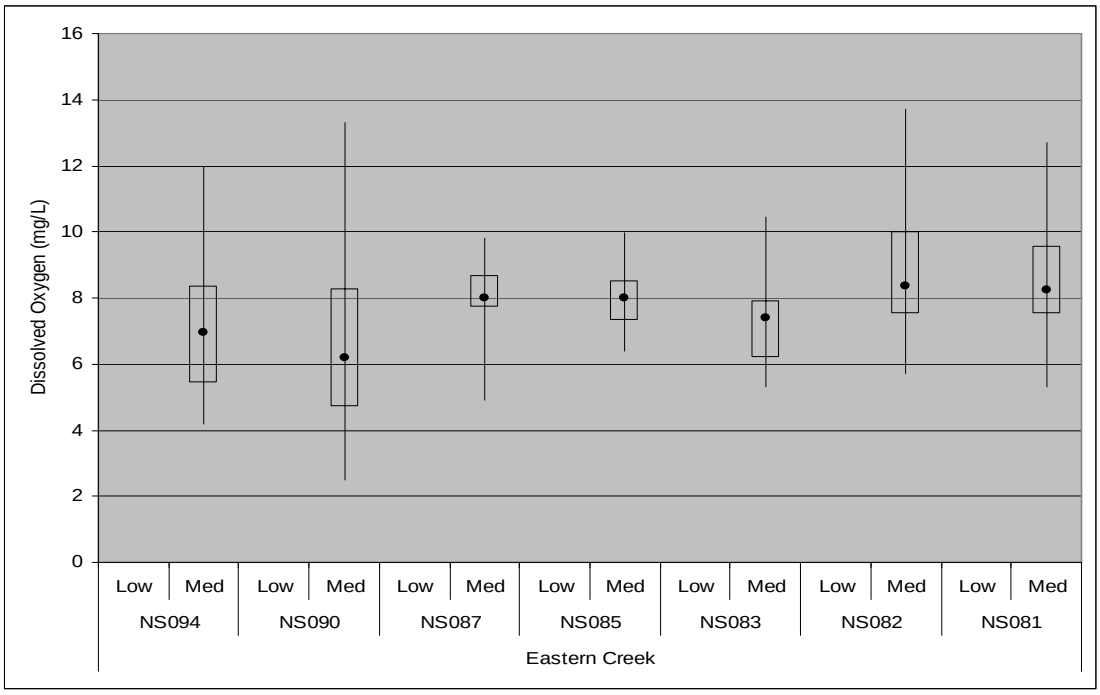


Figure A - 17: Eastern Creek Dissolved Oxygen (mg/L)

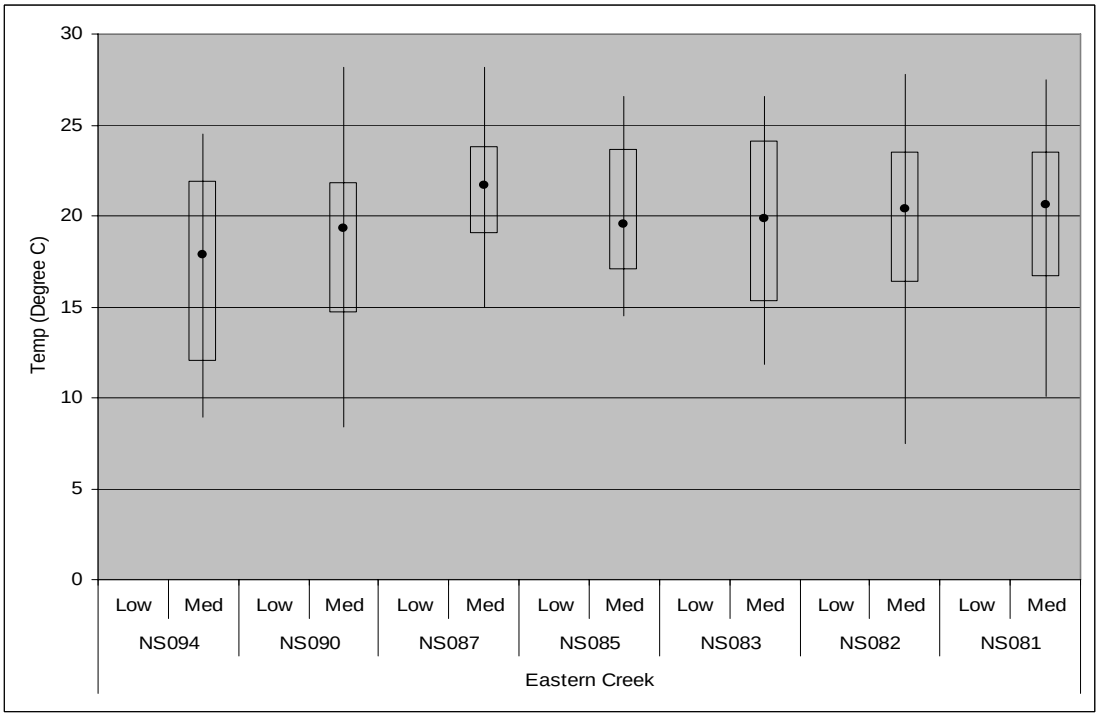


Figure A - 18: Eastern Creek Temperature

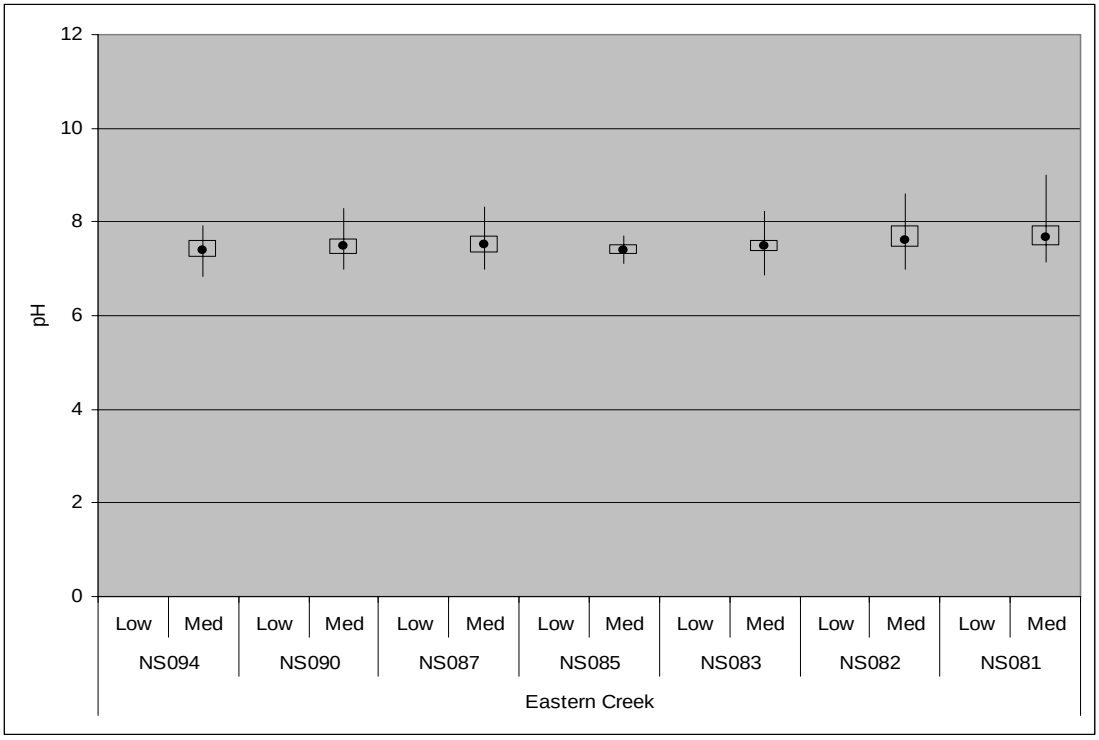


Figure A - 19: Eastern Creek pH

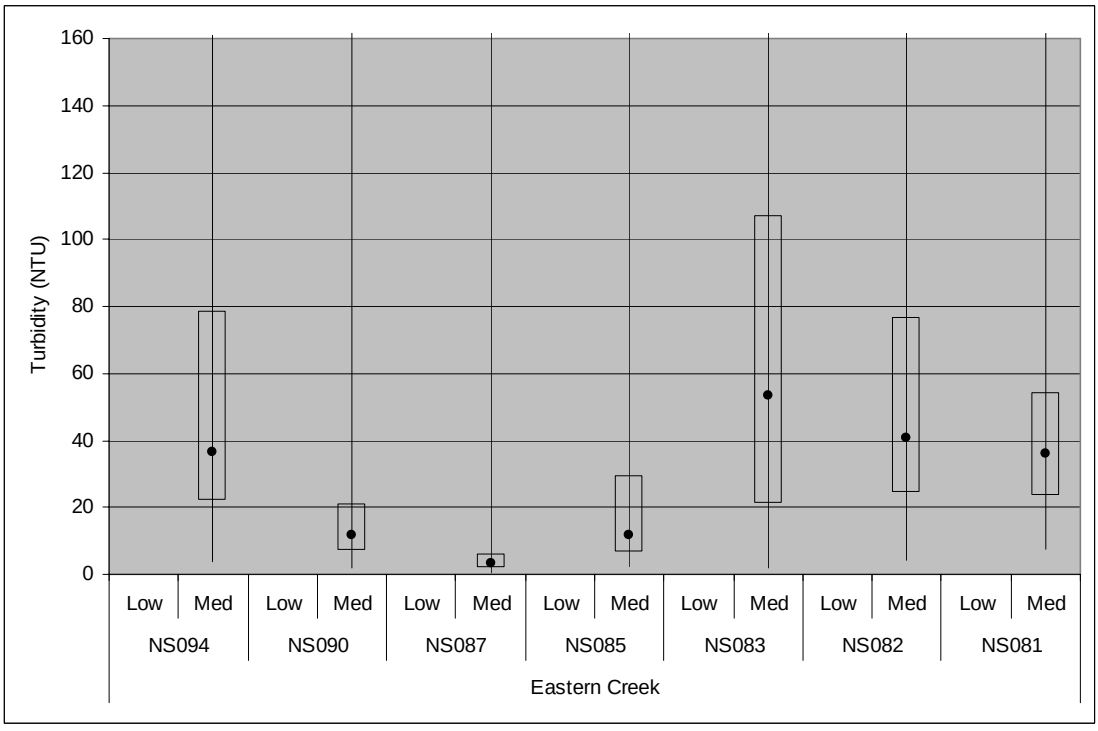


Figure A - 20: Eastern Creek Turbidity

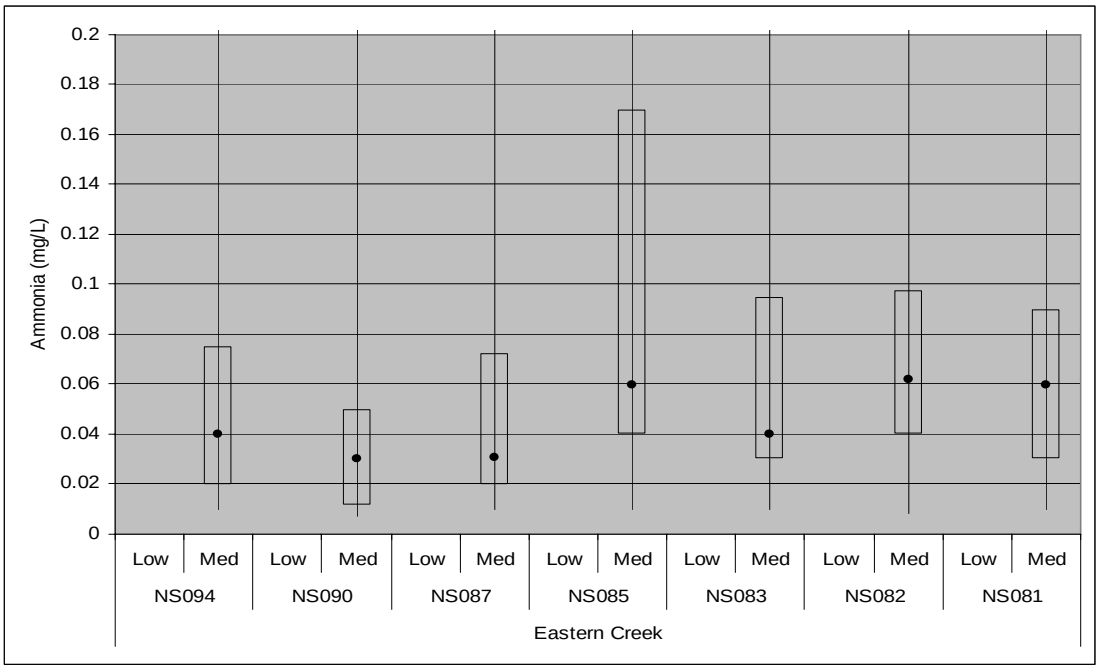


Figure A - 21: Eastern Creek Ammonia

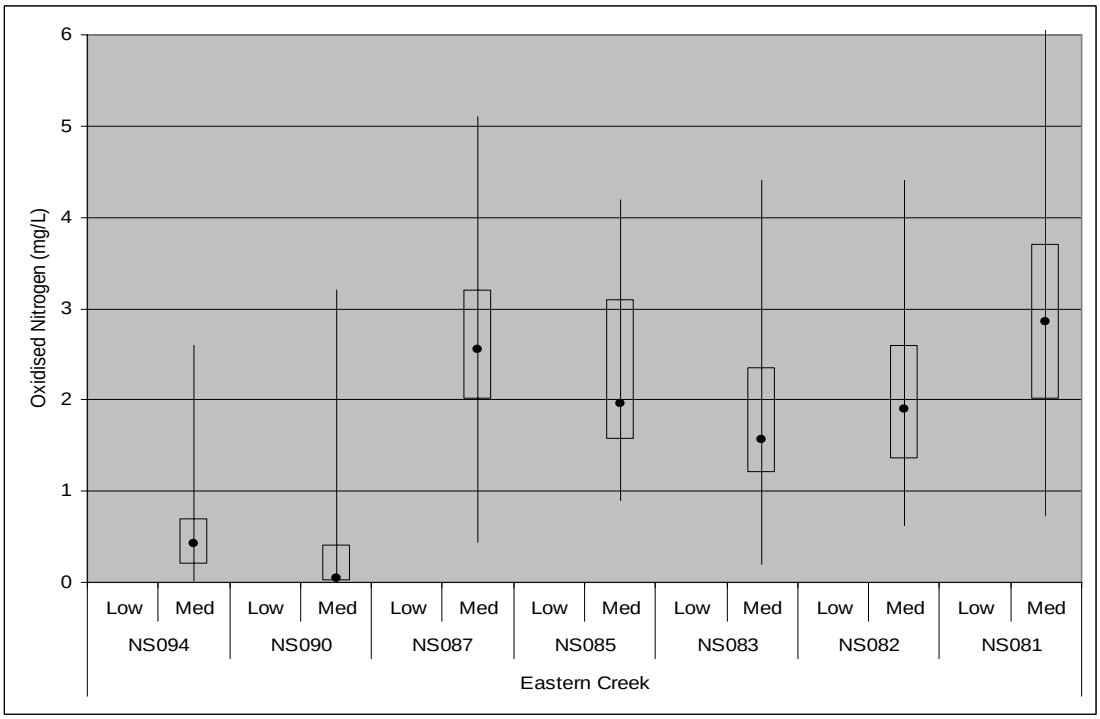


Figure A - 22: Eastern Creek Oxidised Nitrogen

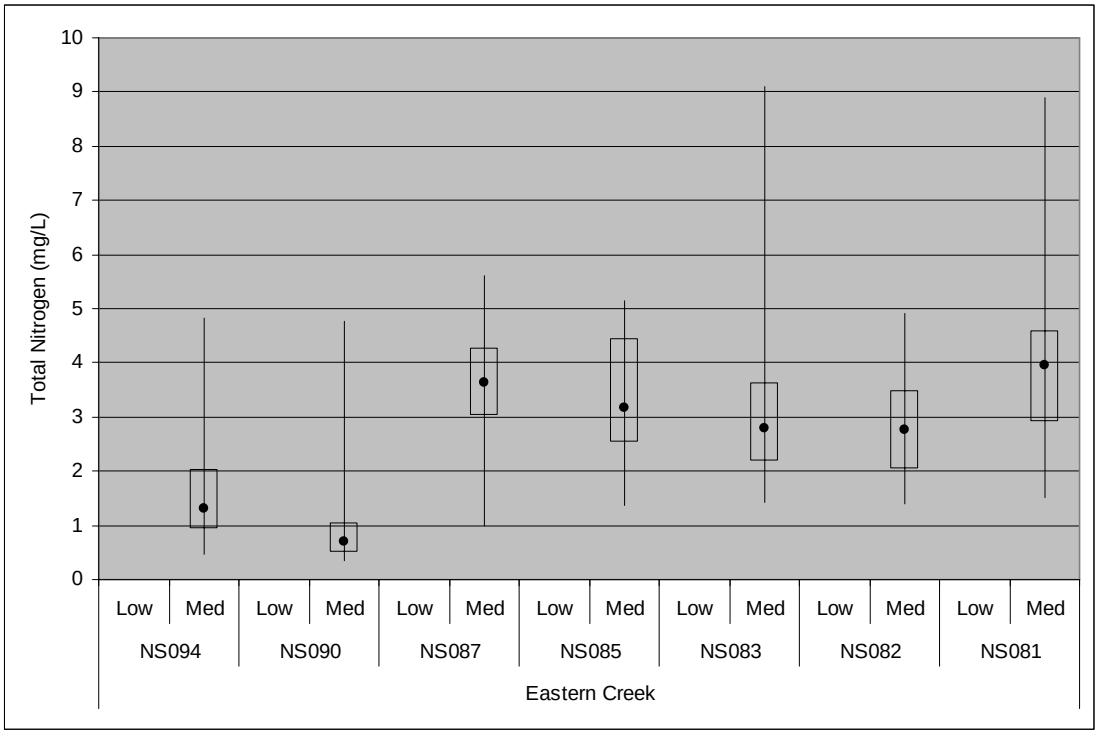


Figure A - 23: Eastern Creek Total Nitrogen

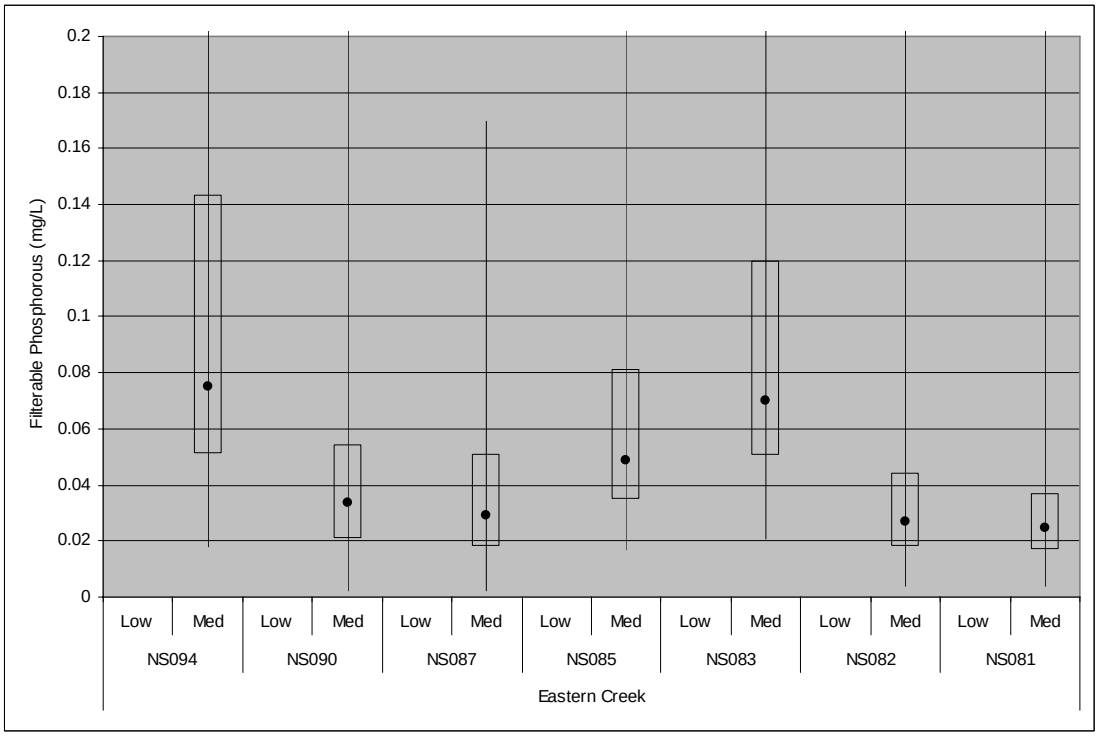


Figure A - 24: Eastern Creek Filterable Phosphorus

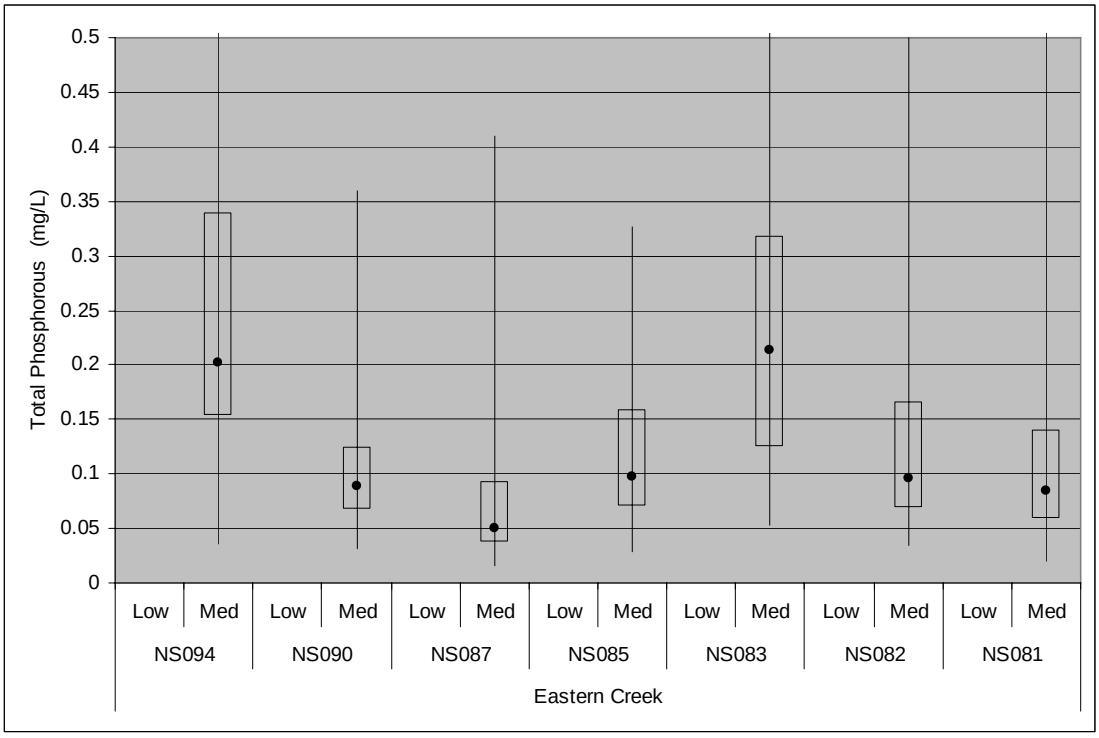


Figure A - 25: Eastern Creek Total Phosphorus

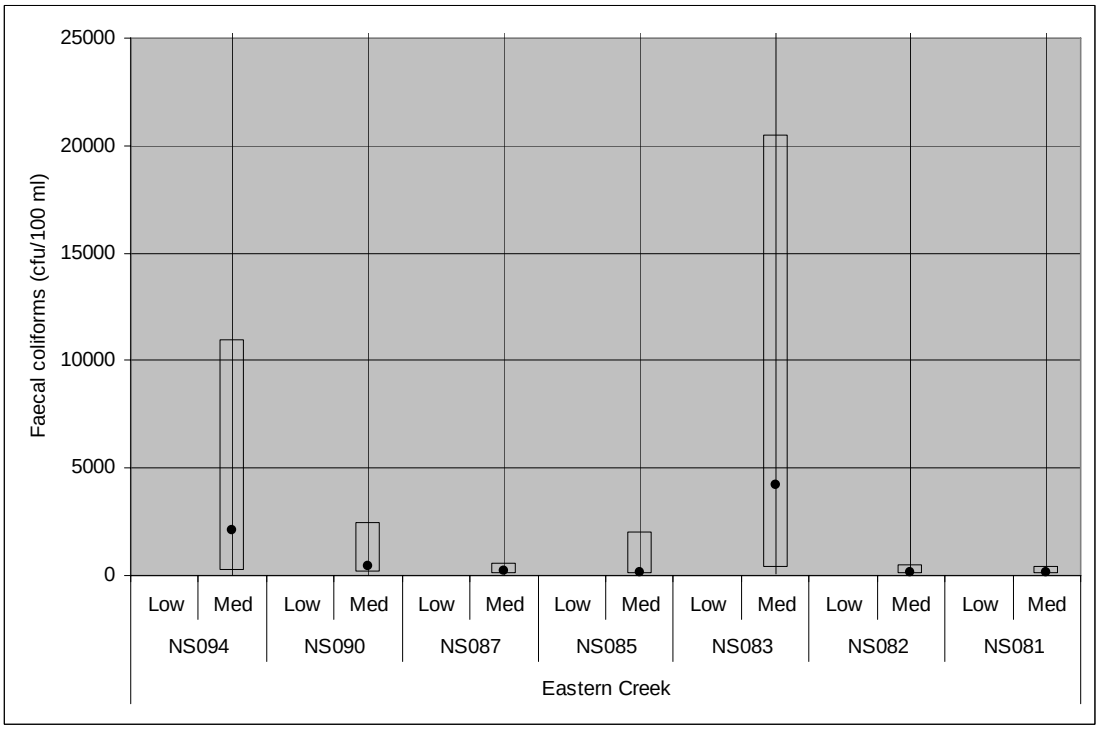


Figure A - 26: Eastern Creek Faecal Coliforms

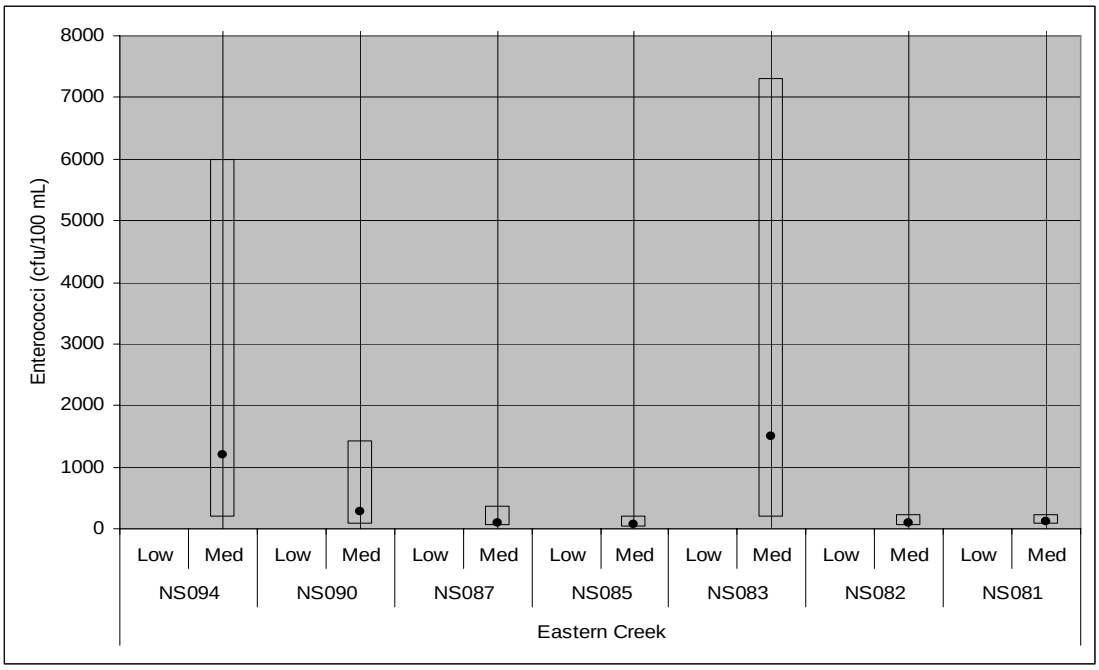


Figure A - 27: Eastern Creek Enterococci

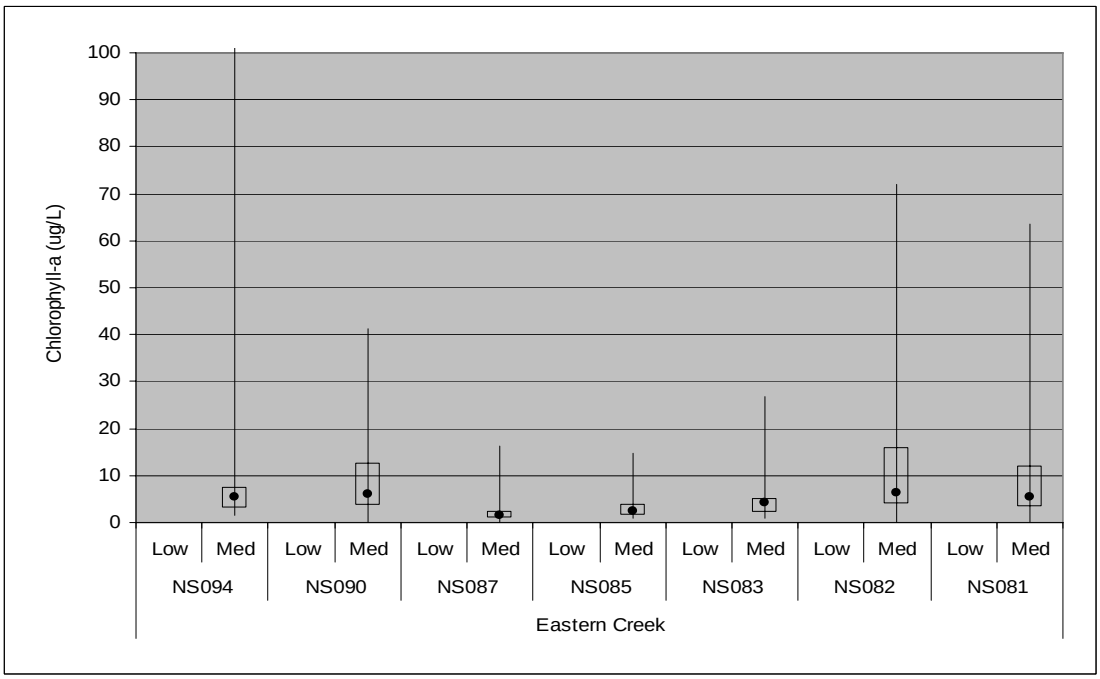


Figure A - 28: Eastern Creek Chlorophyll-a

A.3 South Creek

Table A - 7: South Creek

Site	Data type	Statistic	Conductivity (ms/m	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Temperature	pH	Tubidity (NTU)	Ammonia (mg/L)	Oxidised Nitrogen (mg/L)	Total Nitrogen (mg/L)	Filterable Phosphorus (mg/L)	Total Phosphorus (mg/L)	Faecal Coliforms (cfu/100mL)	Enterococci (cfu/100mL	Chlorophyll-a (ug/L)
NS26 - South Creek at Dunheved Golf Course upstream St Marys STP	Low flow	N	6	6	6	6	6	6	12	12	12	12	12	12	12	12
		Median	64	28	2.8	18.1	7.4	20.2	0.030	0.04	0.69	0.014	0.0615	116	145	20.7
	Median Concentrations	N	88	88	62	88	88	88	175	175	175	175	175	175	175	159
		Median	84	56	4.7	19.3	7.3	21.6	0.050	0.17	0.89	0.013	0.0600	220	190	9.4
NS24 - South Creek at ADI upstream St Marys STP	Low flow	N	6	6	6	6	6	6	12	12	12	12	12	12	12	12
		Median	56	41	4.4	19.0	7.6	18.7	0.040	0.02	0.65	0.014	0.0410	112	126	12.0
	Median Concentrations	N	87	87	61	87	87	58	174	174	174	174	174	174	174	158
		Median	81	64	5.6	18.7	7.4	17.6	0.040	0.20	0.90	0.012	0.0530	185	180	10.3
NS23 - South Creek at ADI Shanes Park downstream St Marys STP	Low flow	N	6	6	6	6	6	6	12	12	12	12	12	12	12	12
		Median	73	86	8.2	22.3	7.8	5.4	0.015	3.60	4.53	0.031	0.0425	220	195	1.4
	Median Concentrations	N	88	88	62	88	88	88	176	176	176	176	176	176	174	160
		Median	74	84	8.0	20.7	7.4	7.2	0.023	2.70	3.61	0.032	0.0595	240	230	2.4
NS14 - South Creek at Richmond Road Bridge upstream Eastern Creek	Low flow	N	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Median Concentrations	N	50	36	36	36	50	50	80	80	80	80	80	76	76	40
		Median	77	81	7.9	20.2	7.4	29.8	0.030	1.46	2.32	0.069	0.1685	730	270	7.9
NS04 - South Creek at Fitzroy Bridge upstream confluence with Hawkesbury-Nepean	Low flow	N	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Median	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Median Concentrations	N	33	33	33	33	32	33	37	37	37	37	37	37	37	37
		Median	88	67	6.2	19.6	7.4	42.6	0.100	1.86	3.15	0.061	0.1560	380	180	6.1

Note: Shaded values exceed relevant guideline value.

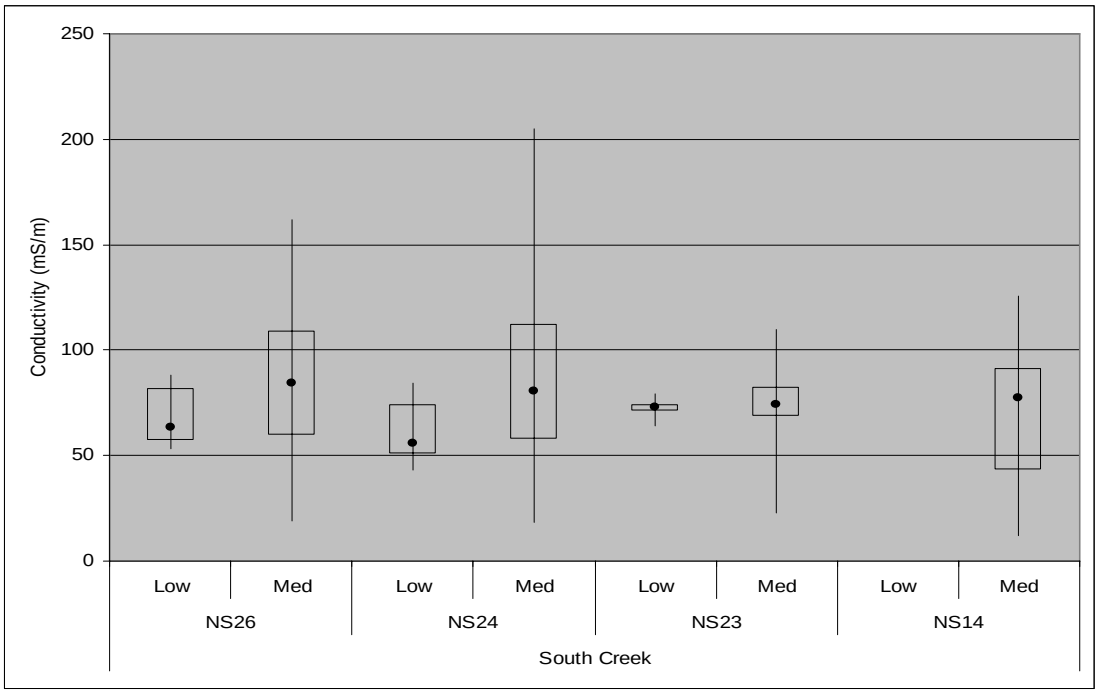


Figure A - 29: South Creek Conductivity

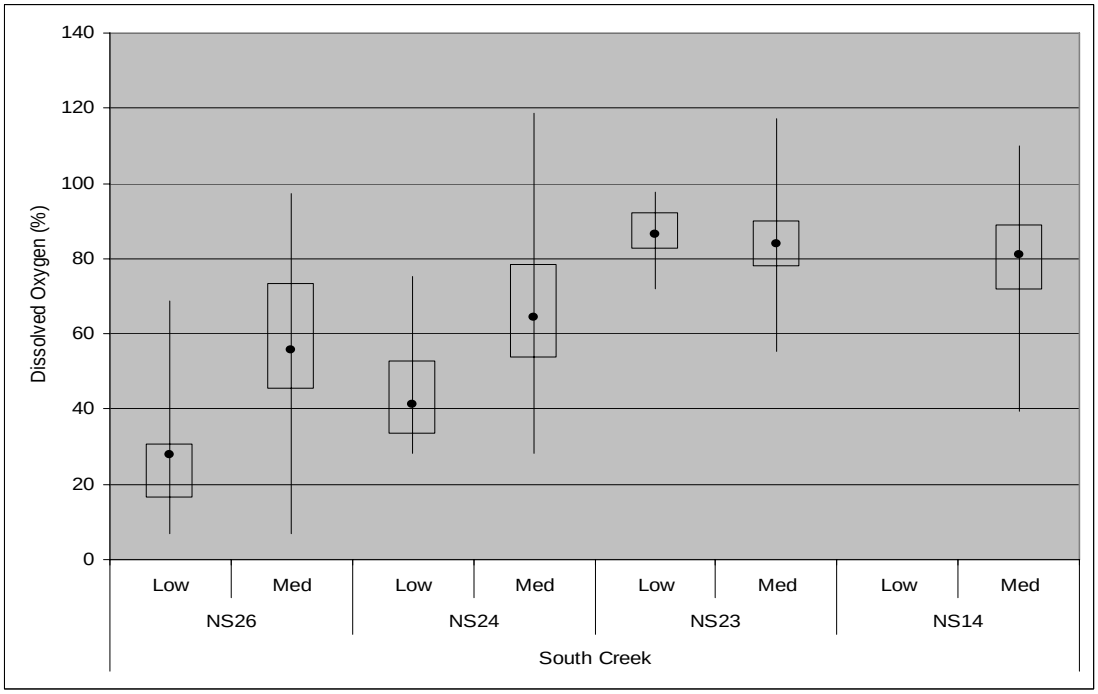


Figure A - 30: South Creek Dissolved Oxygen (% saturation)

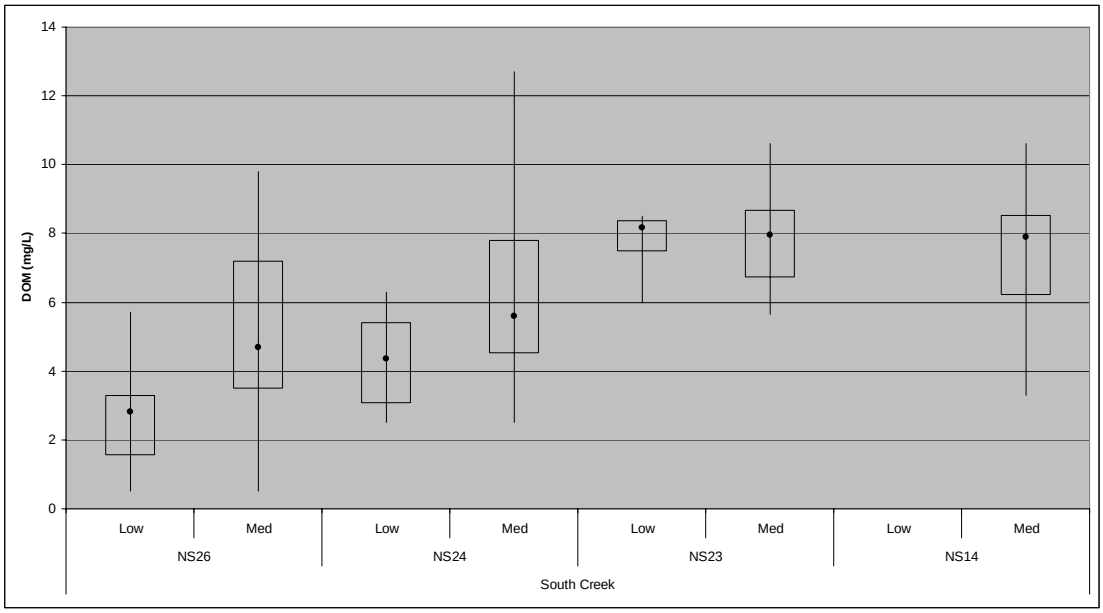


Figure A - 31: South Creek Dissolved Oxygen (mg/L)

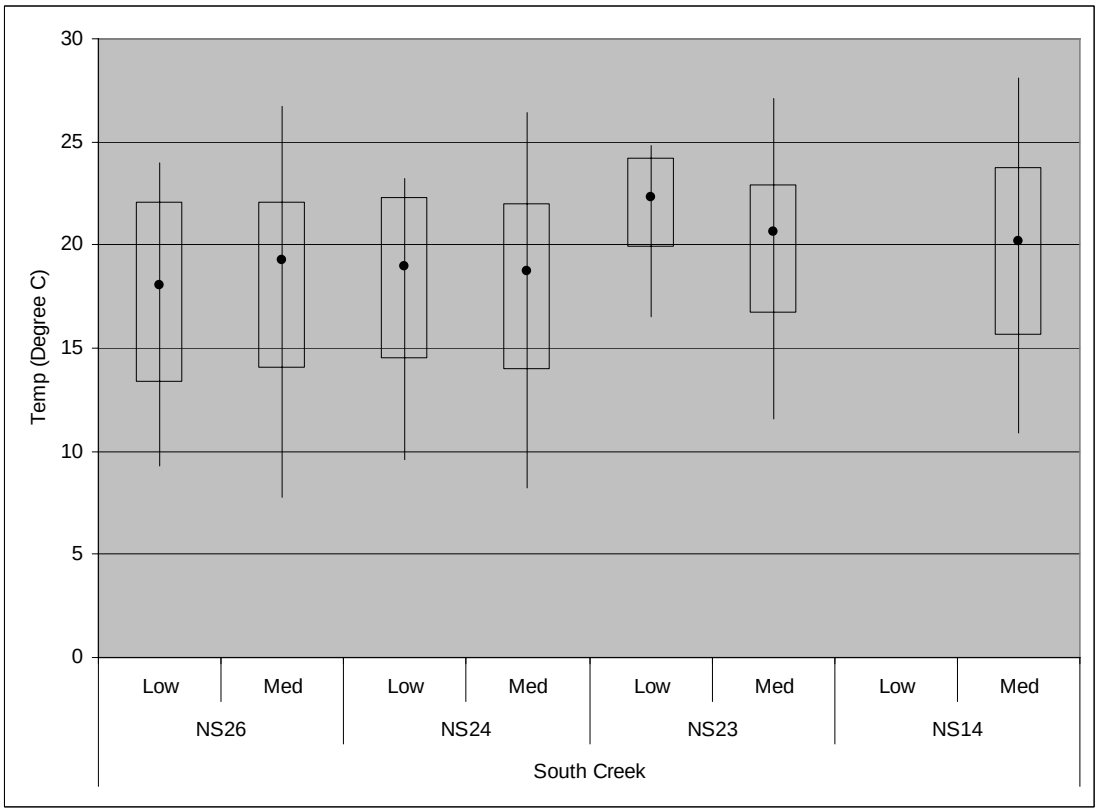


Figure A - 32: South Creek Temperature

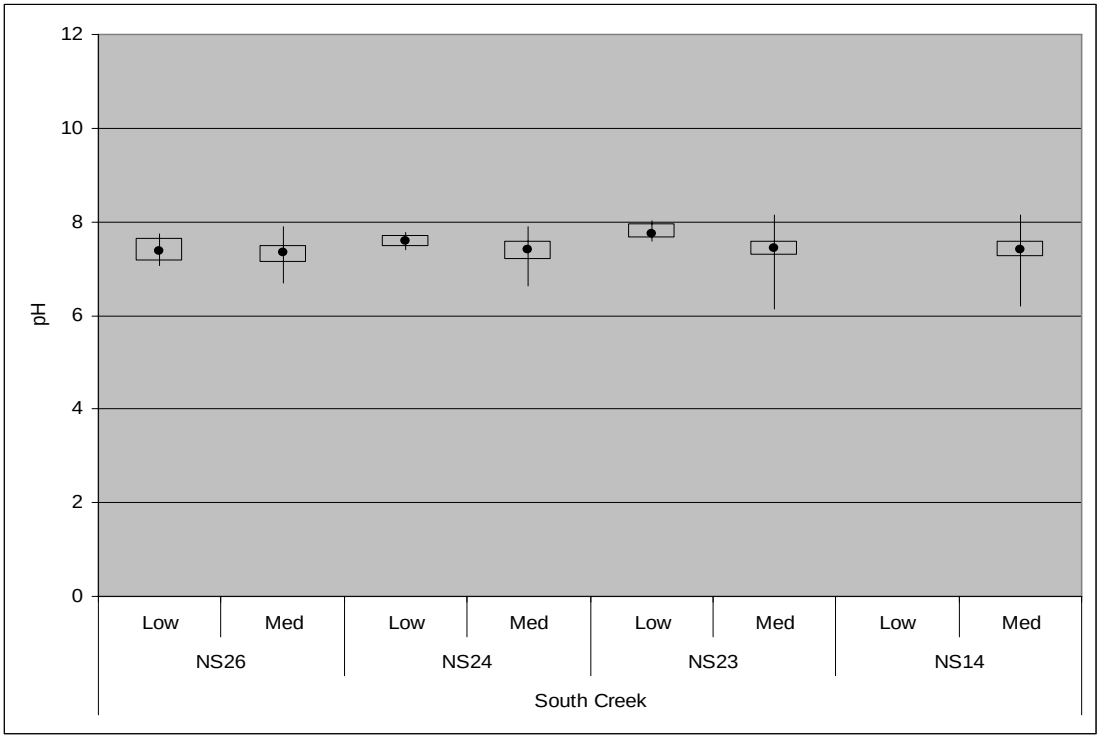


Figure A - 33: South Creek pH

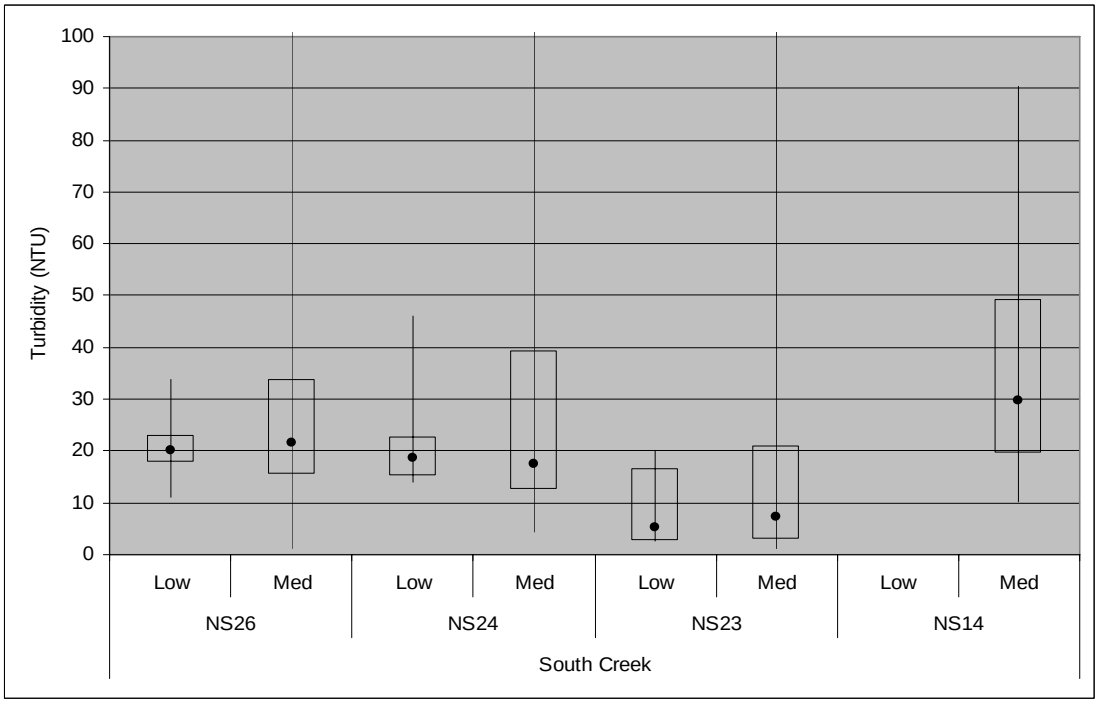


Figure A - 34: South Creek Turbidity

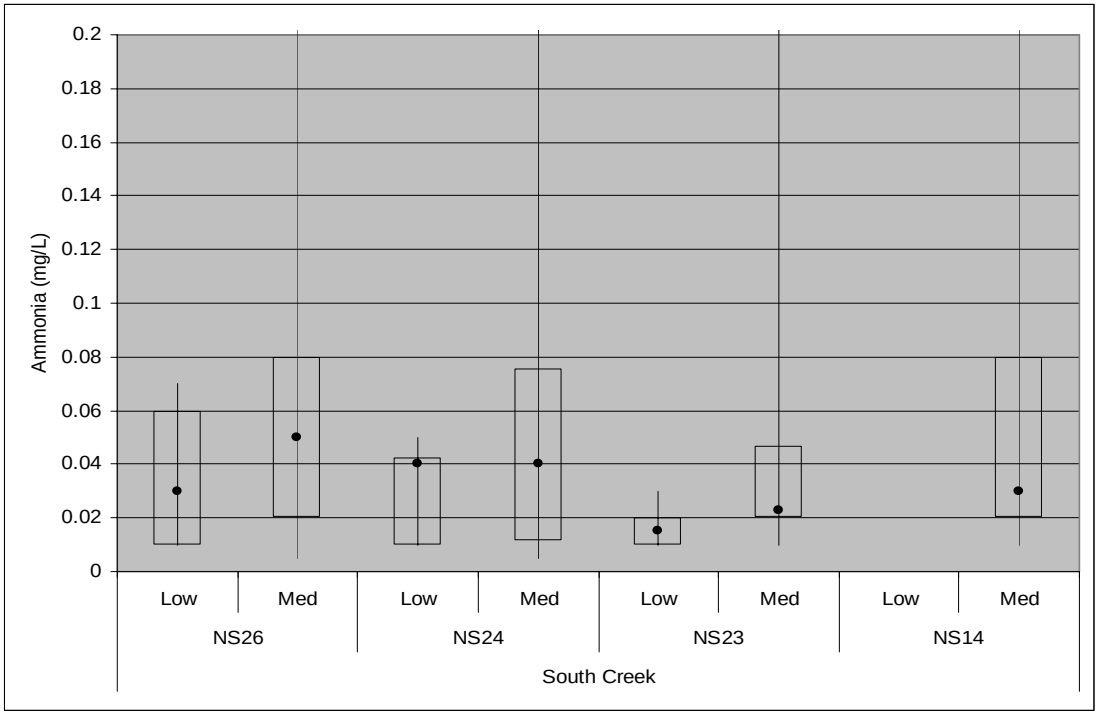


Figure A - 35: South Creek Ammonia

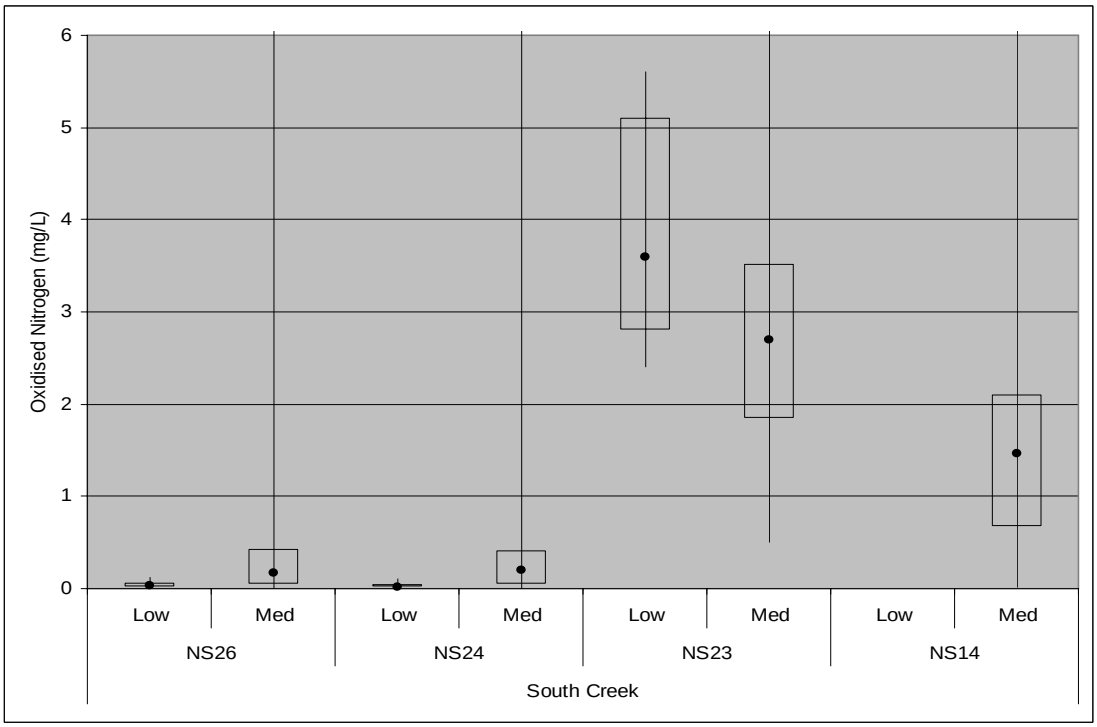


Figure A - 36: South Creek Oxidised Nitrogen

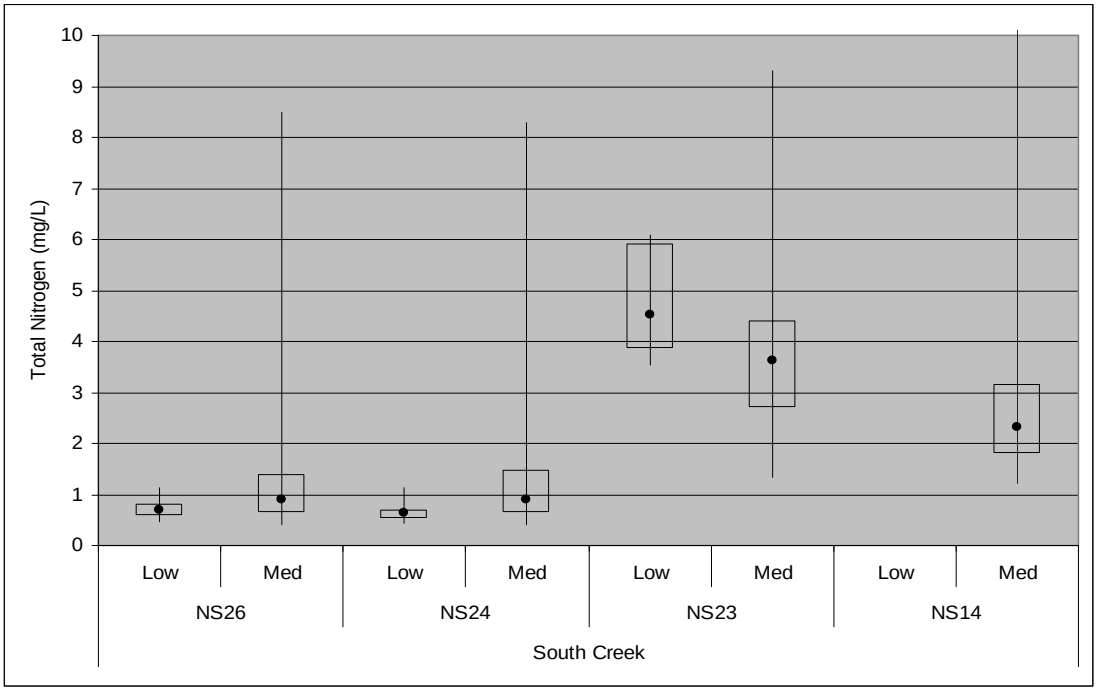


Figure A - 37: South Creek Total Nitrogen

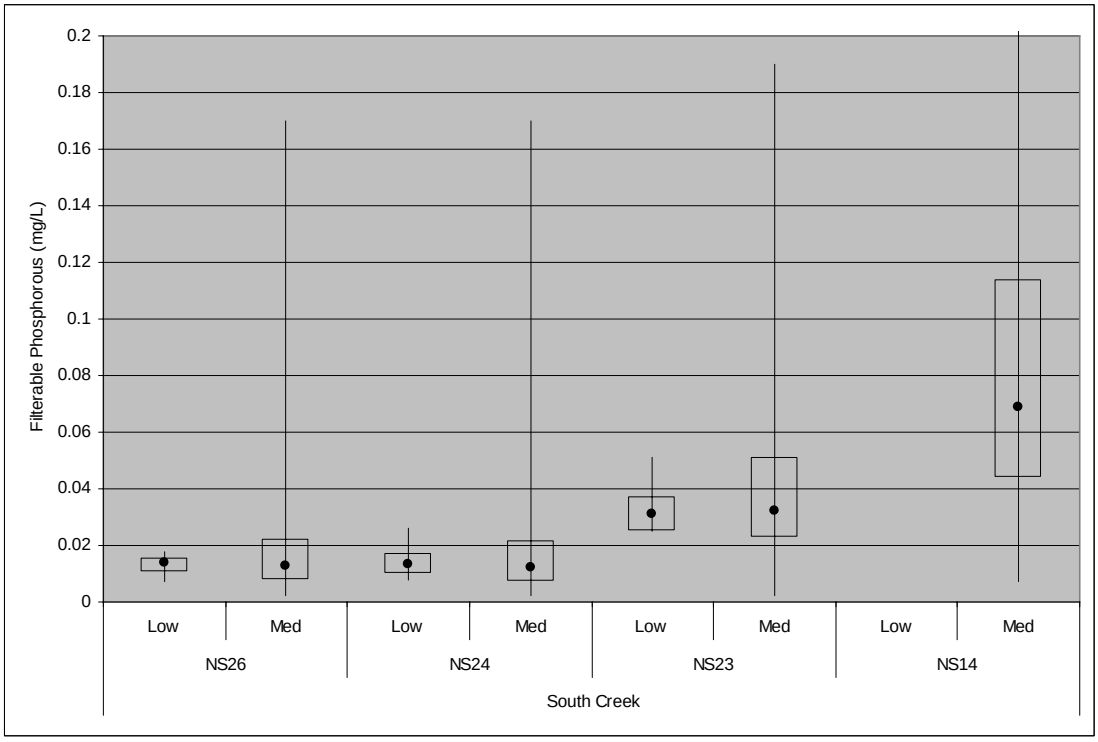


Figure A - 38: South Creek Filterable Phosphorus

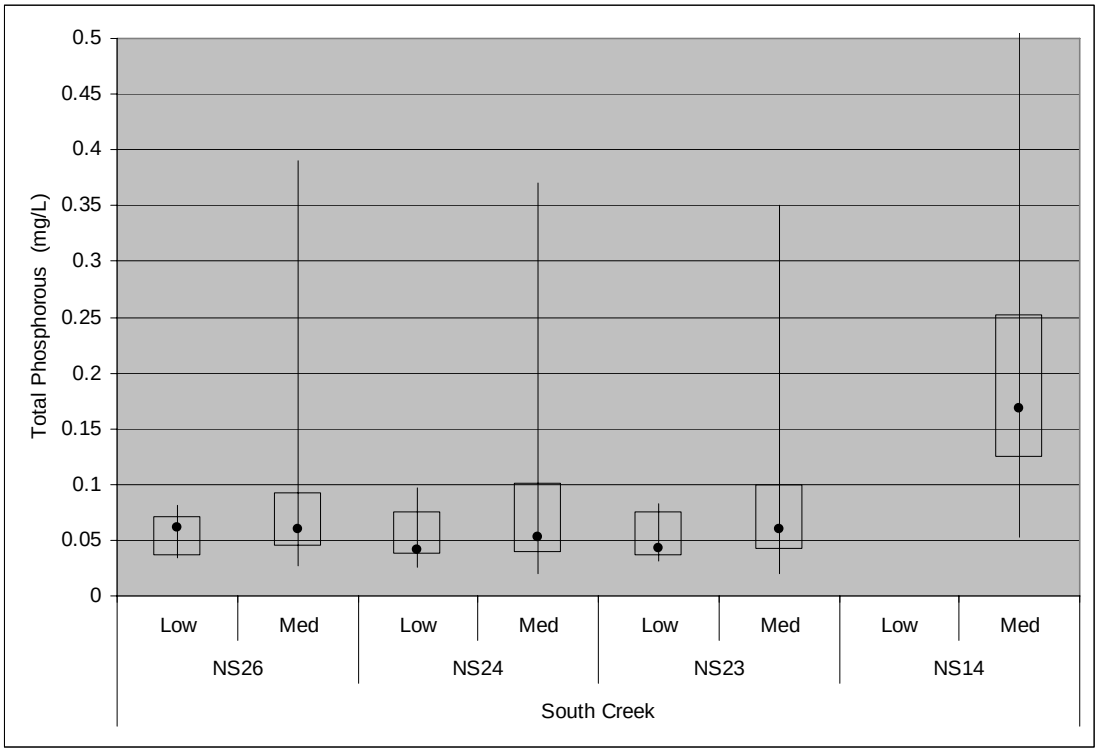


Figure A - 39: South Creek Total Phosphorus

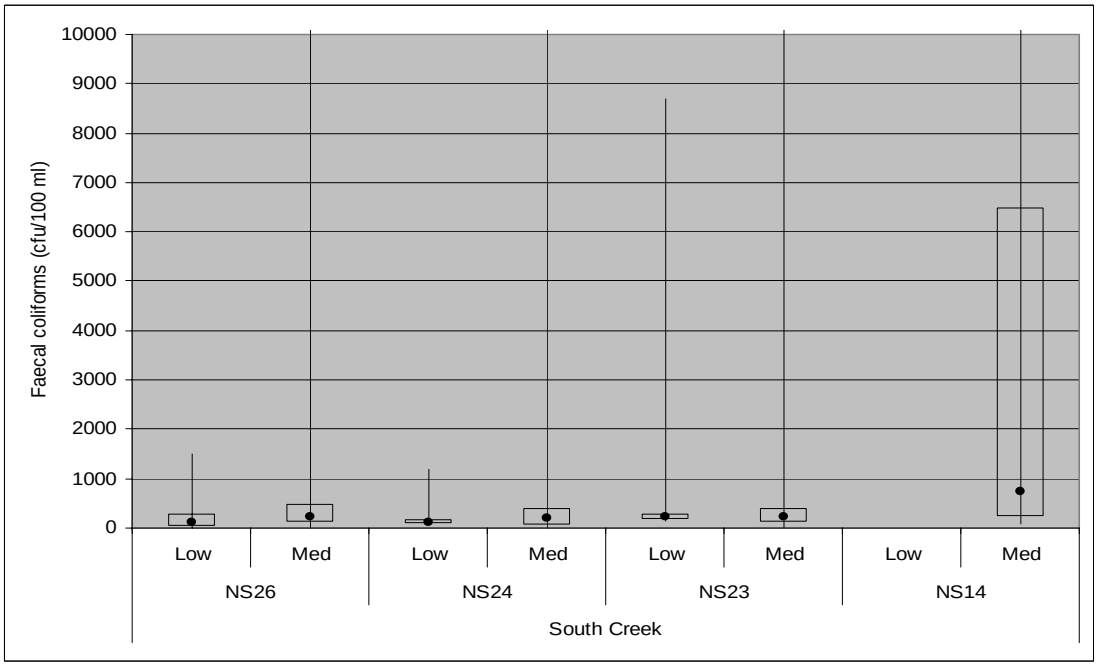


Figure A - 40: South Creek Faecal Coliforms

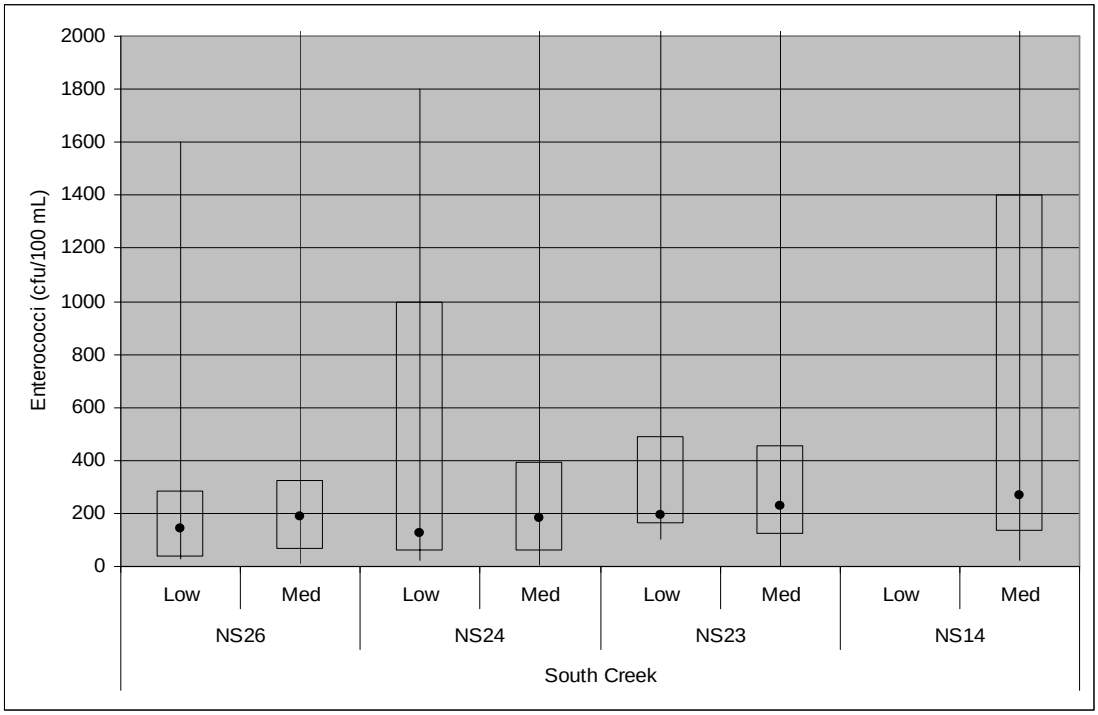


Figure A - 41: South Creek Enterococci

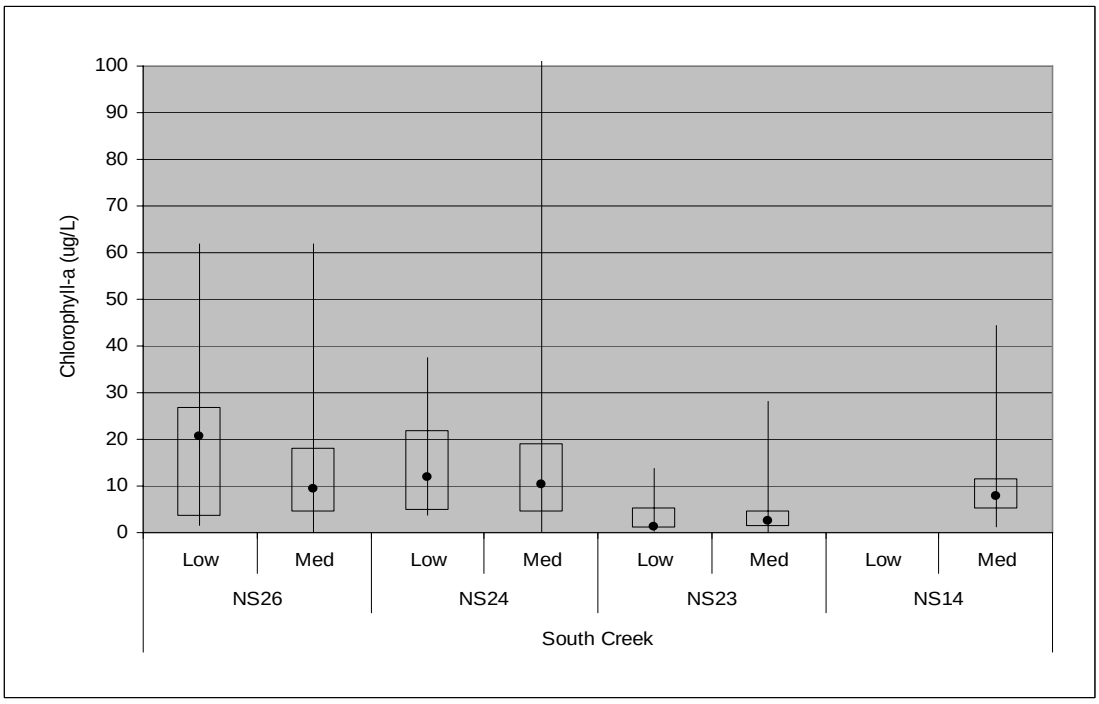


Figure A - 42: South Creek Chlorophyll-a

Appendix D

Human health risk assessment



THE UNIVERSITY OF NEW SOUTH WALES



CENTRE FOR WATER AND WASTE TECHNOLOGY



School of Civil and Environmental Engineering

Screening Health Risk Assessment for the Use of Microfiltration-Reverse Osmosis Treated Tertiary Effluent for Replacement of Environmental Flows

Final Report

David Roser, Stuart Khan, Cheryl Davies, Ryan Signor, Susan Petterson and Nicholas Ashbolt

Centre for Water and Waste Technology
School of Civil and Environmental Engineering
University of NSW

CWWT Report 2006-20
October 2006

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Executive Summary

Sydney Water commissioned the University of New South Wales' Centre for Water and Waste Technology (UNSW-CWWT) to undertake a desk-top screening-level risk assessment of the potential impact on human health of releasing highly treated recycled water into the Hawkesbury-Nepean River immediately downstream of the Penrith Weir. The study considered the potential risks to river users from waterborne pathogens and chemicals. The river uses investigated in the study included recreational use, drinking treated or untreated river water, being exposed to soils irrigated by river water, and eating fish caught from the river. In addition, the potential for cyanobacterial (blue-green algal) blooms arising from the project, under different flow regimes in the river was investigated.

The study did not consider risks arising from other pathways, *e.g.* stormwater, agricultural run-off and the additional effects resulting from background concentrations of microorganisms and chemicals in the river system.

The risk assessment concluded that during normal operation of the advanced water treatment plant (AWTP), no additional health risks were identified from either pathogenic microorganisms or from chemicals by introduction of the replacement flows to the Hawkesbury-Nepean River, for the various river uses investigated.

A detailed summary of the Human Health Risk Assessment is presented in **Appendix E.**

Risk assessment process

In line with EnHealth guidelines on human health risk assessments (EnHealth Council, 2002), the risk assessment was conducted as follows:

- issue identification;
- hazard assessment (includes a literature review of human health risks arising from the project and likely effectiveness of water treatment processes and other barriers, as well as relevant dose-response data);
- exposure assessment (includes quantitation of pathogens and toxic chemicals);
- risk characterisation (this reports the probabilities of infections and acute toxicity or cancer potential for chemicals to aid decision making);
- uncertainty identification (includes uncertainties identified in the above 4 assessment steps and arising in the course of assessment. This summarises the knowledge gaps identified in each stage of the risk assessment);
- risk management (provides a range of management options based on the assessment presented in this report. The issues considered only cover issues relating to management options of Uncertainties highlighted by the assessment *e.g.* data gaps, limitations in the risk estimates provided).

It should be noted that the assessment did not include some components as prescribed by EnHealth. Some steps will be undertaken through separate means or subsequent work. These include 'Community Consultation', 'Management' (except in some identified priority areas)

and 'Reality Checks' (other than those that were possible based on literature or expertise based evaluation).

Hazard assessment

Initial concentrations of potential pathogen hazards in sewage were estimated through a literature review and from examination of pathogen data for treated effluent from Sydney Water's sewage treatment plants (STPs).

The chemical contaminants were subjected to a screening assessment to identify key hazards of potential concern. This involved comparing 95th percentile concentrations of the Schedule 10 list of chemical contaminants (Sydney Water data 2000-2004) with guideline values.

This process identified 27 chemicals possibly at or above guideline values, and for which more detailed risk assessment was undertaken.

Since toxic thresholds could not be identified for endocrine disruptors (EDCs), these chemicals could not be quantitatively assessed. Similarly disinfection by-products (DBPs), could not be quantitatively assessed due to a lack of information on the formation potential of this chemical during the treatment process. As a result, EDCs and DBPs are only discussed in **Appendix E**.

Exposure pathways

The exposure pathways considered were:

- consuming untreated river water used as a domestic supply at Penrith Weir;
- exposed to river water or sediment by ingestion, dermal contact (chemicals only) or inhalation of volatiles (chemicals only) during primary recreation;
- consuming vegetables irrigated with river water (pathogens only);
- exposed to soils irrigated with river water (chemicals only);
- consuming fish which might accumulate contaminants (pathogens only);
- consuming drinking water treated by North Richmond Water Filtration Plant (pathogens only) or not treated (chemicals only).

Key findings from the Risk Characterisation Process

Pathogens

The overall risk from pathogens by the introduction of replacement flows was assessed as "Low" by each of the exposure pathways studied, when the AWTP is working normally.

The worst-case exposure pathway considered in the microbial risk assessment was drinking untreated river water (supplemented with the highly treated recycled water) near Penrith under low flow conditions. This was for three index pathogens *Cryptosporidium* (a human

pathogenic protozoan), *Campylobacter* (a human pathogenic bacterium) and *Rotavirus* (a human pathogenic virus).

In this worst-case exposure pathway, assuming effective microfiltration/reverse osmosis treatment, estimated risks were well below benchmark values of <1 μDALY and "1 in 10,000 risk of infection (more properly expressed as the probability of infection being 10^{-4}.person^{-1}.y^{-1}). One μDALY is one Disability Adjusted Life Year per million people, which is used by the World Health Organization as a measure of safe pathogen health burden. For this exposure pathway, the risk of infection would exceed the benchmark values only when a substantial proportion of the reverse osmosis filtration system is inoperative or when there is concurrent breakdown of both microfiltration and reverse osmosis membranes.

For the other exposure pathways, the risk benchmarks were exceeded for primary recreation at Penrith Weir under a situation of low river flow conditions and concurrent breakdown of both microfiltration and reverse osmosis, only. The consumption of shellfish and irrigated vegetables, and in particular consumption of treated drinking water from the North Richmond reticulated supply presented risks well below the benchmark values.

Chemicals assessed

The only identified risk from chemicals (3 chemicals out of 111) was from recreational exposure to sediments in portions of the river closest to the replacement flow mixing zone, under conditions of poor reverse osmosis removal and low to medium river flow. In this case the risk was assessed as "Low" to "Moderate", even though these three chemicals have not been detected in river water at the current limit of detection.

The initial screening stage of the chemical risk assessment, conducted on tertiary treated effluent data, without microfiltration/reverse osmosis treatment, resulted in the removal from consideration of 84 of the initial 111 Chemicals of Potential Concern (COPCs).

The risk characterisation of the remaining 27 chemicals of potential concern was undertaken in two stages. The first was the quantitative determination of residual risks associated with individual chemical contaminants identified from Schedule 10 monitoring data. This was followed by a qualitative interpretation of the overall risks based on hazard analysis.

Calculated risks for individual carcinogenic and non-carcinogenic chemicals were determined based on relationships and process assumptions described by the US Environmental Protection Agency for the assessment of risk associated with contaminated sites. Cancer risks and hazard quotients determined by these relationships were calculated separately for various exposure routes (*i.e.* oral, dermal, inhalation). The latter included consideration of partitioning (to air, water sediments and aquatic biota) for individual chemicals. Risks for the various pathways were summed to obtain a total exposure risk for each chemical under each exposure pathway.

Non-Cancer chemical risks

No unsafe concentrations of non-cancer risk chemicals were identified.

Hazard quotients (for non-cancer risks) were calculated as a simple ratio between predicted exposure levels and exposure levels determined to be protective of human health. They were

interpreted according to whether they were greater than or less than the Hazard Quotient (HQ) value of 1.0.

Based on HQs, monochloramine, hydrogen sulphide and nickel were the only non-cancer chemicals considered *i.e.* their toxicity to humans was the risk concern because they are not considered to be carcinogenic. For each of these chemicals, calculated hazard quotients were less than 1.0 for each of the considered exposure pathways.

Cancer Risks

The overall risks posed by these chemicals were assessed as 'Low' to 'Moderate'.

Risk estimations for carcinogenic chemicals were interpreted using the benchmark cancer risk (lifetime average probability) of one in a million (10^{-6}). That is, safe levels were assumed where calculated risk values were less than 10^{-6}.

Calculated risk values were less than 10^{-6} for all individual chemicals under the following exposure pathways and routes:

- oral consumption of drinking water;
- recreational activities in the river (with exceptions noted below);
- exposure via irrigated soils.

A few chemicals were calculated to be equal to or slightly above the benchmark under some circumstances for the recreational exposure pathways. These were:

- Aldrin (river segment closest to Penrith Weir under low flow conditions and assuming poor reverse osmosis removal) (maximum exposure risk $1x10^{-6}$);
- Benzo(a)pyrene (river segments closest to Penrith Weir under low or median flow conditions and assuming poor reverse osmosis removal) (maximum exposure risk 2-3 $x10^{-6}$);
- Dibenz(ah)anthracene (river segments closest to Penrith Weir under low or median flow conditions and rivers segments from Penrith Weir to Emu Plains under low flow conditions and poor reverse osmosis removal) (maximum exposure risk $1\text{-}5x10^{-6}$).

These risks were calculated as the sum of a number of exposure pathways. Of these the predominant influence was by dermal contact with river mud (sediment) in river segments.

It is important to note, however, that the identified chemicals may not pose a problem in reality. All three risk estimate sets, with risks exceeding the 10^{-6} risk benchmark were calculated using detection limit values rather than actual 95th percentile concentrations. None of these three compounds, Aldrin, Benzo(a)pyrene and Dibenz(ah)anthracene was detected in the 75 samples (3 analytes x 25 measurements) assayed. It should also be noted that Aldrin has been banned for use in Australia.

Cyanobacterial Toxins

The overall risk of the project increasing the risk of cyanobacterial blooms is "Low" based on reduced total phosphorus load that would be discharged into the Hawkesbury-Nepean River. The reduction in nutrient loads is further discussed in Section 7.4.

Key Inputs from the Literature Survey

Using the selected hazards and initial identification of exposure pathways as guides, a review of the available quantitative information, needed to estimate removal rates of the potential hazards, was undertaken. This was supplemented by available data for the Hawkesbury-Nepean River and background information for the Replacement Flows project (*e.g.* Sydney Water's hydrological model of river flow and dilution regimes). While there was no reported risk assessments of the use of highly treated recycled water for surface water flow replacement that could be used as a model, there was sufficient information on the contaminant classes (hazards), exposure pathways and human effects to estimate risks using the EnHealth framework. Key findings were as follows:

- membranes vary appreciably in their effectiveness as barriers to pathogens and chemicals depending on nominal pore size, manufacturer, units in series, operational practice, and the contaminant type;
- microfiltration/reverse osmosis treatment under normal operating conditions is expected to reduce pathogens by more than a billion-fold;
- microfiltration/reverse osmosis is less effective at reducing chemicals than pathogens. Large charged organic chemicals would typically be reduced in excess of 1,000-fold, but small neutral molecules and ions may be less effectively reduced, with removals ranging from close to zero up to 1,000-fold. When considering the effectiveness of microfiltration/reverse osmosis treatment it is essential to assess each chemical species individually or on the basis of key attributes (*e.g.* molecule size, charge, hydrophobicity);
- phosphate concentrations should be reduced by reverse osmosis by about 25- to 63-fold;
- dilution at the point of release into the river should further reduce contaminant concentrations under 20^{th} (high) and 80^{th} percentile (low) river flows by 80-fold and 4-fold, respectively assuming negligible background concentrations in ambient water;
- once in the environment further protection to human health would be provided by further dilution, pathogen inactivation, and chemical degradation and partitioning between air, water, and sediments, and additional water treatment where water is extracted for potable uses.

Conclusions

No additional risk from pathogens was identified for the pathways examined from the introduction of highly treated recycled water to the Hawkesbury-Nepean River during effective operation of the microfiltration/reverse osmosis treatment process. Furthermore, due to the conservative worst-case assumptions used in the study, uncertainties related to the pathogen risk assessment were considered unlikely to affect the study outcomes based on:

- direct consumption in recreation would be far less than via the raw drinking water route and thus the latter estimates would identify whether there was a major risk;
- it was unclear if raw mussels are currently consumed by the public;
- normal good hygiene practice requires raw vegetables be withheld before marketing, are washed before consumption and both would provide a large degree of additional protection not accounted for in this study.

In regard to chemicals, no additional risk was identified for the majority of chemicals investigated (108 out of 111 chemicals) from the introduction of the highly treated replacement flows during effective operation of the microfiltration/reverse osmosis treatment process. A marginal risk was calculated for three of the chemicals by one exposure pathway only. This risk is likely to be overestimated, however, given the sensitivities of current detection methodologies. These chemicals were not detected in any of the samples used in the study so the minimum detection limit was used as a conservative estimate in calculations. It is recommended that endocrine disrupting chemicals and disinfection by-products be further investigated due to the uncertain nature of the risk, with the understanding that these risks can largely be managed operationally.

The impact on cyanobacterial risk levels by the implementation of the project was seen as positive based on a reduction in nutrient loads.

Recommendations

It was not seen as a major function of the study to recommend specific management options for the microfiltration/reverse osmosis treatment process. Nevertheless the exposure analysis process identified a number of areas where the suggestion of management options would likely be appropriate and whose significance might be assessed in subsequent studies as a matter of priority.

The microfiltration/reverse osmosis plant should be maintained at a high degree of functionality with any suspected malfunction triggering rapid shut down. This is likely to be feasible because of the modular design of microfiltration/reverse osmosis plants. The total risk should be very small from any such malfunctions but it is recommended that a model of failure modes, their impact, and the detection and management actions triggered should be developed to confirm and aid in the development and testing of system management protocols.

Evidence that shows that microfiltration/reverse osmosis systems are very effective under normal operating conditions already exists. The construction of a small pilot test unit may provide further useful data on the functioning of a full-scale plant, however, it is the affect of failure conditions on risk that needs further investigation. Thus it is considered that testing would be more appropriate on the full-scale constructed system with suspension of its operation when malfunctions are detected and close studies of such malfunctions. Such work could include:

- confirmation of predicted performance;
- confirmation of capacity of failure detection systems;
- challenge testing of seasoned units taken off line;

- challenge testing of an operational part of the treatment train taken off-line, using safe surrogate microorganisms (*e.g.* bacteriophage) and chemicals (*e.g.* fluorescent dyes).

The efficacy of membranes in removal of chemicals under a range of conditions should be investigated at pilot scale to verify the outcomes of the risk assessment. This will assist in optimising the membranes to be used at the full-scale plant and to determine whether any chemicals require further management. This may include specific trade waste and source control options.

Whilst the number and range of chemicals that can be realistically monitored limit chemical screening itself, biological endpoint testing can be included to detect potential impacts from chemicals not considered here or from cumulative impacts from chemicals that may be present at trace concentrations.

Once operational at full scale the highly treated water should be monitored to verify removal to levels based on relevant guideline values and after plant commissioning an ongoing program of testing should be agreed with NSW Health using the guideline values, biological endpoint testing (which in time will cover emerging issues such as EDCs) and compliance with the Australian Drinking Water Guidelines at North Richmond Water Filtration Plant. Some investigation of disinfection by-product formation, removal efficiencies and fate is recommended to further assess the risks.

The operational integrity of the reverse osmosis treatment process can be routinely monitored by standard online measurements, such as salinity and total organic carbon (TOC). The suitability of these criteria for reverse osmosis treatment, however, may be limited by their sensitivity at the very low salinity and TOC concentrations expected for a well-performing reverse osmosis plant. The effectiveness of these (and other suitable) integrity tests should be investigated on an on-going basis. Target operational values should be carefully identified and justified. Furthermore, detailed plans should be developed for operational procedures to be undertaken when the target values are exceeded.

The risk assessment identified sediment (river mud) as a potential exposure pathway, via the dermal route, for some chemicals. This was a calculated risk based on limit of detection concentrations; these three chemicals were not detected in the sewage samples used in the study. It is recommended to undertake a sediment survey following commissioning of the plant to refine the risk assessment outcomes.

A detailed characterisation of exposed populations and relevant uses of water from the Hawkesbury-Nepean River would better inform future risk assessment activities. For example, it would be valuable to determine:

- the actual degree of access to various reaches of the river;
- the populations that extract water from the river for drinking or other purposes without treatment;
- the fishing activities that are undertaken in various reaches of the river;
- the nature and typical frequencies (for individuals) of various recreational activities at the river.

In addition, the assessment of consumption of aquatic biota for chemicals requires further collection of data of the amount and types of fish consumed from the river.

Glossary

Term/Abbreviation	Meaning
ADI	Acceptable daily intake
COPCs	Chemicals of potential concern
CWWT	Centre for Water and Waste Technology
D/S	Downstream
DALYs	Disability Adjusted Life Years, 1 µDALY is 1 millionth of a DALY and suggested WHO benchmark acceptable risk
DR	Decimal reduction value
EDC	Endocrine disrupting chemical
Environmental Flows	Minimum flows of water (by volume and season) necessary to maintain aquatic biota and ecosystem processes (NSW State of the Environment Report)
HACCP	Hazard Analysis of Critical Control Point – Risk assessment system widely used in the food and water industries
Hazardous Events	Defined as "incidents or situations that can potentially contribute to the presence of a hazard" (Nadebaum *et al.* 2004)
Index pathogens	Pathogens selected as being representative of major groups (viruses, bacteria, protozoa), that produces infections typical of the group, are very important members in terms of the extent of potential illness caused and represent worst case for the group.
MF	Microfiltration
NF	Nanofiltration
PDF	Probability Density Function, statistical description of variation
PEC	Predicted environmental concentration
PNEC	Predicted no-effect concentration
QMRA	Quantitative Microbial Risk Assessment
RO	Reverse Osmosis
S_{90}	Total radiation exposure required for 90% reduction in pathogen concentration
STP	Sewage Treatment Plant
T_{90}	Time for 90% reduction in pathogen concentration
UF	Ultrafiltration
WTP	Water Treatment Plant

Limitations Statement

The intended purposes of this report and the associated services performed by the Centre for Water and Waste Technology (CWWT) are to:

1) Provide a literature review for Sydney Water and NSW Department of Health on the microbiological, chemical and cyanobacterial risks to which human populations might be exposed from the release of highly treated recycled water for replacement flows released into the Hawkesbury-Nepean River at Penrith;
2) Using currently available quantitative techniques estimate the risks to populations under a set of selected scenarios reflecting mooted water release strategies; and
3) Provide expert interpretation and opinion on the significance of the risks estimated and whether based on current guidelines and benchmarks the proposed release strategy is compatible with safe human use of the Hawkesbury-Nepean River water.

This report only considers additional risks arising from releases to the river of tertiary treated sewage which has been further treated by microfiltration (MF) and reverse osmosis (RO) under nominal Sewage Treatment Plant (STP) operating conditions (*i.e.* not during STP malfunction when water would not enter the MF-RO plant) all else being equal. This report does not consider risks from pathogens and contaminants entering the river via other pathways *e.g.* from stormwater, agricultural run-off, wading animals, septic tank systems, industrial discharges, spills, bather faecal deposition or other upstream Sewage Treatment Plants.

This report presents data and recommendations indicating that the risks arising from the proposed flow replacement scheme pose only a very low risk to human health. This must not be interpreted however as indicating that the scheme must or should go ahead.

The assessment presented here is considered by the authors to be current best practice. However this is an organisational opinion reflecting the current state of risk assessment and new draft national guidelines rather than official NSW government policy. It should be noted that the discipline of quantitative risk assessment is currently undergoing rapid development as evidenced by the new guidelines.

The report content is not, and should not be considered, an opinion concerning issues not covered by the scope of this report.

This report has been prepared on behalf of and for the exclusive use of the Sydney Water and the NSW Department of Health and is subject to and issued in connection with the provisions of the agreement between CWWT and the Sydney Water. CWWT accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon this report by any third party.

Part A Introduction

1 Background to Study

As part of the Western Sydney Recycled Water Initiative (NSW Metropolitan Water Plan 2006) it has been proposed that tertiary-treated effluent from the Penrith, St. Marys and Quakers Hill sewage treatment plants (STPs) undergo advanced treatment via Microfiltration (MF) and Reverse Osmosis (RO) to produce water suitable for replacing environmental flows to the Hawkesbury-Nepean River (Figure 1-1). As part of the planning process, Sydney Water was requested to undertake a human health risk assessment of the proposed Replacement Flows project.

Sydney Water commissioned the University of New South Wales's Centre for Water and Waste Technology (CWWT) in April 2006 to undertake a desk-top 'risk assessment' on agreed scenarios using quantitative techniques to simulate the impact on human health of releasing highly treated wastewater into the Hawkesbury-Nepean River immediately downstream of the Penrith Weir.

In principle Microfiltration (MF) and Reverse Osmosis (RO) would be applied to undisinfected tertiary sewage. The resulting highly purified water would be used to replace environmental flows in the river downstream (D/S) of the Penrith Sewage Treatment Plant (STP). The flow from the Penrith STP would be supplemented by water from St Marys and Quakers Hil STPs (NSW Government 2006). This highly treated 'replacement' water would be used among other things for replacing environmental flows in the Hawkesbury-Nepean River that would otherwise need to be released from Lake Burragorang and/or other Nepean reservoirs to maintain the River's ecological health (Figure 1-1). Anderson (2006) provides a summary of the issues, needs and options which the proposed project is aimed at supporting, including future water demands in Western Sydney amounting in the case of the agricultural sector to up to 31 Gigalitres per year.

The initially agreed exposure scenarios to be considered were:
1. Consumption of contaminants in raw river water used as a domestic supply for potable purposes;
2. Ingestion of contaminants in river water during primary contact recreation;
3. Consumption of contaminants via vegetables irrigated with river water; and
4. Consumption of contaminants via fish.

Initially primary recreation exposure was taken as accidental ingestion during bathing. It was requested subsequently to expand the exposure analysis to include dermal contact and aerosol inhalation.

The aim of Part A is to outline our approach to risk assessment, in particular the rationale for, and structure of, the 'desk-top' risk assessment undertaken. Parts B, C and D then present the results of the assessments undertaken for pathogens, chemicals and cyanobacteria respectively. The approaches for the different contaminant groups differ somewhat reflecting different methodologies, relevant pathways and available data. In each instance we have:
1. Undertaken a brief literature review and collated relevant local data with a view to hazard identification, and dose-response assessment;
2. Used this data to undertake exposure assessment so as to generate quantitative estimates of risk to which human populations could be exposed; and
3. Based on the exposure assessment developed a (provisional) risk characterisation.

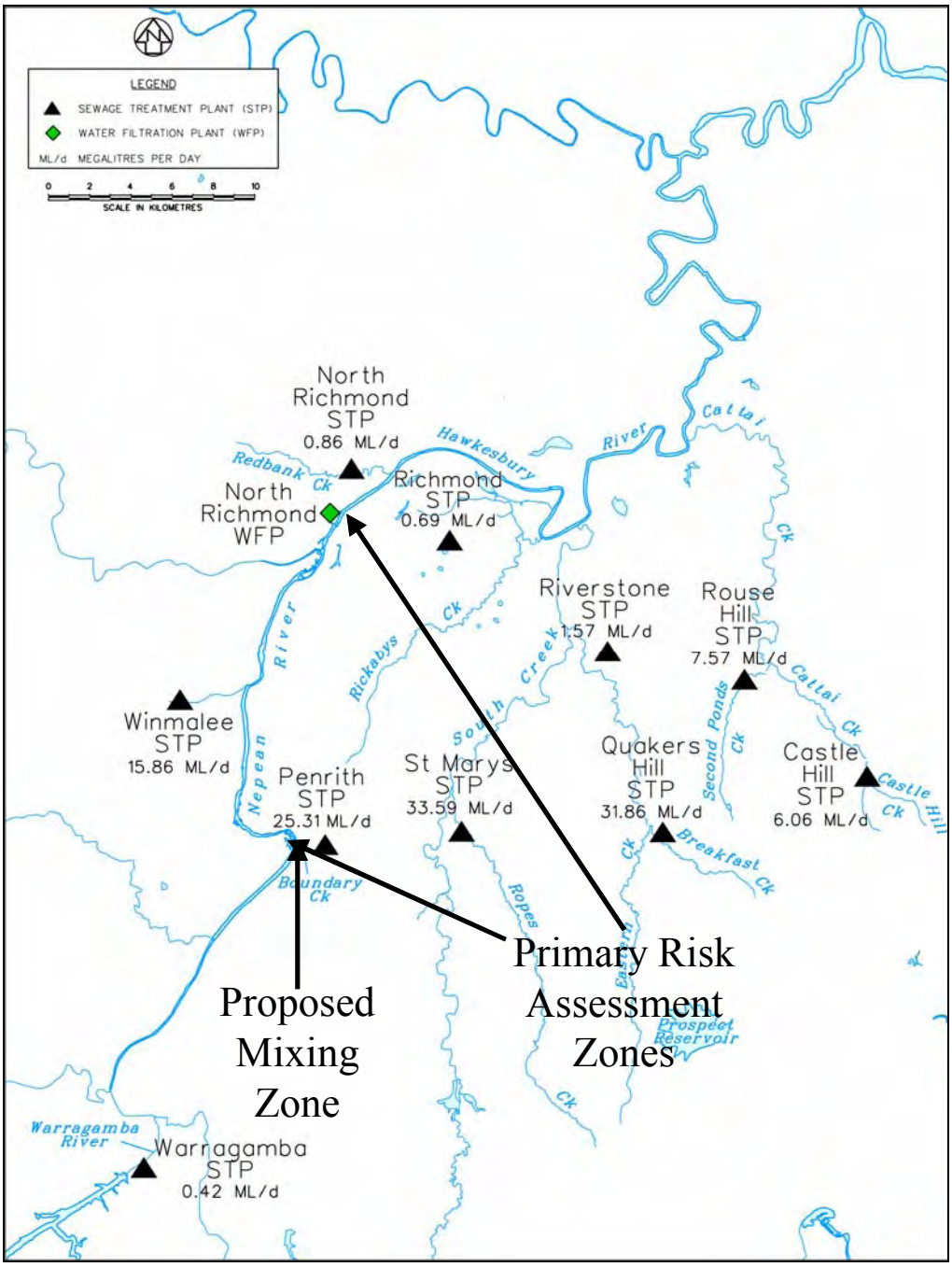


Figure 1-1. Middle Reaches of the Hawkesbury-Nepean River showing the location of the main STPs, the proposed mixing zone and the main locations used for risk assessment calculation

2 Assessment Guidelines and Criteria, and Report Structure

The primary exposure pathways of concern identified conceptually at the project's inception were those leading to direct consumption of replacement flow water from the river downstream of the proposed point of introduction of the replacement water stream. The most likely mechanism of exposure was seen as accidental ingestion as a result of primary contact recreation.

Accordingly in the risk assessment project plan submitted to, and agreed with, by Sydney Water in consultation with NSW Department of Health it was proposed to base the risk assessment primarily on the following three documents, with others such as ANZECC/ARMCANZ (2000) and USEPA(1989) being used as supporting sources:

1. The new NH&MRC (2005) recreational water guidelines;
2. The draft NH&MRC/NRMMC (2005) guidelines for safe reuse of water;
3. The CRC for Water Quality and Treatment's "A Guide To Hazard Identification and Risk Assessment For Drinking Water Supplies" (Nadebaum *et al.* 2004) developed in support of the Australian Drinking Water Guidelines (NWQMS, 2004) new focus on risk assessment and management.

These were proposed because:

1. They considered the proposed water use (recycling) and the main impact situation (primary recreation), and consumption as the exposure mode of most concern;
2. Being recent, their guideline targets would be most up to date; and
3. CWWT had been involved in the development of the first two guidelines and was most familiar with their application issues.

A general project structure was proposed and undertaken by CWWT-UNSW in line with the tender from Sydney Water. Its main features were to be:

1. Development of a refined study design for consideration by Sydney Water;
2. A literature review of source water quality, barriers, exposure pathways and receptors and a collation of local literature data for the Western Sydney Sewage Treatment plants;
3. Assessment to be focused on 3 to 4 'index' pathogens present in sewage and range of toxic chemicals reported in sewage, particularly 'Schedule 10' chemicals identified in a previous Sydney Water risk assessment. The cyanobacterial toxin risk assessment method remained to be developed but it was initially proposed to be based on the increase in the risk of blooms;
4. Risks to be estimated for pathogens and toxic chemicals primarily, and cyanobacteria as a secondary factor, at a number of key points along the river representing the most likely exposure points or zones between Penrith Weir and Wisemans Ferry;
5. Risks to be calculated as required *i.e.* the risk from a pathway in a high risk upstream zone can serve as a conservative risk estimate for a point further downstream so unless there is good reason no further quantitative risk estimation is required for mooted exposure assessment points further down river; and
6. Calculation of risks based on the advice in the above guidelines and other relevant approaches documented in the literature, and the interpretation of risk estimates in terms of broader acceptability of the proposed scheme.

Following an initial review, an additional pair of primary guideline documents was identified (EnHealth 2001; EnHealth Council, 2002), which it was proposed, should inform the

structure of the assessment. As a result the assessment's format has been altered from the first draft above. This reorganisation did not reflect any change in the substance of the approach undertaken but only a change in format.

As a result the revised draft report (this document) now incorporates features of each of five key guideline documents. The remainder of this Part (A) outlines the five **key** risk assessment documents (Section 2) and the Study Design (Section 3) developed using these documents as guides and other secondary guideline information as appropriate. For example where an Australian guidelines value for a toxic chemical was not available, a WHO or US EPA value might be used.

Whereas the original report considered all contaminants together, now pathogens, chemicals and cyanobacterial toxins have been separated into Parts B, C, and D respectively, with each Part being divided into the following headings as far as practical:

- Issue Identification;
- Hazard Identification divided into:
    - Hazard Assessment (equivalent to first part of literature review and local data collation); and
    - Dose-Response Assessment (equivalent to final section of literature review);
- Exposure Assessment (equivalent to the method description in the previous risk estimation step);
- Risk Characterisation (equivalent to previous risk estimation process outputs and data interpretation section);
- Uncertainties (identify in the above four assessment steps and arising in the course of assessment as a whole); and
- Management (Discussion and Recommendations) (The issues considered did not cover the whole of the replacement water project but only issues relating to risk management which address Uncertainties *e.g.* data gaps, limitations in the risk estimates provided).

2.1 NH&MRC (2005) Recreational Water Guidelines

The new Guidelines for Managing Risks in Recreational Water (NH&MRC, 2005) provide a risk-management approach for the development of legislation and standards to ensure that recreational water environments are managed as safely as possible. The guidelines aim to promote the protection of protect human health from threats posed by the recreational use of coastal, estuarine and fresh waters, such as natural and artificial hazards. It is extensively based on recent WHO (2003) guidelines and includes guidance on the management of risk from pathogens, toxic chemicals and cyanobacteria arising from primary contact recreation. Summary download document information is as follows:

- Published year: 2005
- Available in print: No
- Status: 2nd edition in prep: http://www.nhmrc.gov.au/publications/synopses/eh38.htm
- Reference No: EH38

Further background information can be obtained from: nhmrc.publications@nhmrc.gov.au.

The new Guidelines for Managing Risks in Recreational Water was endorsed by Council in June 2005, released in September 2005 and the first edition was used in the present study. A

2nd edition is currently being reprinted to correct inconsistencies that appeared in the 1st edition. The expected timeframe for the release of the revised Guidelines for Managing Risks in Recreational Water is December 2006. It is understood that these changes are minor typographical ones and do not affect any substantial aspect of this assessment.

2.2 Draft Recycled Water Guidelines (NH&MRC/NRMMC, 2005)

There is considerable pressure to increase water recycling to cope with ongoing drought and increasing demand for water. Water recycling programs are being developed by all jurisdictions as key elements of integrated water cycle management. Recycling, particularly substitution for non-drinking water uses of potable water, is seen as critical to effectively managing demand and deferring expensive new infrastructure.

Consequently, the Environment Protection and Heritage Council and the Natural Resource Management Ministerial Council initiated the development of national guidelines for water recycling. The guidelines comprise a risk management framework and specific guidance on managing the health risks and the environmental risks associated with the use of recycled water. The guidelines initially focus on:

- large-scale treated sewage and grey-water to be used for:
    - residential garden watering, car washing, toilet flushing and clothes washing;
    - irrigation for urban recreational and open space, and agriculture and horticulture;
    - fire protection and fire fighting systems;
    - industrial uses, including cooling water; and
- grey-water treated on-site (including in high rise apartments and office blocks) for use for garden watering, car washing, toilet flushing and clothes washing.

Phase two of guideline development, which commence in 2006, will focus on stormwater reuse, aquifer storage and recovery and indirect potable reuse as methods for recycling reclaimed water.

The release of the draft set of guidelines gives organisations and individuals the opportunity to be informed about the guideline development process and to provide comment that can be taken into account prior to their finalisation. The purpose of the document is to provide guidelines for assessing risk (rather than to provide a 'how to' manual for water recycling), and a particular focus will be placed on obtaining feedback from the public consultation process as to the utility of the guidelines for different types of users.

(text above reproduced largely from http://www.ephc.gov.au/ephc/water_recycling.html)

2.3 Drinking Water Risk Assessment Guide (Nadebaum et al. 2004)

The Cooperative Research Centre for Water Quality and Treatment, in collaboration with the National Health and Medical Research Council/Natural Resource Management Ministerial Council (NH&MRC/NRMMC) and key stakeholders, developed a Framework for Management of Drinking Water Quality (the Framework) for incorporation into the Australian Drinking Water Guidelines most recent revisions (Nadebaum *et al.* 2004). The Framework promotes increased awareness of a comprehensive preventive strategy for drinking water quality management based on quality and risk management principles. It provides guidance on a proactive approach for minimising health risk in water supply

systems and provides greater attention and better measures of control for system management, extending from the catchment to the consumer.

The Framework was developed as a quality management approach designed specifically for drinking water systems and addressed several elements considered good practice in system management of drinking water supplies. A key feature of the Framework is system analysis and system management. This involves understanding the entire water supply system, the hazards and events that can compromise drinking water quality, and the preventive measures and operational control necessary for assuring safe and reliable drinking water.

This CRC document is intended to provide water authorities and other organisations with guidance which will assist in their assessment and management of risks to drinking water quality, with particular emphasis on conducting hazard identification and risk assessment. Preventive measures and management strategies necessary for controlling hazards are also highlighted. Additional information and guidance on the Framework are provided in the current revisions to the Australian Drinking Water Guidelines. This document includes:

- a methodology for conducting hazard identification and risk assessment;
- checklists of common sources of hazards to water quality and hazardous events;
- hazard fact sheets outlining issues associated with common sources and hazardous events, and possible preventive measures for managing the risk;
- various case studies to illustrate consequences from unforeseen and rare events; and
- a summary of hazards to assist understanding of the various contaminants that may be found in drinking water.

The assessment process is summarised in Figure 2-1. The text above was largely reproduced from Nadebaum *et al.* (2004). An issue raised briefly in the recreation guidelines but considered at length in the CRC guide is the issue of 'Hazardous Events' and periods of elevated risk. This has very important implications for risk quantification as it indicates that risk will vary greatly for a given situation depending on circumstances adding to the complexity of assessments.

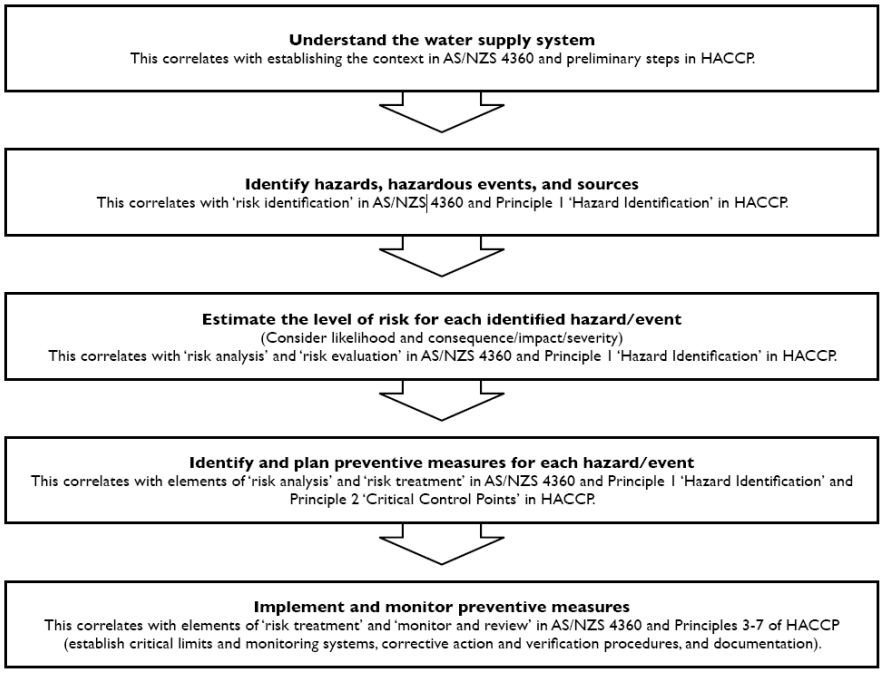


Figure 2-1. Water Supply Risk Assessment (reproduced from Nadebaum *et al.* 2004)

2.4 Health Impact Assessment Guidelines (Enhealth, 2001)

Health Impact Assessment (HIA) is a process that systematically identifies, and examines, in a balanced way, both the potential positive and negative health impacts of an activity.

The Enhealth (2001) guidelines specifically address the use of HIA when conducting Environmental Impact Assessment, further developing the National Health and Medical Research Council National Framework for Environmental and Health Impact Assessment in the light of experience in implementing HIA in Australia and overseas. In this planning context the outcomes of HIA provide a starting point for efforts to maximise positive health impacts and prevent or minimise negative impacts. Rectifying problems during planning is usually the preferred approach; rather than having to deal with them once a development is under construction or in place.

A summary of the process is shown in Figure 2-2. The text in this section is largely reproduced from Enhealth (2001).

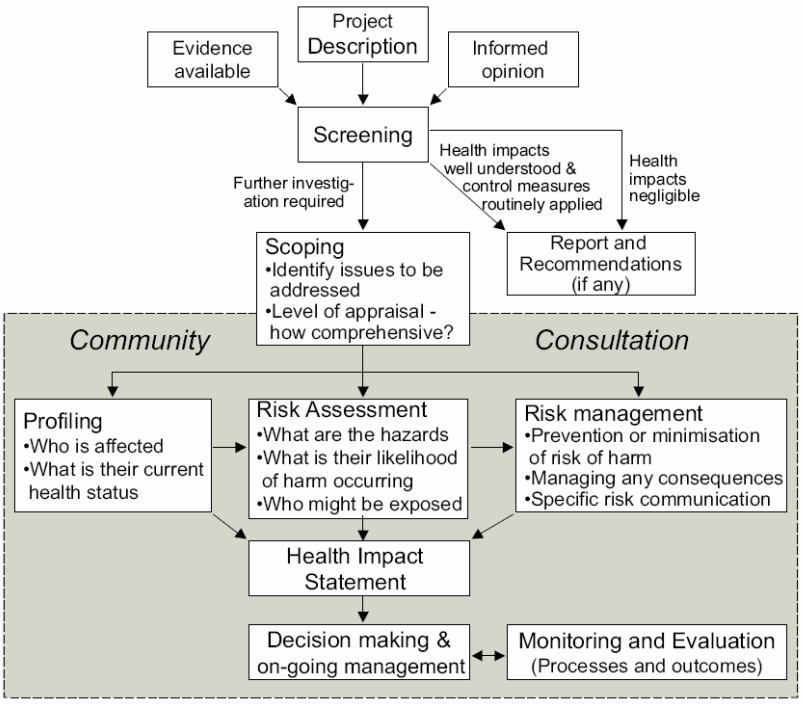


Figure 2-2. HIA Process Framework (reproduced from Enhealth, 2001)

2.5 Health Risk Assessment Guidelines (EnHealth Council 2002)

Risk assessment is the process of estimating the potential impact of a chemical, physical, microbiological or psychosocial hazard on a specified human population or ecological system under a specific set of conditions and for a certain timeframe.

Risk assessment is intended 'to provide complete information to risk managers, specifically policymakers and regulators, so that the best possible decisions are made'. There are uncertainties related to risk assessment and it is important to make the best possible use of available information.

This document provides extensive guidance on how risk assessment might be done in practice. Although the guidelines were developed principally with chemicals in mind many aspects are in theory applicable to pathogens and cyanobacteria. A summary of the recommended HRA process is shown in Figure 2-3. The text in this section is largely reproduced from EnHealth Council (2002) guidelines.

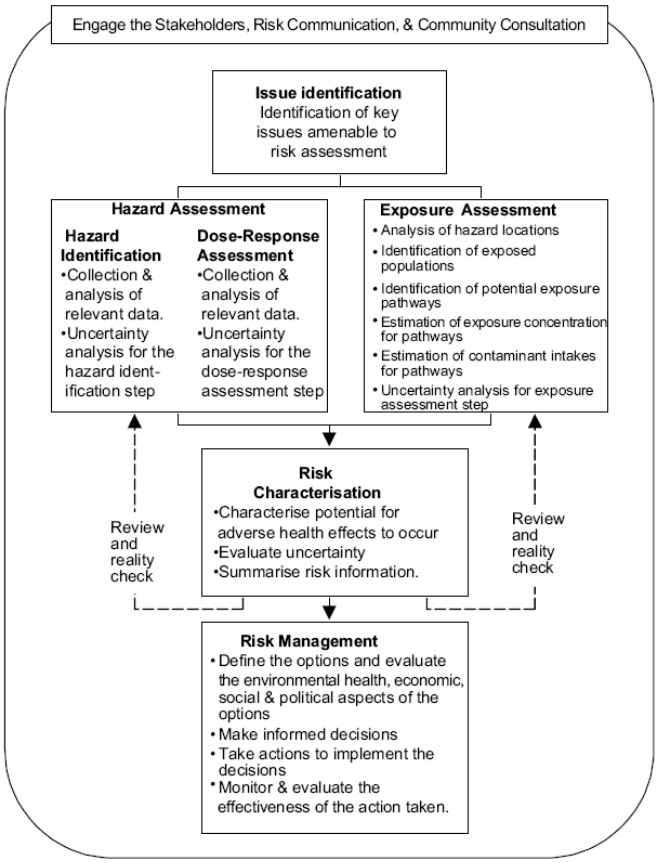


Figure 2-3. Risk Assessment Model Proposed in and Reproduced from EnHealth Council (2002)

3 Study Design

3.1 Assessment Scale and Boundaries

The risk guidelines above document a large range of assessments and activities, which might be undertaken in the present instance. And, as with Environmental Impact Assessment, the potential scale of these assessments ranges from cursory qualitative assessment to a full quantitative Health Impact Assessment.

The scale of Environmental Impact Assessment undertaken with EISs in NSW is controlled to a large extent by detailed rules set out in legal instruments such as the Environmental Planning and Assessment Act regulations. But as yet no mandatory regulations on when a full HIA should be triggered exist in NSW and what should be its contents. The EnHealth Council (2002 pg. viii) guidelines recognise the complexity for practitioners of HIA and HRA application in stating:

> "Due to the complexity and scale of the environmental health risk assessment process a concise 'cookbook' is not practicable. Similarly, the situation-specific issues are often sufficiently complex and 'situation-specific' that a manageable and complete algorithm for decision-making cannot be drafted; the document provides a series of guidelines and checklists to assist the decision-making process."

They also recognise (EnHealth Council 2002 pg. xiv) the need to not undertake excessive or unnecessary risk assessment:

> "In many instances, situation-specific health risk assessments may not be necessary as the nature and magnitude of the risks will be quite apparent, there may be no population at risk, or decisions on risk management may be made on other grounds. In such cases, the significant resources required for a detailed risk assessment would be better directed to risk management steps".

Thus it was essential to set clear boundaries, scale and aims on the current assessment. In determining these both the positive aspects of the project and uncertainties needed to be considered. No clear health related negatives were identifiable from initial consideration of the flow replacement scheme concept.

On the positive side the proposal would be expected to greatly enhance the quality of Western's Sydney's treated wastewater prior to it being released into the environment. And the water was expected to be notionally of a water quality sufficient for drinking as evidenced particularly by Singapore 'NEWater' which uses similar feedwater (*i.e.* treated sewage) and treatment technology.

There were however sources of uncertainty. No quantitative risk estimates were available where highly treated sewage had been used to replace surface water environmental flows, which could be used to inform opinion in a qualitative assessment. While reverse osmosis (RO) and microfiltration (MF) to a lesser extent can be very effective treatment barriers, the final risk to which humans could be exposed would be dependent not only on these barrier but the composition of the feedwater and other downstream barriers, all of which required local assessment. The drinking water risk assessment guide highlighted the need to understand hazardous events when assessing risk. But no information was readily available on failure rates and modes for the proposed MF-RO plant. Finally there are now documented

public concerns about the risks from water reuse in Australia and overseas which indicate the need for auditable risk estimates, additional to 'expert opinion', even if these estimates show that there are no risks of significance.

These positive aspects and uncertainties were discussed between CWWT-UNSW, Sydney Water and NSW Health with a view to determining the appropriate scale of risk assessment required, the risks to be assessed and the style of risk assessment. It was agreed there were no apparent major risks sufficient to immediately justify a study equivalent to a full Health Impact Assessment. But also there were too many uncertainties to rely on a simple qualitative assessment especially in light of the proposal's scale (31 Gigalitres per year).

So it was decided to undertake a 'desk-top' investigation *i.e.* quantitatively estimate risks likely to arise using only existing local historical and literature data. This was consistent with the following advice and principles in guidelines:

1. The recreational water guidelines (NH&MRC, 2005) propose before any large-scale assessment is undertaken that historical data is evaluated to identify data available and data gaps. This should lead to a 'Provisional' assessment, which may or may not indicate further action is warranted.
2. The drinking water risk assessment guide (Nadebaum *et al.* 2004) highlighted the range of risks, which might be considered, and implicitly a need to prioritise from the range of risks possible.
3. EnHealth Council (2002 pg. xii) suggests "A preliminary situation-specific risk assessment can be undertaken by choosing to apply environmental Health criteria, which are derived using risk assessment techniques and can be applied generically to a range of situations."
4. The Enhealth (2001) document identifies a 'Screening Stage' (Figure 2-2, Appendix 3) before full HIA is undertaken to determine the level of assessment (rapid, intermediate, comprehensive).

Such "Screening for health issues...is usually, if not invariably, undertaken by the agency responsible for determining whether a development needs to be assessed, and if so, to what extent."(Enhealth, 2001; Section 3.1.3). A model tool developed in the United Kingdom for the 'Screening Stage' of HIA is reproduced in Appendix 3 of the Enhealth (2001) document.

It was in support of auditable screening that our 'Desktop' assessment was designed (Figure 3-1). The rationale was that in order to undertake screening it is first essential to address three precursor steps, that is 'assemble available evidence', develop 'a project description' suited to risk assessment and provide a framework for 'informed opinion'. A quantitative rather than qualitative assessment was seen as preferable because:

- The data available for the key risk concerns (pathogens, chemicals, cyanobacterial blooms) was not yet in a form suited to 'Screening' but could be after further data analysis and processing;
- While the project was focused on reverse osmosis, project risk needed to describe and consider the wider context and synergisms. Analysis of contaminant exposure pathways using quantitative techniques was seen as a rational way to do this as the impacts were localised to a definable stretch of the Hawkesbury-Nepean River; and
- As deliberate 'flow replacement' is novel there is no specific case study that could be used as the basis of 'informed opinion'. However reasonable data was judged to exist on the major contaminant sources, pathways and receptors as well as methods for

integrating this information. So it was felt that opinion could be reasonably well informed by a Desk-top assessment.

The main limitation was that a Desktop assessment would not permit all tasks associated with a full health risk assessment to be undertaken. So only assessments of those risks of concern and amenable to consideration from a 'tight perspective' (Table 1 Enhealth, 2001) and amenable to quantitative interpretation and auditing were undertaken (Figure 3-2). This was seen as reasonable as there was only limited time to consult with the community, risk management was more appropriate to develop after Screening had been completed, and 'Reality Checking' would be difficult as no new data was to be collected.

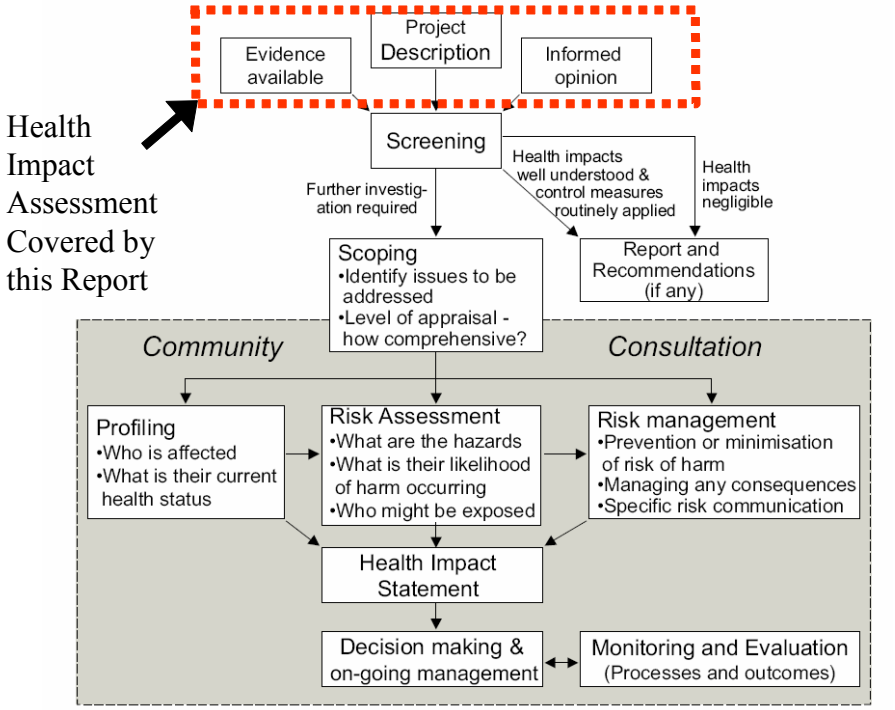


Figure 3-1. Location of the present study

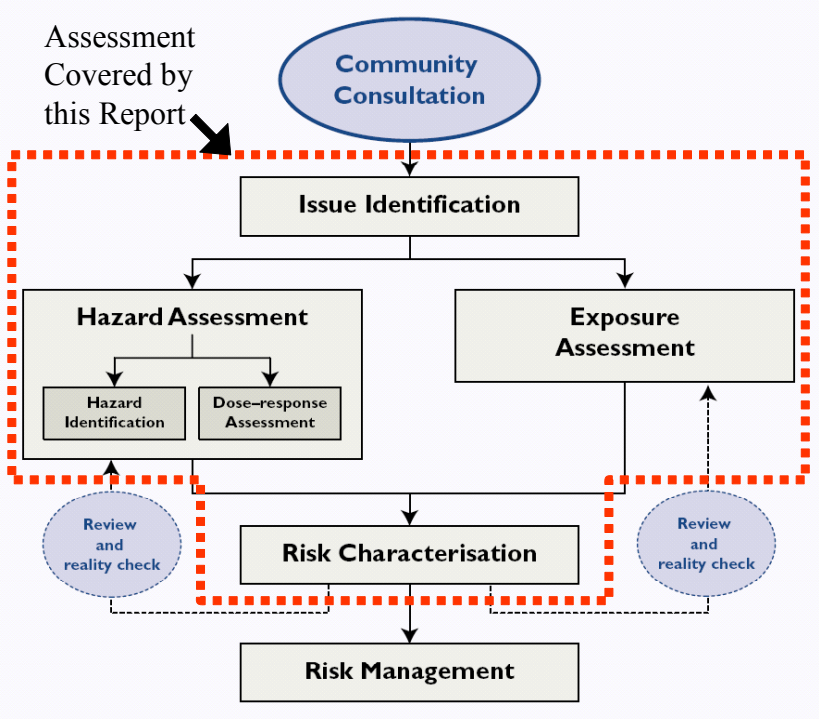


Figure 3-2. Portion of Full Risk Assessment Process Undertaken in this Provisional Assessment

3.2 Applying the (DeskTop) Risk Assessment Model

The report has been divided into four Parts, this introduction (Part A) and three (Parts B, C and D) corresponding respectively to assessments for pathogens, chemicals and cyanobacterial bloom/toxin risks. Each of these parts has been in turn divided into 4 major sections corresponding to Issue Identification, Hazard Assessment, Exposure Assessment and Risk Characterisation. This section introduces and outlines what was done in each of the four sections.

While Risk Management was not considered specifically, each of the three contaminant group risk assessments was structured to inform and support risk management decisions. And the risk modelling has been fully documented so that subsequent 'reality testing' can be undertaken as is appropriate.

Quantifying all risks from all possible exposure pathways to all possible risk agents at all points along the river under all possible circumstances was logistically impossible within this study. So to make the task manageable while ensuring that the risk estimates were still credible and assessments well targeted, the following strategy summarised in Table 3-1 was developed.

Table 3-1. Summary of Data Collation and Scenario Modelling Tasks

Step	Applies
1. Identify major exposure pathways	Generally
2. Identify a limited number of representative 'index pathogens' for which to estimate risks	To Pathogens
3. Develop a reference toxic chemical list	To Chemicals
4. Identify and quantitatively define source contaminants, the performance of each barrier and (human) receptor responses (termed from here Source/Barrier/Response probability density functions)	Generally
5. Undertake screening assessment and develop a list of Chemicals of Potential Concern	To Chemicals
6. Cross match each index pathogen to barrier performance data	To Pathogens
7. Cross match each toxic chemical to barrier performance data (may be done later if this is more efficient)	To Chemicals
8. Identify representative or high priority exposure points	Generally
9. Identify: a. Source/Barrier/Response probability density functions representing Nominal (*i.e.* baseline) risk conditions, and b. conservative elevated risk conditions particularly those associated with credible Hazardous Events.	Generally
10. Identify from Literature Dose-Response Relationships	Generally
11. By comparing Nominal and Hazardous Event Source/Barrier/Response probability density functions (if necessary using sensitivity analysis) identify critical barriers whose failure or suboptimal effectiveness would most tend to maximise risk	Generally
12. Construct credible Hazardous Event scenarios (*i.e.* identify the Hazardous Event PDF and the frequency with which these conditions might occur)	Generally
13. Starting with the worst case exposure pathway and Nominal representative scenario(s) (*e.g.* different flow conditions) identify those scenarios where risk may be a concern	Generally
14. Construct and model these worst case scenarios and compare to Benchmarks	Generally
15. Repeat including the Hazardous Event	Generally
16. Develop Nominal scenarios for other exposure pathways using the worst exposure pathway scenario as a model	Generally
17. Working downstream repeat the exposure pathway assessment cycle with each other station	Generally
18. Under special high concern risk assessments (*e.g.* exposure of reticulated water consumers)	Generally
19. Tabulate major risk estimates	Generally
20. Identify stations where the benchmarks may be exceeded and hence the boundary between zones of benchmark exceedence and zones of no exceedence	Generally

Notes:

1. Most of these tasks were undertaken in Part A of this report.
2. Probability Density Functions include Point values including modal and maximum values.

3.2.1 Issue Identification - Qualitative Risk Assessment

The generic risks considered in this study are those which were identified in a provisional qualitative risk assessment at the project's commencement. This assessment identified:

1. Priority contaminant classes (water borne pathogens, toxic chemicals and cyanobacterial toxins);
2. Exposure pathways; and
3. 'Stations' along the River representing zones where risks might be estimated.

Of the three contaminant classes, pathogens and toxic chemicals were considered the most important as the qualitative assessment suggested that the attributes of the replacement water should be such that cyanobacterial blooms would not be significantly promoted.

Five general exposure pathways were identified for consideration. In order of likelihood they were:

1. Exposure from Primary or Secondary Recreation Contact;
2. Consumption in public reticulated water;
3. Consumption through raw irrigated vegetables;
4. Consumption of untreated water through private water supply; and
5. Consumption through eating of raw fish and bivalves.

The chemical risk assessment considered inhalation and dermal contact as part of the recreation contract assessment. The microbial risk assessment did not consider aerosols in detail, as the risk was perceived as not being a concern. The rationale for this is presented in Uncertainty section 8.3.2.

Estimation of all risks at all points along the river for all contaminants was logistically impractical and was not seen as necessary given the 'Screening' nature of the assessment. So to efficiently but conservatively identify likely risks, the scenario of "direct consumption through an untreated private water supply immediately downstream of Penrith", though unlikely, was assessed first *i.e.* the pathway having the greatest potential Impact or Consequence though not necessarily posing the highest Likelihood or overall risk.

The provisional risks levels taken for prioritising work were:

- Pathogens – low to moderate;
- Chemicals – low to moderate; and
- Cyanobacterial toxins – low.

Thus most of the risk assessment focused on pathogens and chemicals. There is no quantitative methodology, which could be applied, in the present instance for assessing the risk from cyanobacterial toxins. So the likelihood of increased incidence of cyanobacterial blooms was assessed based on the NH&MRC (2005) Recreation Guidelines.

3.2.2 Hazard Assessment

Initial examination of the literature and local data (Hazard Identification) showed that the use of recycled water for replacement of surface water environmental flows is a novel reuse application and there are no direct precedents which have been fully assessed using modern risk assessment techniques. However, there was sufficient information on the contaminant classes, exposure pathways and receptors to quantitatively estimate risks. The review summarised primarily information relevant the risk assessment processes (Table 3-2). The data was used then in exposure assessments. Dose-Response literature was collected as part of the literature review.

Recognition of Uncertainty was built into the assessment in a range of ways *e.g.*:

- Worst-case exposures (*i.e.* at Penrith Weir) were assessed first. (The rationale here was that if the worst case (*i.e.* upstream) exposures proved to have relatively low risk, when compared to literature benchmarks, there was little point in further estimation of risks downstream where these would be comparable or less.);
- A number of index pathogens with markedly different inactivation characteristics were modeled and compared;
- Data source concentrations and parametric descriptors of each pathway included measures of variability where available;

- Each exposure pathway class was used to develop a number of exposure scenarios.
- A range of Dose-response relationships were identified and compared.

Table 3-2. Material Covered In Literature Review

Section	Material Covered
1. Introduction / Background	• Barriers and Exposure Pathways • Quantitative Microbial Risk Assessment • NH&MRC Recreation guidelines • Chemical Risk Assessment • (Enhealth guidelines)
2. Source material composition	• Contaminant concentration in Western Sydney STPs • Contaminant concentrations in secondary and tertiary treated effluent
3. Efficacy of MF-RO Treatment	• Pathogen and chemical concentrations in tertiary-treated effluent of the type from Penrith and other Western Sydney STPs supplemented by North American and European literature. • Percent reductions in pathogen concentrations by reverse osmosis • Removal by and breakdown of reverse osmosis process.
4. Fate of pathogens in rivers after flow replacement	• Transport velocity • Inactivation kinetics – pathogens and indicators in freshwater • Entrainment in sediment and resuspension
5. Fate of chemical contaminants in rivers after flow replacement	• Environmental partitioning (*e.g.* volatilisation, sedimentation, accumulation in soil and biota which may be directly or subsequently consumed) • Environmental degradation
6. Human Exposure Consumption, and Response	• Water quantity consumed via different pathways • Dose-response (infection, illness) • Toxicity and carcinogenicity • Risk benchmarks

3.2.3 Exposure Assessment

Risks were estimated quantitatively assuming that the barrier concept (Figure 3-3) applied. Different populations of consumers were estimated to be exposed to a quantity or load of contaminants based on:

1. Contaminant concentration in the initial waste stream;
2. Subsequent reduction of contaminant concentration;
    a. following dilution of replacement flows in receiving waters; and
    b. due to their interaction with various barriers, the principle of which are:
        i. Treatment processes such as membrane and chlorination filtration;
        ii. Inactivation or immobilisation by natural processes such as sunlight, volatilisation and sedimentation;
        iii. The total loads individuals are exposed to *e.g.* due to the varying quantity of water consumed;
3. Final consumption of quantities of water characteristic of the pathway.

In the case of the proposed replacement flow scheme a range of general exposure pathways were identified (Figure 3-4) and these have been used to construct a general set of exposure pathways for the Hawkesbury-Nepean River (Figure 3-5).

Hazard locations and exposed populations were identified through the process of exposure pathway construction. Exposure concentrations and contaminant intakes were estimated as point estimates and where appropriate probability density functions.

The model populations considered for risk modeling were those people:

- Ingesting (or being exposed by dermal contact or via aerosols) to untreated water as a result of primary recreation or (less likely) through consumption of untreated water for potable purposes;
- Consuming treated river water from the North Richmond Water Treatment Plant; and
- Consuming vegetables or shellfish (pathogens only) irrigated with river water.

Modelling assumed consumption took place at varying points along the river. Initially it was proposed to assess consumption primarily at the Penrith Weir, North Richmond, Windsor, Sackville, and Wiseman's Ferry and at points in between if appropriate given the model parameters.

Uncertainty was addressed by estimation of risks for a range of scenarios.

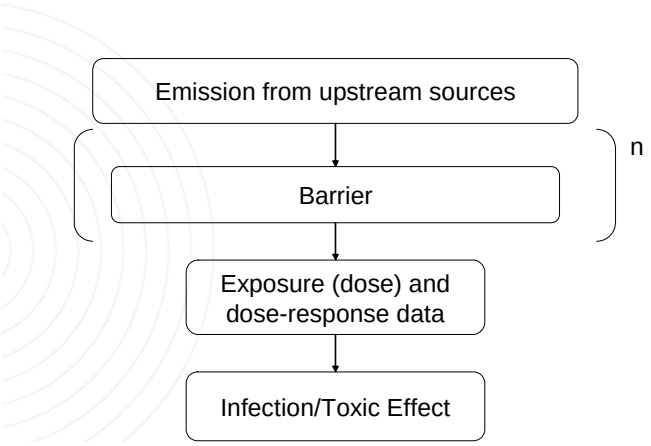


Figure 3-3. General Source/Barrier/Exposure Model

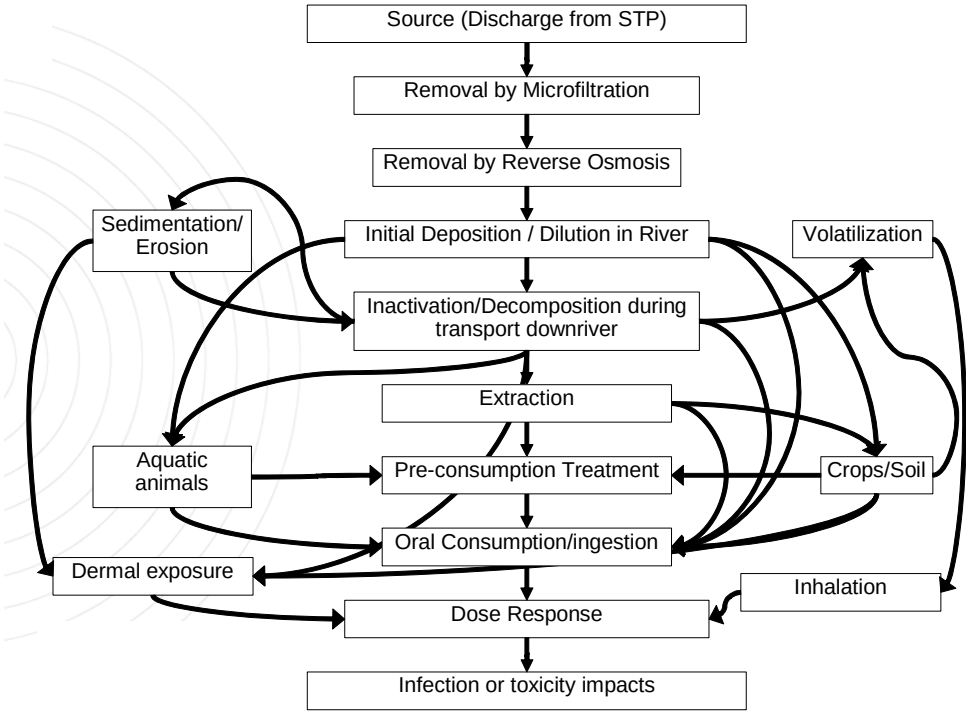


Figure 3-4. Summary of exposure pathways identified

Note: Chlorination effects are not considered as the extent of chlorination or chloramination to be undertaken is unclear.

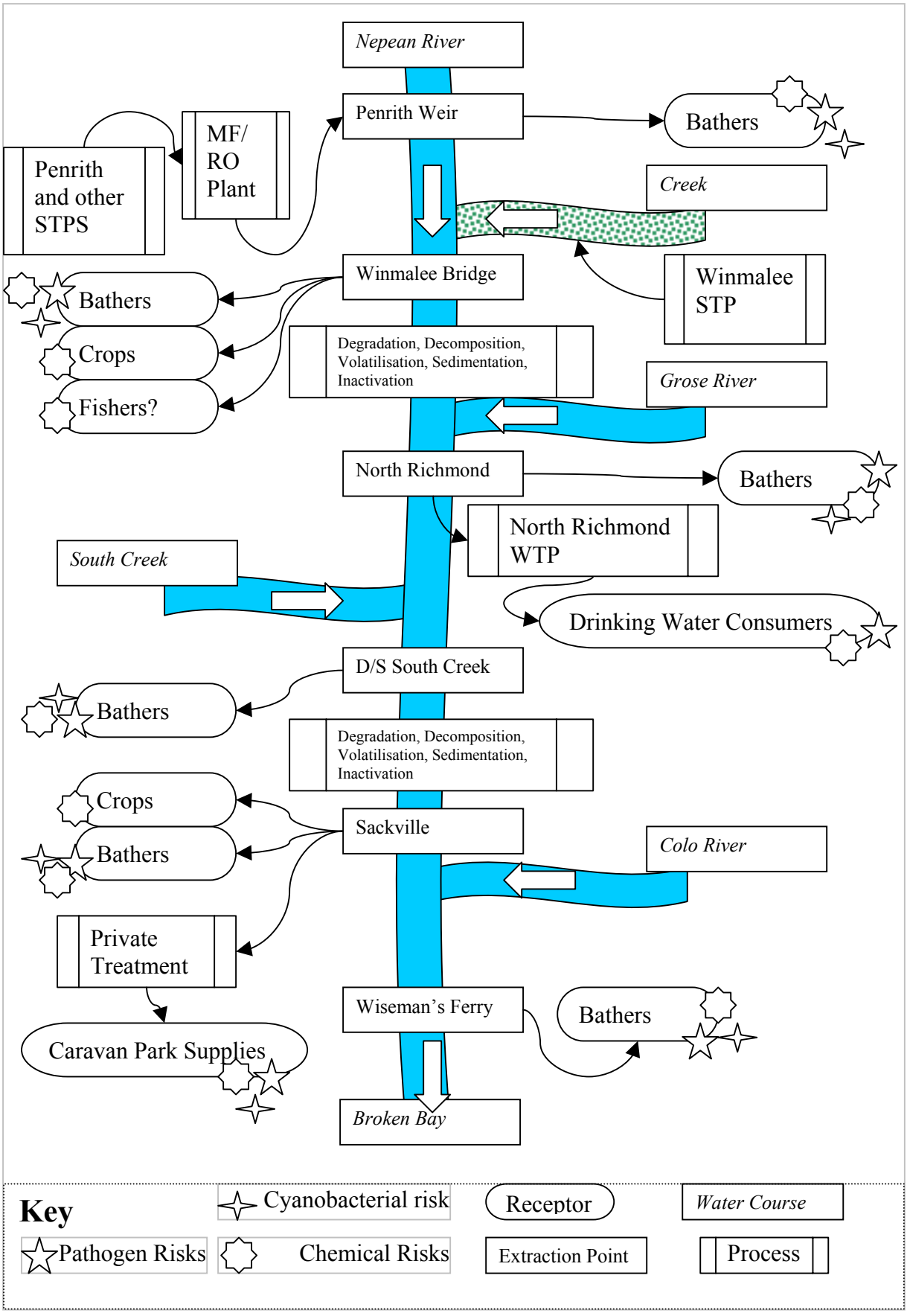


Figure 3-5. Conceptual Model of Likely HN Risk Exposure Pathways

3.2.4 Risk Characterisation

The sensitivity of populations to the pathogen loads they are exposed to, was estimated in terms of :

- the probability of infection and disease severity expressed in μDALYs for pathogens;
- acute toxicity and cancer potential for chemicals.

These characterisation steps provided 'absolute' risk estimates for different scenarios which could be compared to 'Benchmark' values usually taken as 'no adverse effect levels'. In this way scenarios of concern could be identified. In the case of cyanobacteria it was only possible to assess relative risk *i.e.* whether risk was likely to increase compared to present conditions.

Overall risks were assessed by cross matching Risk Estimates for each different scenario and exposure class with the Likelihood of the scenario and exposure class to generate overall risk ratings and conclusions. Where appropriate this information was summarised in table format for each different class and scenario for pathogens and chemicals.

3.3 Quantification of Risk

3.3.1 Microbial Risk Assessment

Quantitative microbial risk assessment was undertaken based on the modeling principles detailed by Haas *et al.* (1999), general Water Safety Plan and risk assessment principles described in WHO (2001) and national guidelines (National Water Quality Management Strategy, 2004) and techniques developed through the EU MicroRisk Project (Medema *et al.*, 2006).

There are many pathogens whose infection rates might be considered (see Haas and Eisenberg, 2001) so it was decided that the pathogen risk analysis should be focused on three 'index pathogens' representing the three major gastrointestinal illness causing agent groups:

- *Cryptosporidium* representing parasitic protozoa
- *Campylobacter* representing bacterial pathogens
- Rotavirus representing waterborne viruses.

All three pathogens are known to be present in the sewage of developed countries, and have a low dose-response relationship (*i.e.* these pathogens are highly infectious). Accordingly review data were collected with these three in mind. Other pathogen and indicator data are included to illustrate where these index pathogens sit within the range of microbial agents in respect to such attributes as their abundance in wastewater, survival in the environment and infectivity.

In addition the residual loads of enterococci contributed by replacement water release were estimated to determine whether such water release would be likely to increase the concentrations of indicators to a point where the recreational water microbial class (NH&MRC 2005) is likely to change.

3.3.2 Chemical Risk Assessment

The chemical hazard assessment process was comprised of two main activities. These are 'hazard identification' and 'dose-response assessment' in line with the EnHealth Council (2002) guidelines.

The hazard identification was approached by the collection and analysis of relevant local data. The principal available relevant data was that acquired by sewage treatment effluent monitoring undertaken by Sydney Water. This data, known as "Schedule 10 data" consists of 111 organic and inorganic chemical parameters. Schedule 10 data were combined for the three relevant sewage treatment plants (Penrith STP, Quakers Hill STP and St Marys STP) for the years 2000-2004. This provided a minimum of 25 data points for each of the 111 chemical parameters.

Since a significant proportion of the monitoring results were below analytical detection limits, considerable uncertainty was inherent. As a consequence, most calculations were undertaken using 95th percentile concentrations (the concentration greater than 95% of the data points) as considerably more conservative figures than the concentrations means.

A number of chemicals were also assessed that are not included in the Schedule 10 list and included some that could potentially form within the advanced water treatment plant. These were selected based on the recognised public concerns for some chemicals (endocrine disrupting chemicals, EDCs) and the potential for formation during the advanced treatment process (disinfection and biofouling control by-products – NDMA and halogenated organics).

Discussion of the potential removal of the chemical hazards during the advanced water treatment process concludes the hazard identification.

Dose-response assessment involved the collection and analysis of relevant data based on human health end-points for specific chemicals. The sources considered for this information included Acceptable Daily Intakes (ADI) from the ADI List published by the Australian Government, Acute reference doses (ARfD) from the ARfD List published by the Australian Government, Data included in the Australian Drinking Water Guidelines and the Guidelines for Managing Risks in Recreational Water (both published by the Australian Government), and data included in World Health Organization Guidelines for Drinking Water Quality, Finally, quantitative data was selected from US EPA sources since these were the most comprehensive and most conservative of the secondary information sources considered.

Human health dose-response data was not available for EDCs, requiring the risks associated with these compounds to be (extremely conservatively) assessed by comparison to other organisms. This was seen as not unreasonable as many 'human' chemical dose-response values have in fact been derived from animal models. These data often have consumption volume of *ca* 2 litres built into them.

Exposure assessment comprised the identification of potential exposure pathways, the estimation of exposure concentration for pathways, and the estimation of contaminant intakes for pathways.

Hazardous locations were confined primarily to the stretch of the Hawkesbury-Nepean River between the Penrith weir (point of treated water input) and the North Richmond Drinking

Water Treatment Plant. An additional hazardous location was considered involving a hypothetical irrigation scenario using water from this stretch of the river.

Exposed populations were considered as those which may drink water sourced from the Hawkesbury-Nepean River, use the Hawkesbury-Nepean River for recreational purposes or use water from the river for domestic irrigation of agricultural soils.

The exposure pathways considered included using the sourced water for a household supply (including oral consumption as well as inhalation of volatile components); accidental intake by recreational users; and exposure via soil subsequent to irrigation (including direct accidental ingestion by children as well as uptake in food).

The estimation of exposure concentrations for pathways was again based on 95th percentile concentrations of Schedule 10 data and subsequent chemical removal by various barriers. The principal barriers considered included advanced water treatment (reverse osmosis), dilution in the river, chemical partitioning (between water, air, sediment and soil) and chemical degradation. This provided for the calculation of estimated concentrations at key points of exposure.

The estimation of contaminant intakes for pathways was achieved by incorporating established exposure estimations in quantitative risk calculations for acute and chronic hazards.

3.3.3 Cyanobacteria (Blue-Green algae)

Cyanobacterial toxin concentrations and types vary greatly depending on a range of factors including the dominant species, competition from green algae, weather, river flow, stratification, season and whether or not a bloom is in progress. So the concentrations that occur as a result of impacts cannot be easily predicted or their risk quantified.

As a result the criteria in the NH&MRC (2005) risk assessment based guidelines identifies factors predisposing water to blooms. These were the focus of quantitative assessment.

Part B. Pathogen Assessment

4 Issue Identification

Conceptually, water-borne pathogens have been recognised as posing a serious threat to human health for over a century since the original development of germ theory and epidemiology. Despite this it is only in the last 10 to 20 years that a sound detailed and quantitative picture of the range of hazards and risks, and the ecology of pathogens has emerged in the scientific literature.

Much of this is due to technological developments. In addition to the nucleic acid technology which has revolutionised microbial taxonomy and made viral detection close to routine, there have been a range of other contributing developments including the:

- Development of methods for extracting microbial cells from water volumes as large as 1 kilolitre including ones based on membrane filtration technology;
- Application of quantitative statistics to the theory of quantitative microbial risk assessment; and
- The development of systematic frameworks such as HACCP for identifying and managing risks.

The major text in this area is that of Haas *et al.* (1999). For readers unfamiliar with recent developments, the WHO (2001) volume edited by Fewtrell and Bartram is strongly recommended as a primer as it covers many of these advances in concise summary form. Further to this, quantitative analysis of pathogen data is now becoming routine in response to the acceleration in the collection of environmental pathogen data and the need for more precise interpretation. The EU MicroRisk (www.microrisk.com) exemplifies this transition from research to routine management tool (Medema *et al.,* 2006) and the methods in this latter study form the basis for much of assessment and data analysis undertaken here.

5 Hazard Assessment

Hazard Assessment was undertaken by a general Literature Review and analysis of the historical data. This work focused on acquiring quantitative data describing pathogen source fate and transport.

5.1 Hazard Identification

5.1.1 Source Water Composition

A range of pathogen data were identified in data sets provided by Sydney Water (Table 5-1) and in the literature (Table 5-2). The main limitation with the available data was that most was collected as part of compliance monitoring and after disinfection. As it is not necessarily proposed to disinfect the treated wastewater before MF-RO (and indeed would be of questionable purpose) it was seen as preferable to collate data on microbial concentration data characteristic of sewage after secondary or tertiary treatment but before disinfection.

Table 5-1. Pathogen Concentrations in Sydney Inland STP Effluent Before Disinfection

Analyte/ Pathogen	Concentration	Systems where Measured	Comments	Data Source
Thermotolerant coliforms	12-83 28-200 (median) 63-2100 (95^{th} percentile)	Tertiary plants - Table 1 system		Long and Ashbolt (1994)
Cryptosporidium confirmed	< $0.04.L^{-1}$ (2 samples); $0.03.L^{-1}$ (2 samples)	Rouse Hill	Recovery adjusted, recovery was 47%-82%	Data provided by Sydney Water
Cryptosporidium	After chlorination <0.025-<$0.14.L^{-1}$ (12 samples); tertiary treatment <0.02 (3 samples), $0.15.L^{-1}$(1 sample)	Hornsby chlorinated effluent	No recovery reported (1999); confirmation not reported	
Giardia confirmed	< $0.03 .L^{-1}$ (3 samples); $0.03. L^{-1}$ (1 sample)	Rouse Hill	Recovery adjusted, recovery was 60%-81%	
Giardia	After chlorination 0.05-$3.3.L^{-1}$ (9 samples samples) < 0.05 (3 samples); tertiary treatment $0.03.L^{-1}$(1 samples), <$0.03.L^{-1}$(3 sample)	Hornsby chlorinated effluent	No recovery reported (1999); confirmation not reported	
Enterococci	10-$260.L^{-1}$ (13 samples), < $10.L^{-1}$ (23 samples)	Hornsby chlorinated effluent		
Thermotolerant coliforms	Median concentration 10-$940.L^{-1}$, 95^{th} percentile up to 4400, maximum up to 120000	Penrith, St Marys Quakers Hill Riverstone and Rouse Hill		

Note:

1. Measurements from Sydney Waterways or post disinfection are not included as it is assumed that MF-RO feedwater would be highly treated but not disinfected.

Table 5-2. Pathogen concentrations in treated STP Effluents

Pathogen	Concentration	Level of treatment	Systems where Measured	Comments	Cited Reference
Rotavirus	1687 av 7.5- 374 . L^{-1} 100% positive; n=7	Secondary Treated (and primary)	United States		Smith and Gerba (1982)
	750 L^{-1}av. 0-1500; 50% positive in 0.2 L samples	Activated sludge no disinfection	United Kingdom		Bates *et al.* (1984)
	1012 L^{-1}av 48-3228 7 samples 100% positive ;	Activated sludge unchlorinated	United States		Rao *et al.* (1988)
	9.6 L^{-1}; 0-32 14 samples – n=14, 21 % positive	Activated sludge chlorinated?	United States		Rao *et al.,* (1988)
	15-350.L^{-1}	Secondary Treated only	Texas		Smith and Gerba (1982)
Enteroviruses	50% detection maximum 9.5.100 L^{-1}, geomean 1.5. 100L^{-1}	Post clarification and filtration	Florida US Water reclamation for golf course		Rose *et al.* (1996)
Cryptosporidium	Median 0.14-0.22 oocysts L^{-1} ; 95th percentile = 0.6; 'viability' (=confirmed 8%)	Tertiary	Spain	Survey looked at 3 STPs	Montemayor *et al.* (2005)
	42% positive geomean 2.9.100L^{-1}, maximum 13.100L^{-1}	Post clarification and filtration	Florida US Water reclamation for golf course	Older method, no recovery reported	Rose *et al.* (1996)
Campylobacter	Of 12 samples, 12 positive at detection limit of 30.L^{-1}. Maximum = 10^4.L^{-1}, median = 10^3.L^{-1}	Trickling filter		Upper limits after trickling filter without chlorination (4 chlorinated samples < $3x10^2$.L^{-1}	Koenraad *et al.* (1994)
	0-820 per 100 mL after treatment in reservoir, inflow 5900-8200	Outflow from 2 sewage treatment plants	Libya	Present in 1 treatment plant, absent from other – pond reduces concentrations	Betaaieb and Jones (1990)
Cryptosporidium	0.13 (1 system); range <2.L^{-1} - <10.L^{-1}	Outflow from 3 pilot scale treatment systems	Sweden		Ottoson *et al.* (2006)
Norovirus	22-300; range <100-5000. L^{-1}				
Enteroviruses	Mean 160-3500; range <250 to $3x10^5$ .L^{-1}				
Giardia	0.4 (1 system); <2 – 6.L^{-1}				
Adenovirus	<1, 300, 800 .L^{-1}	Unfiltered Secondary Effluent	Australian data	(min, average, maximum	WSL (2003)
	7, 9, 70 .L^{-1}		NZ survey		

Pathogen	Concentration	Level of treatment	Systems where Measured	Comments	Cited Reference
	200, 4000, 40,000 L^{-1}		NZ scoping study		
	10-10,000 $.L^{-1}$	raw sewage	Guidelines value	Range	NRMMC/EPHC (2005)

5.1.2 Treatment Processes

5.1.2.1 Removal of Microorganisms by Microfiltration

LeChevallier and Au (2004) provide an extensive general review of water treatment processes considered in this risk assessment and their effectiveness in removing microorganisms from water.

From discussions with Sydney Water it is proposed that Microfiltration (MF) would be used as a pretreatment to reduce fouling of reverse osmosis (RO) membranes. However it also provides an effective second barrier for microorganisms. Together the MF and RO units provide significant redundancy of removal. MF as its name suggests filters most particles greater than 1 μm in diameter (nominal cut-off is typically 0.05 to 0.2 μm). As a result it is effective at removing bacteria and protozoa but not notionally viruses. In practice, however, virus sized particles are also markedly reduced in concentration apparently by being trapped in the smaller pores occurring in the membrane matrix and by additionally trapped particles.

The removal effectiveness of MF and RO can be expressed in various formats. In this review we have used the Decimal Reduction (DR) as the standard measure. The DR is the $\log_{10}$ of the ratio calculated by dividing the initial contaminant concentration by its final concentration after barrier effects have been applied.

Typical DR values are shown in Table 5-3. Removal depends on the membrane class used and there is also marked variation between brands and the membranes from the same manufacturer differing in pore size. For larger particles, DR values of 4 to 7 are commonly reported. For virus particles DR of 2 to 3 is probably more reasonable.

Table 5-3. Reported Removal of Protozoa, bacteria and virus particles by Microfiltration

Analyte	DR Values	Summary of Study	Comments	Reference
Bacteria	3.1-3.6 min for smaller was 2.9, upper limit was 3.8	0.1 and 0.05 μm membranes used with sewage and spiked water	0.2 μm membrane less efficient indicating size cut off is important	Sadr Ghayeni *et al.* (1999)
Indicator bacteria	2-3	versatile removal of particles by hollow fibre ultrafilters	Early study	Jacangelo *et al.* (1989)
Various	Removal rates vary depending on system	Review of membrane removal technologies	Reviewed 70 studies – notes aim is to achieve < 1 virus particle in 10^8 litres	Madaeni (1999)
Giardia and *Cryptosporidium*	Typically 3.3 - ≥4.5	Short review based on numerous pilot studies	Larger pore size of 0.2 um can reduce removal especially of bacteriophage due to	LeChevallier and Au (2004)

Analyte	DR Values	Summary of Study	Comments	Reference
			their size	
Bacillus subtilis	5-6	Pilot plant study 3 different membranes compared		Panglisch *et al.* (1998)
MS 2	2-5		Depends on brand	
MS 2, PRD1, *Clostridium perfringens*, *Giardia* and *Cryptosporidium*	2.5-3.5 (bacterio-phage), 6.2 for bacteria (*Clostridium*)	Pilot plant study, 4 different membranes compared	Comment again on virus removal being more limited	Lovins *et al.* (2002)
Cryptosporidium	4.3-5.5	Study of removal rates	0.2 µm pore size used	Drodz and Schwartzbrod (1997)
Bacteria	7-8	Study of different membranes	0.1 µm pore	Masden (1987)
Bacteriophage	0-1 (worst case)	'Study of MS2 removal '	Bench scale microfiltration	Jacangelo *et al.* (1995)
Cryptosporidium and *Giardia*	4.2- >7.0		Varies between membrane and pilot plant	

Notes

1. The DR is the $\log_{10}$ of the ratio of the initial contaminant concentration divided by its final concentration.
2. DRs shown here are for 'microfiltration' rather than ultrafiltration or nanofiltration except where indicated.

5.1.2.2 Removal of Pathogens by Reverse Osmosis

The primary barrier proposed for removing contaminants proposed by Sydney Water is reverse osmosis (RO). The technology for RO based polishing secondarily treated sewage is now well established as a result of ongoing pilot trials in California in support of groundwater recharge (*e.g.* NWRI, 2005; NWRI 2004).

Theoretically no microorganisms should be able to penetrate RO membranes and in practice this appears to largely be the case, with many studies reporting RO systems reducing all microorganisms below detection limits (

Table 5-4). In practice a reasonable DR minimum estimate for ROs working nominally is *ca* 6.5.

Most high quality DR estimates appear to be modal values based on the results of experimental bench top or pilot scale test units. Full-scale MF-RO plants by contrast tend to have hundreds of parallel modules and inter-module performance variability does not appear well documented in respect to microorganisms. These uncertainties should not be taken as indicating that RO membranes do not work. On the contrary the available data indicates that RO is a remarkably effective technology, which can remove with very high efficiency most sewage contaminants of concern from sewage under nominal operating conditions. Long-term operational data on full-scale MF-RO plants however is sparse.

Table 5-4. Decimal Reduction of Contaminants by RO Reported in Various Studies

Analyte	DR Factors	References	Comments
MS-2 Bacteriophage	> 5.4	Mi *et al.,* (2004)	Control
Conductivity (salts)	ca 1.8	Kitis *et al.* (2003a, 2003b)	Degree of removal after compromise also studied
RWT (organic dye)	3.9		
Microspheres (24 nm)	>4.0		
MS2	>6.7		
Cryptosporidium	>6	Adham *et al.* (1998)	Summary conclusions by Westrell *et al.* (2003) Table 2
Rotavirus	3-7	Madaeni (1999); Adham *et al.* (1998)	
Campylobacter	>7	Madaeni (1999); Adham *et al.* (1998)	
Bacteria - *B. subtilis* spores	5.5-5.9 (hollow fibre membranes) 2.2-4.5 (spiral wound membranes	Owen *et al.* (1999) cited in LeChevallier and Au 2004	Pilot scale; decimal reduction of 8.0-11 was achieved in the same work with nanofiltration
Bacterial spores, protozoa and bacteriophage	>= 5.5 logs	Lovins *et al.* (1999) and Gullick *et al.* (2000)	Summary conclusions by LeChevallier and Au (2004)
MS-2	> 6.5	Commerton *et al.* (2005)	
MS 2	3-4	Hu *et al.* (2003)	Large pores used to explain poorer performance than nanofiltration
MS 2	>3.4/>6.5 />7.4 3.7/5.6/6.9 1.4/2.7/5.8 >4.5/>4.9/ >6.0 1.9/4.6/5.0	Adham *et al.* (1999)	(minimum/median/ maximum) Isolated membranes – not crossflow and use of particle free water – still concludes QC measures essential

5.1.2.3 Membrane Malfunction

Current pilot scale data suggests that when operating nominally MF and RO in series are a remarkably powerful and reliable technology for reducing contaminants in treated sewage to very low or undetectable levels. The use of two or more RO modules in series is a simple method for introducing further safety and redundancy into these water treatment systems. The modular design (*i.e.* hundreds to thousands of filtration units operating in parallel) means that the impact of module failure for a full-scale system should be one to three orders less than estimates for treatment systems based on only one or a few parallel treatment streams.

It is important, however, to also recognise that MF-RO test facilities tend to have only a few units operating in parallel. On the positive side this means that reported losses of efficiency tend to overstate the scale of the problem that should conceptually be observed in a full-scale plant.

The need to better quantify how reliable full-scale MF-RO systems are as part of the risk assessment process is clear. Even Qualitative Risk Assessment processes demands that risk assessors estimate how frequently Hazardous Events occur in treatment processes and how severe such events are (Nadebaum *et al.* 2004). The matter is particularly of concern in the case of high efficiency systems such as MF and RO membranes. Gale (2002) in his discussion of fault tree theory illustrates how the effectiveness of such systems in the reduction of pathogen risks can be compromised by what appear to be minor failures and how ineffective water quality compliance monitoring can be at detecting such problems.

That Hazardous Events and failure modes are a concern is being increasingly recognised within the water treatment industry generally, including those researchers concerned with MF and RO. As a result there are now data on failure modes, the loss in efficiency and estimates of fault detection method sensitivity (Table 5-5). What still appears to be lacking is good long-term data of malfunction frequency. LeChevallier and Au (2004) for example in their thorough review of water treatment indicate the importance of the issue and the need for well-designed management systems. But they provide no statistics or discussion on water treatment plant breakdown quantification in general or in respect to microfiltration or reverse osmosis in particular.

The reasons for this data gap require further investigation. Possible reasons may be:
1. the traditional focus on end point testing;
2. the main use for RO systems to date being salinity reduction which is easily monitored on online and via end point testing;
3. limited analysis of RO data; and
4. statistical data on failure modes being treated as commercial in confidence by manufacturers.

For example there appears to be a great quantity of statistics on common measures of water quality such as coliform concentrations from Californian pilot plants at the exits to treatment plants but little on long-term effectiveness of treatment plant sub-units.

It is emphasised that limited data on breakdowns does not imply poor contaminant removal compared to other treatment processes. Rather it suggests they are relatively rare and not well documented. Indeed our experience in developing risk assessment for other water treatment systems via the EU MicroRisk project (*e.g.* Medema *et al.* 2006) indicates that statistical data on hazardous event magnitude, frequency and duration in water treatment is generally scarce. As indicated above, the modular nature of MF-RO systems means that failures are unlikely to be total. The study of Hong *et al.* (2001) furthermore suggests that failure of sub-units should be possible to detect. It is also possible that there are data on membrane failure at operational plants that has yet to be published or collated but which is likely to be as Water Safety Plans with their emphasis on risk management are increasingly adopted.

Table 5-5. Reliability Membrane Filtration and other Water Treatment Systems

Process	Removal Efficiency Issue(s)	Study	Model Contaminants	Findings	Reference
Reverse Osmosis	Loss of pressure didn't occur much but flow dropped to zero	Study of biofouling impacts	Biofouling	Cleaning recommended every 3-4 months for third stage, other stages longer	Bartels *et al.* (2005)
Reverse Osmosis	Removal reduced from >6 to as low as 2.2 in the case of MS-2 bacteriophage	Study of experimental compromised membranes in 3 different types of test units. Compromise includes cracked O rings and fouled elements	Salinity, Rhodamine WT, Microspheres and MS-2 phage	MS- 2 DR reduced markedly to varying extents depending on analyte	Kitis *et al.* (2003a)

Process	Removal Efficiency Issue(s)	Study	Model Contaminants	Findings	Reference
MF and Ultrafiltration	Solids accumulation and optimizing filter operation	Study of backwash conditions	General	Identified 'Dead areas' where fouling can form. Problem can be addressed by manipulation of backwash cycles.	Hillis *et al.* (1998)
MF+RO	Removal of viruses in pilot plant with a similar configuration to that proposed	Pilot scale removal of bacteriophage from secondary treated wastewater	MS-2 coliphage	RO performed well but MF only reduced bacteriophages by 1 order of magnitude	Iranpour (1998)
RO	Reduction in DR	Study of effects of compromise of units of two different brand types	MS-2, Microspheres	DR reduced to 3-4	Mi *et al.* (2004)
MF and Ultrafiltration	Effect of scale of MF failure on output water quality observed	Effect of compromise of rack (50 elements) at full-scale MF-RO plant	*Bacillus subtilis* spores	Various - From starting DR of >6.4 DR reduced to as low as 2.5 for compromised element and 4.2 for whole rack	Mi *et al.* (2005)
MF	Sensitivity of surrogates/ Monitoring of membrane failure	Study of techniques for monitoring membrane compromise	Coliforms and turbidity	Pressure decay and diffusive air flow tests allow one damaged fibre in 66,000 to be detected	Hong *et al.* (2001)
Water treatment Generally	Estimates of water treatment process failure rates are rare	General water treatment failure rate estimation	Serious treatment incident	0.05 incidents / y 1-30 days	Olofsson *et al.* (2001) cited in Westrell *et al.* (2003)
			Microbial pollution in treatment	0.0071 incidents per year 1-30 days	

5.1.2.4 Removal of Microorganisms by the Singapore MF-RO Plant

An illustration of the unpublished data that may be obtainable is that summarised in Table 5-6 and Table 5-7. This data provided by Dr Greg Leslie UNSW on the performance over recent years of the Singapore MF-RO water recycling facility proved a very valuable complement to the literature data. Unlike most of the literature studies it came from a full-scale plant operated over several years. And it included a large body of primary data from which critical risk statistics could be estimated.

In particular analysis of the before and after microfiltration data showed the following:

1. Microfiltration was very effective at removing those microbiological analytes present in high concentrations in the partially treated wastewater *i.e.* thermotolerant coliforms, HPCs, Somatic coliphage, Enterococci and *C. perfringens* (Table 5-6);

2. From the data it was possible to estimate the coefficients of the DR probability density functions – highly desirable data for QMRA because they provide estimates of barrier performance variability;
3. Median Microfiltation DR reductions ranged from 4.9 to 7.9 in line with literature values.
4. Point estimates of DR values were consistent with median values estimated for the better quantified analytes; and
5. There was no evidence of catastrophic failure from coliform or other indicator data sets with high sensitivity. And the data indicated a maximum failure rate (based on thermotolerant data) or less than 1 failure day in 67 (*i.e.* p. < 0.015).

The data set also illustrated the limitations of standard monitoring of such systems.

1. After the MF process very few microorganisms relative to the analysis detection limit were actually challenging the RO system making the compliance data of little use in estimating RO performance or reliability. The main superficial exception was heterotrophic bacteria but the counts both in and out appeared likely to be at the method detection limit and were probably of little significance.
2. Only the upper limit only of MF effectiveness was possible to estimate in the case of *Cryptosporidium, Giardia,* and male specific coliphages due to the low concentrations of these analytes in the feedwater rather than the high removal rates.
3. No useful QMRA simulations or conclusions were possible for enteroviruses because assays were semiquantitative and data provided incomplete.
4. How variable MF performance can be (*e.g.* the $\log_{10}$ standard deviation of the measured removal was estimated to be 1.74 for somatic coliphage indicating the ±2 standard deviation values for DR removals were 1.3 and 8.9).

Table 5-6. Decimal Reduction Statistics Estimated from Singapore Microfiltration Monitoring Data for Analytes with Substantial Numbers of Detects after Filtration

Analyte	Log normal DR Probability Density Function Coefficients		Cumulative Distribution Statistics for Decimal Reduction Estimated from Monte Carlo Simulation			
	Mean	Standard deviation	median	average reduction	Percentiles 95th	99th
total coliforms	6.72	1.89	1.91E+07*	1.03E+03	2.50E+04	4.83E+03
Thermotolerant coliforms	7.92	2.12	1.21E+08	3.28E+03	3.65E+05	1.01E+03
HPCs	5.00	0.72	9.91E+06	3.98E+05	1.54E+04	4.80E+04
Somatic coliphage	5.10	1.74	7.86E+06	1.14E+02	5.71E+03	8.67E+02
Enterococci	7.40	1.88	3.94E+08	2.36E+04	4.94E+05	9.45E+04
C. perfringens	4.85	1.49	1.42E+05	3.69E+03	3.98E+03	4.06E+02

* E equates to a factor of 10, so E+03 is 10^3 or 1000

Table 5-7. Decimal Reduction Statistics Estimated from Singapore Microfiltration Monitoring Data for Analytes with Few or No Detects after Filtration

Analyte	units	average feedwater concentration	detection limit	No. of non detects	Reduction based on detection limit of 0.5	Reduction based on detection limit of 0.5 in n samples
Male specific coliphage	Pfu. $100mL^{-1}$	146.3	1	35	2.92E+02*	1.02E+04
Giardia	Cysts. $100L^{-1}$	2566	not specified	10	5.13E+03	1.80E+05

Analyte	units	average feedwater concentration	detection limit	No. of non detects	Reduction based on detection limit of 0.5	Reduction based on detection limit of 0.5 in n samples
			depends on sample			
Cryptosporidium	Oocysts. $100L^{-1}$	40.4	not specified depends on sample	10	8.08E+01	2.83E+03
Enteroviruses	presence/ absence	11 of 13 samples positive	Reported to vary but no indication in data	not tested	-	-

* E equates to a factor of 10, so E+03 is 10^3 or 1000

5.1.2.5 Pathogen Removal at North Richmond Water Treatment Plant

The largest well-defined population, which would be exposed to replacement flow releases, is that supplied by water from the North Richmond water treatment plant. This treatment plant includes in addition to chlorination, dissolved air flotation and rapid sand filtration, all of which can markedly reduce pathogen concentrations. LeChevallier and Au (2004) and Hijnen *et al.* (2005) have reported the general reductions, which may be achieved. In the end data collected in Australia as part of the MicroRisk project on a water treatment plant which also included DAF and Rapid Sand Filtration (Signor *et al.* 2006) were selected for modelling the protection likely to be provided by this treatment plant (Table 5-8).

Table 5-8. Decimal Reduction Functions for Major Pathogen Barrier Classes Comparable to those at North Richmond Water Treatment Plant

Process	Analyte	Probability Density Function Describing DR (Coefficient names)	Coefficients	Comments	Reference
DAF	Protozoa	Normal (mean, standard deviation)	1.72, 0.61	Based on yeast removal at full-scale	Signor *et al.* (2006)
	Bacteria		2.38, 0.38	Based on total coliform removal at full-scale	
	Viruses	Triangular (Min, Mode, Max)	0.2,1.9,4.3	Based on generic flocculation data	Table 3.4 Westrell (2004)
Rapid Sand filtration	Protozoa	Normal (mean, standard deviation)	3.57, 0.45	Based on yeast removal at full-scale	Signor *et al.* (2006)
	Bacteria		1.12, 0.4	Based on total coliform removal at full-scale	
	Viruses	Uniform (Min, Max)	0.7,1.2	Based on generic flocculation data	Table 3.4 Westrell (2004)
Chlorination	Protozoa	Triangular (Min, Mode, Max)	0, 0.4, 1.0	Base on various generic data	
	Bacteria		2.5, 3.5, 5.0		
	Viruses		1.5, 2.0, 3.0		

5.1.3 Fate and Transport in the Environment

5.1.3.1 Travel Time and Dilution

Upon entry into the river the replacement water contaminants will be diluted to varying extents depending on the base flow at the time. Risk will be highest at the point of introduction of the replacement water into the river during low flow periods.

Downstream risk will decrease further as contaminants are inactivated, immobilised and volatilised to varying extents. High flows will reduce risk by increasing dilution of contaminants but increase it by increasing velocity and reducing travel, and hence inactivation, time. Conversely low flows will lead to less dilution but increase travel times and hence the opportunity for inactivation.

To estimate the protection provided by the river environment it is necessary to have simultaneous estimates of contaminant dilution and travel time along the length of the river. Estimates of both were possible to obtain through simulation modelling using Sydney Water's model for the Hawkesbury-Nepean flows. The model allowed the extent of dilution of a hypothetical particle to be estimated for different flow fixed regimes (Figure 5-1) and travel times for different flows at selected reference stations (Figure 5-2). Using this information estimates of travel time, average velocity and dilution were developed for 3 flow regimes and 6 exposure stations (Table 5-9). The 20th, 50th and 80th percentile flows were selected in the initial qualitative risk assessment as being indicative of high, median and low flow conditions. The six points along the river were selected to cover reaches within the freshwater section of the river downstream of Penrith.

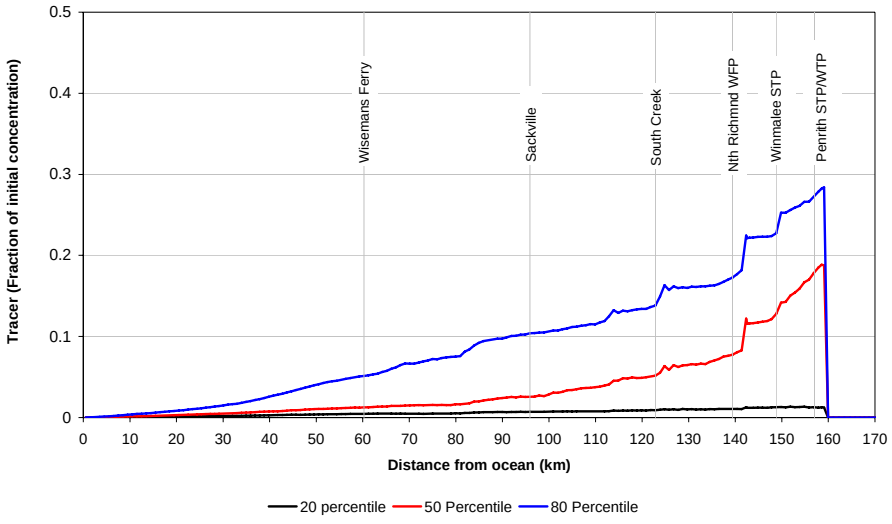


Figure 5-1. Dilution of particles deposited the Hawkesbury-Nepean River at Penrith under low (80th percentile), Median and high (20th percentile) flow conditions.

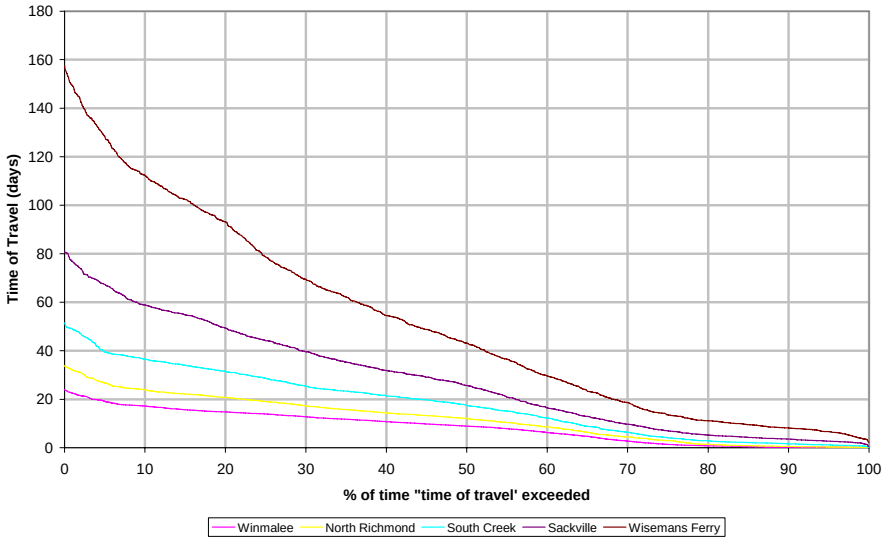


Figure 5-2. Time for particles deposited at Penrith to Travel to Downstream to Each Risk Assessment Station

5.1.3.2 Inactivation kinetics for pathogens and indicators in surface freshwater

A range of studies indicates that inactivation of pathogens and indicators in surface waters follow first order kinetics. This has led the USEPA (2001) to propose as part of its TMDL methodology estimating exposure concentrations downstream by combining the concentrations of pathogens at their source waters, these inactivation rates, and dilution + travel time downstream.

This methodology was seen as applicable in the present study and we collated a range of such kinetic data. The USEPA collation of data was supplemented with other data which could be used to estimate inactivation rates for bacterial indicators and the index pathogens (Table 5-10).

A key requirement was estimating inactivation rates for *Cryptosporidium*, which has a reputation for slow inactivation by disinfection (LeChevallier *et al.* 2004) and in the environment (Hipsey *et al.* 2005). Several estimates were obtained based on a number of assay methodologies including ones based on infectivity and viability (Table 5-11).

Detailed results of three other studies of indicators, pathogens and bacteriophage survival in surface waters have been reproduced in Table 5-12,

Table 5-13 , and Table 5-14 as they demonstrate how different environmental factors especially temperature and sunlight, can affect inactivation.

Though data on virus inactivation is less available it appears that coliphages provide a good model of their behaviour (*e.g.* Nasser and Oman, 1999; Arraj *et al.* 2005).

Table 5-9. Summary of Hawkesbury-Nepean Flow Attributes Extracted for Modelling the Decline in Microbial and Chemical Concentration

Station	Distance from sea (km)	Distance from Release (km)	Dilution Factor			Travel time (days)			Average Flow Velocity (cm.s^{-1}) over preceding reach		
			Flow Percentile			Flow Percentile			Flow Percentile		
			20th	50th	80th	20th	50th	80th	20th	50th	80th
Penrith Weir	157	0	0.01279	0.17800	0.27240	0	0	0	-	-	-
Winmalee	148	9	0.01259	0.12130	0.22386	0.80	8.91	14.78	13.02	1.17	0.70
North Richmond	139	17.42	0.01053	0.07769	0.17272	1.39	12.08	20.70	16.52	3.07	1.65
South Ck	123	33.99	0.00913	0.05170	0.13814	2.83	17.43	31.49	13.32	3.58	1.78
Sackville	96	60.91	0.00707	0.02583	0.10408	5.22	25.70	49.37	13.04	3.77	1.74
Wisemans Ferry	60	96.56	0.00467	0.01255	0.05139	11.12	43.14	93.19	6.99	2.37	0.94

Table 5-10. General Inactivation Rates Reported for Microbial Cells in Freshwaters

Microorganism	System/ Location Conditions	Inactivation Algorithm	Coefficients	Primary Reference	Secondary Reference	Comments
Total coliforms	Freshwater 20^{o}C	First order constant k(day^{-1})	1-5.5	Thomann and Mueller (1987)	Table 6-1 USEPA (2001)	
	Seawater: 20^{o}C		0.7-3.0			
	Non-sterile river water (12 days) (no temperature indicated)		0.42	Baudisova, (1997)		
Fecal coliforms	Seawater, sunlight		37-110	Thomann and Mueller (1987)		
	Non sterile river water (12 days)		0.51	Baudisova (1997)		no temperature indicated
	Sand: 4 ^{o}C, 25 ^{o}C, 35 ^{o}C		0.043, 0.124, 0.146	Howell *et al.* (1996)		
	Loam: 4 ^{o}C, 25 ^{o}C, 35 ^{o}C		0.043, 0.108, 0.156			
	Clay: 4 ^{o}C, 25 ^{o}C, 35 ^{o}C		0.025, 0.022, 0.083			
	Sediment at 8 ^{o}C		0.010-0.023	Sherer *et al.* (1992)	-	
E. coli	Seawater, 10-30 $^{o}/_{oo}$		0.08-2.0	Thomann and Mueller (1987)	Table 6-1 USEPA (2001)	
	Nonsterile river water 37^{o}C (12 days)		0.53	Baudisova (1997)		
	Nonsterile river water: 44^{o}C (12 days)		0.54			

Microorganism	System/ Location Conditions	Inactivation Algorithm	Coefficients	Primary Reference	Secondary Reference	Comments
	Natural surface water: 5°C (42 days)		0.102	Medema *et al.* (1997)	Table 6-1 USEPA (2001)	These are log_{10} reduction values
	Natural surface water 15°C (0-14 days) (14-42 days)		0.202 0.049			
Streptococcus faecalis	Freshwater: 20°C		0.4-0.9	Thomann and Mueller (1987)		
	Freshwater: 4°C		0.1-0.4			
	Storm water: 20°C (0-3 days)		0.3			
	Storm water: 20°C (3-14 days)		0.1			
Streptococcus bovis	Storm water: 20°C		1.5			
Faecal streptococci	Seawater sunlighted		18-55	Howell *et al.* (1996)		
	Sand: 4 °C, 25 °C, 35 °C		0.013, 0.119, 0.103			
	Loam: 4 °C, 25 °C, 35 °C		0.010, 0.064, 0.130			
	Clay: 4 °C, 25 °C, 35 °C		0.019, 0.025, 0.095			
	Sediment at 8 °C		0.018-0.033	Sherer *et al.* (1992)		
Faecal enterococci	Natural surface water: 5°C	Log_{10} reduction.d^{-1}	0.077	Medema *et al.* (1997)	Table 6-1 USEPA (2001)	42 days
	Natural surface water: 15 °C		0.233(0-14 days), 0.025 (14-42 days)			biphasic
Salmonella typhimurium	Storm water: 20°C (0-3 days)	First order constant k(day^{-1})	1.1	Thomann and Mueller (1987)		
	Storm water: 20°C (3-14 days)		0.1			
Cryptosporidium	Microcosms Natural surface water: 5°C	Log_{10} reduction.d^{-1}	0.010	Medema *et al.* (1997)		35 days
	Microcosms Natural surface water: 15°C		0.024			
Coxsackie	Marine waters: 25°C	First order constant k(day^{-1})	0.12	Thomann and Mueller (1987)		
	Marine waters: 4°C		0.03			
Echo 6	Marine waters: 25°C		0.08			
	Marine waters: 4°C		0.03			
Polio type1	Marine waters: 25°C		0.16			
	Marine waters: 4°C		0.05			
Rotavirus	Freshwater		0.14-0.46	Raphael *et al.* (1985)	Westrell (2004)	
Enterohaemogenic *E. coli*	Freshwater		0.12-0.33	Wang and Doyle (1998)	Westrell (2004)	
Campylobacter	River waters Dark 20 °C		1.11 in 6 hours	Obiro-Danso *et al.* (2001)		Natural populations

Microorganism	System/ Location Conditions	Inactivation Algorithm	Coefficients	Primary Reference	Secondary Reference	Comments
Rotavirus	River waters Dark 10 °C	T_{90}	1.56 in 96 hours	Raphael *et al.* (1985)		
	River waters Dark 4 °C		1.22 in 96 hours			
	River waters 17-20 °C Surface Artificial sunlight Lancaster		8 in 40-60 minutes			Inoculated
	Natural population in sunlight		25 min			
	Populations in distilled water and artificial seawater	T_{90} DR	4-9 min			
	Raw water 4 °C		(< 2 in 10 days)			Abstract only
Cryptosporidium	Raw water 20 °C	DR	2 in 10 days	Medema *et al.* (2001a)		
	Surface water		0.0057-0.046 per day			General review
Rotavirus			0.24-0.48 per day			
Enterovirus			0.01-0.2 per day			
Hepatitis A			0.05-0.2 per day			
Enterococci			0.17-0.77 per day			
E. coli			0.23-0.46 per day			
Coliforms			0.77 per day			
Giardia			0.023-0.23 per day			

Notes:

1. The primary reference is the original source, the secondary reference is that where the data was extracted from and is more readily available. Most primary references were obtained to confirm the values shown were reported accurately.
2. T_{90} is the time for a 1 $\log_{10}$(90%) reduction in microbial concentration.
3. DR = Decimal Reduction.
4. Biphasic means reductions area governed by 2 relationships, often reflecting the presence of subpopulations of microorganisms, which are more resisitant to inactivation.

Table 5-11. Inactivation of *Cryptosporidium*

Experimental Conditions	Method	Temperature	k (d^{-1})	T_{90} (days)	Comments	Reference
Various including stools, cattle faeces, and various waters	Dye exclusion	4-37 °C	$10^{(0.058*\text{temperature} -2.68)}$	-	Based on Jenkins (1997) and Robertson *et al.* (1992)	Russell Walker Jr (1997)
		10	0.0079	290		
		15	0.015	149		
		20	0.030	76		
		25	0.058	39		
Natural River Water in the dark	Excystation	5	0.023	100	Include 95% confidence intervals	Medema *et al.* (1997)
		15	0.055	42		
	Dye Exclusion	5	0.023	100		
		15	0.041	*56*		
Autoclaved River Water in the dark	Excystation	5	0.023	100		
		15	0.013	*167*		
	Dye Exclusion	5	0.023	100		
		15	0.025	*91*		
River Water	Cell culture infectivity	4	0.0116	200	Filter sterilised water very similar at 21-23°C	Pokorny *et al.* (2002)
		10	0.0091	250		
		21-23	0.079	29		

Notes:
1. Dye exclusion refers to the ability of cells to exclude nucleic acid staining dyes such as propidium iodide. This conceptually indicates an intact cell envelope.
2. Excystation refers to the capacity or otherwise of *Cryptosporidium* oocysts to hatch in a suitable medium.
3. Cell culture infectivity refers to the ability of *Cryptosporidium* oocyst to both hatch and infect suitable tissue culture cells.

Table 5-12. T_{90}s (hours) for Microorganisms Under Varying Environmental Conditions in Natural River Water Reported by Evison (1988)

Environmental Factor	Parameter Value	Microorganism					
		E. coli	Faecal streptococci	*Shigella sonnei*	*Salmonella typhimurium 12a*	*Campylobacter fetus*	Bacteriophage MS-2
Light $Wh.m^{-2}$	1354	1.4	2.3	1.6	8.1	-	-
	787	3.9	5.0	3.8	31.9	-	-
Salinity $^{o}/_{oo}$	0	194	166	406	204	-	-
	0.44	79	91	-[3]	1022	-	-
	3.5	232	614	560	560	-	-
Temperature °C	10	297	116	138	739	118	1185
	15	234	162	295	235	84	654
	20	108	56	177	175	60	274
	25	68	67	98	186	27	499
Nutrients (%sewage added)	0.025	176	362	-	108	57	479
	2.5	86	72	-	134	64	433

Notes:
1. Selected Data Filter sterilised (0.2 µm) Freshwater only.
2. Under dark conditions at 15 °C except where otherwise stated.
3. Positive value – no die off detected in experimental system.

Table 5-13. Sunlight inactivation of bacteria (Adapted from Sinton *et al.* 2006)

Environmental Conditions	Parameter	Units	Microorganism		
			E. coli	*Salmonella enterica*	*Campylobacter jejuni*
Summer	T_{90}	h	2.07	1.34	0.48
	k	h^{-1}	(1.11)	(1.71)	(4.79)
	S_{90}	MJ m^{-2}	6.6	4.1	1.19
Winter	T_{90}	h	13.1	18.0	0.66
	k	h^{-1}	(0.176)	(0.128)	(3.49)
	S_{90}	MJ m^{-2}	13.5	14.0	0.84
Dark	T_{90}	h	548	67.4	82.6
	k	h^{-1}	0.004	0.034	0.028

Notes:
1. Estimated over 8 hour period at 14 ^{o}C near Christchurch NZ (43^{o}S)
2. On day of measurement (note different measurements on different days).

Table 5-14. Inactivation Rates for Bacteria and Coliphage under full sunlight (adapted from Noble *et al.* 2004)

Environmental Conditions	Parameter	Parameter	Microorganism		
			E. coli	**Enterococci**	**F+specific coliphage**
High Solar Radiation	T_{90}	hours	17.1	8.45	55.8
	k	h^{-1}	0.13	0.272	0.041
Low Solar Radiation	T_{90}	hours	42.5	9.46	92.1
	k	h^{-1}	0.054	0.24	0.025

Notes:
1. Low radiation corresponded to light under a screen and in polycarbonate bottles.
2. Experiments undertaken 20/August/ 2000 peaking at measured insolation of 1100 W.m^{-2} – California summer. A screen used to simulate low radiation and appeared to reduce intensity by 75%. Day length appears to be 12 hours.
3. Experiments conducted over 3 days.

5.1.3.3 Sedimentation and Resuspension

A possible complicating factor in estimating microbial inactivation is binding of microorganisms to particulate material, its sedimentation in the river and subsequent remobilisation. And a range of studies indicates that microbial cells often die-off more slowly in sediments (

Table 5-15) than in surface water.

Remobilisation of sediment microorganisms however appears unlikely under predominant flow conditions in the river. In Table 5-9 it can be seen that even under 20th percentile flow conditions the river flows at less than 0.2 m.s^{-1}. This is still well below the velocity at which erosion is likely to place (see Figure 5-3 adapted from Postma 1967 cited in Thomas and Meybeck 1996). As a result it seems likely that there would be little opportunity for resuspension except under high flow conditions by which time there would have been extensive opportunity for inactivation of those pathogens previously entrained in the sediments even at the reduced rates prevailing in this environment. Additionally at flow velocities of 0.5 m.s^{-1} dilution would also be very high providing further reduction in risk.

Table 5-15. Deposition, Inactivation and Mobilisation of Microorganisms in Sediments

Microorganisms	Study Summary	Observations	Comments	Reference
Cryptosporidium	Flume measurements of entrainment. For an 80cm deep river with a velocity of 0.2 m/s entrainment takes place over 2.6-7.6 km	*Cryptosporidium* become entrained in sediment at rates depending on sediment makeup, water depth and water velocity. Model still needs development.	Data collected was of insufficient resolution to determine equilibrium rates smaller percentages Binding to material is unclear.	Searcy *et al.* 2006
E. coli	Interaction of *E. coli* survival, bacteriophage predation with salinity and clay	High salinity (around sea water) leads to clay deposition on bacteria and protection from predation.		Roper and Marshall 1974
Thermotolerant coliforms	Measurement of the loss of organisms stored in sediment during released of reservoir water	Once entrainment occurs loss is very rapid. Loss of viability while bed seems limited.	The potential for dead spots at bends where accumulation may occur was noted.	Wilkinson *et al.* 1995
E. coli	Artificial release of water mobilising *E. coli*	Increase in *E. coli* by 2 orders of magnitude of organisms presumed to be in the stream.	Elimination of storm flow confounding effect.	Nagels *et al.* 2002
E. coli	Inactivation in seawater and sediment	T_{90}s of 1-2 days at 24 ^{o}C	Slower than seawater but still fast	Gerba and McLeod 1976
Bacterial indicators and Salmonella	Sediment and Water in estuary	T_{90} in sediment for bacteria was 6-20 days. Concentration in sediment and water downstream reduced by a factor of 10 per 2-3 km in water and per 4 km in sediment. This study also estimated light attenuation as a function of turbidity. *E. coli* T_{90}s increased by a factor of 10 for light intensity reductions of 100	Shows accumulation in sediment greatly reduced with distance and follows a log linear curve. Change in light intensity was recorded in seawater.	Pommepuy *et al.* 1992

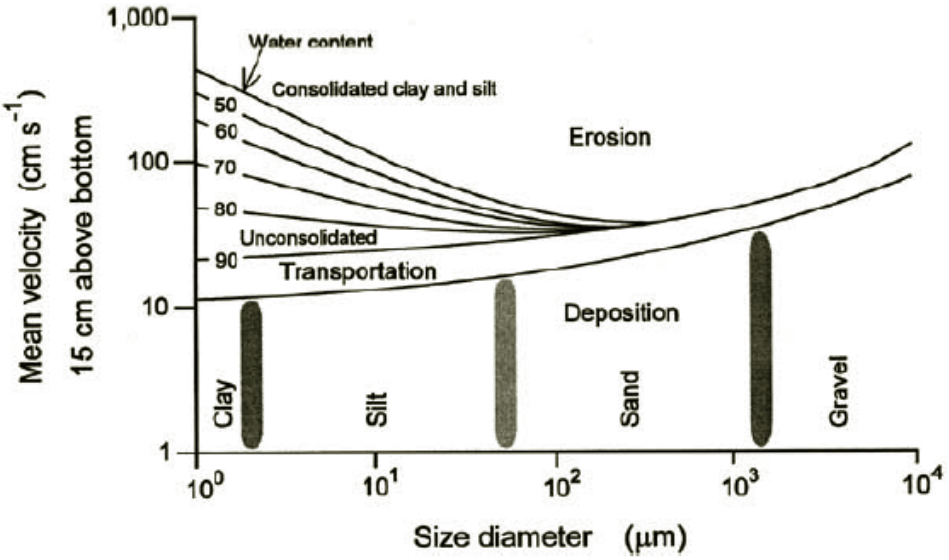


Figure 5-3. Deposition and Mobilisation of Small Particles in surface waters in relation to particle size and flow velocity

Notes:
1. Reproduced from Postma (1967) as cited in Thomas and Meybeck 1996

5.2 Consumption and Exposure

According to van Heerden *et al.* (2005a) "an exposure analysis (under recreational conditions) consists of four principles: (i) the average concentration of viruses in the water, (ii) the efficiency of the recovery procedure, (iii) the viability of the viruses and (iv) the average volume of water consumed per individual.". This section summarises information on the latter exposure information.

5.2.1 Direct Water Consumption

Rates of deliberate potable cold water consumption and accidental ingestion of water during recreation are now relatively well documented. A summary of European and Australian data on reticulated potable water shows deliberate consumption of cold tap water is of the order of 0.75 Litres per person per day (Table 5-16).

Accidental ingestion of river water during primary recreation is believed to be considerably less and of the order of 0.05 Litres per primary contact event (Table 5-17). The risk from this source is further mitigated by the fact that people are unlikely to undertake recreation every day of the summer let alone during the winter months in a developed country like Australia where such bathing optional.

Table 5-16. Daily Consumption of Potable Water in Different Countries

Country	Average Daily Intake (litres)	Probability Density Function	Coefficients	Study
Netherlands	0.25	Poisson	Gamma=0.7061	Mons *et al.* (2005)
UK	0.57	Poisson	Gamma=2.8149	
Germany	0.38	Gamma	alpha=1.0676, beta=2.3489	
Australia (Melbourne)	0.75	Poisson	Gamma=3.3684	

Australia (Adelaide)	0.75	Poisson	Gamma=2.8676	
Sweden	0.93	Lognormal	10^{th}, 50^{th} and 90^{th} percentiles= 0.4, 0.8 and 1.6 respectively	Table 2 Westrell *et al.* (2004)
Canada	0.386	Average	0.386 (point value)	Cited in Table 4 Westrell *et al.* (2004)
USA	0.506	Average	0.506 (point value)	
France	0.77 (winter) to 0.9 (spring)	Average	0.77 (winter) to 0.9 (spring)	

Table 5-17. Intake During Recreation

Intake Estimate[1]	Circumstances	Primary reference
≤100 mL^2	Full body immersion (swimming, children playing, body washing)	DWAF (1996), WHO (1998) Genthe and Rhoda (1999) Haas *et al.* (1999)
50 mL^2	Skiing, windsurfing canoeing with repeated immersion	Medema *et al.* (2001a)
10 mL^2	Accidental during laundry, fishing and irrigation related activities	Medema *et al.* (2001a); Genthe and Rhoda (1999)
30 mL^3	Recreational swimming	Crabtree *et al.* (1997); Dufour *et al*. (2006)
5.7 mL	Swallowed volume per freshwater diver-professional divers	Schijven and De Roda Husman (2006)
3.4 -13 mL	Sports divers with ordinary masks	Schijven and De Roda Husman 2006

Notes:
1. All estimates were developed by their authors with quantitative risk assessment in mind.
2. Adapted from Table 1 of Steyn *et al.* 2004
3. Cited in Van Heerden *et al.* 2005a, 2005b

5.2.2 Consumption of Irrigation Water

A full analysis of pathogen risks arising from Irrigation Water Consumption involves estimation of irrigation rates, retention of water on plant surfaces, rates transfer of pathogen proportion and subsequent inactivation (*e.g.* Peterson 2002, Hamilton *et al.* 2006) prior to consumption.

A simpler conservative screening estimate for consumption is identified in the draft (NR&MMC & EPHC, 2005) guidelines. This proposes the assumption of 5 mL of water consumed per serving of lettuce without any inactivation.

5.2.3 Consumption of Contaminants Accumulated in Animals

Because of bioaccumulation, estimation of pathogen uptake via animals is probably the most difficult estimate. This is because a range of factors controls accumulation and in the case of microorganisms the final concentration reflects equilibrium between uptake, inactivation *in situ* and excretion, which is highly species and situation specific. In NSW shellfish are of greatest concern with respect to bioaccumulation of pathogens. Cox (1997) proposed estimates of maximum consumption (60 to 240 grams per serving) based on USEPA data and an order of magnitude bioaccumulation factor for viruses (1000X), which could be used in risk estimation.

In the case of the Hawkesbury-Nepean River the most significant conceptual risk identified was the consumption of shellfish as these might be consumed raw whereas this is unlikely with vertebrate fish. There are no oysters grown in the zones of the river considered, however there are prehistoric shellfish middens (freshwater mussels). No reports of their current

consumption were encountered and discussions with a local expert on shellfish bioaccumulation (Dr Maria Byrne Sydney University) indicated local consumption was unlikely. Nevertheless this scenario was seen as a reasonable worst case scenario which had a credible conceptual basis and was suitable for quantitative risk estimation.

5.2.4 Land-Use Patterns and Risk Assessment Considerations

In the estimation of microbiological risks 6 potential assessment stations were identified of which only two were in the end used. This was partly because the risks at the station of most concern were low. But also the risk of most concern, drinking of untreated water, was very unlikely to occur. Examination of satellite photographs and local maps showed that on the left bank of the river there are no land holdings which are likely to be using raw river water for potable purposes on a regular basis. Immediately adjacent to the mixing zones there is a low security detention centre, which is presumed to be on reticulated water given its proximity to Penrith. Further downstream there are some residential areas but these appear to be suburban subdivisions, again most likely to be on reticulated water. Beyond this the principle left bank land use appears to be native bushland until one gets to Winmalee.

A similar situation exists on the right bank with all riverside land being currently occupied by sand extraction operations which will eventually be developed as part of the Penrith Lakes residential scheme and will also presumably be on treated reticulated water.

The first land occupied by farming (Castlereagh), which might conceivably use raw river water, is located 6.5 km downstream on the right bank.

Thus the microbiological and chemical scenarios, which were focused on potable consumption at Penrith, can be clearly seen as worse than are likely to be encountered in reality.

5.3 Dose-Response Relationships

WHO (Fewtrell and Bartram, 2001) identifies a range of dose-response curves for various pathogens and since this time others have been collated. In the MicroRisk project (Medema *et al.* 2006) a number of conservative response curves were identified (Table 5-18) for the index pathogens. Those for *Cryptosporidium*, *Campylobacter* and Rotavirus all indicated infectious dose probabilities of > 0.1 per organism ingested.

An additional measure available for expressing human risk is the Disability Adjusted Life Year or DALY. This corrects for variations in the disease burden arising from different diseases. Though fewer DALY conversion factors are available than infection dose-response curves they are available for the three index pathogens proposed for modelling (Havelaar *et al.* 2000, Havelaar and Melse 2003, Prus and Havelaar, 2001).

Table 5-18. Dose-response curves for the selected pathogens

Pathogen	Dose Response Equation	Equation coefficients	DALY per infection	Reference
Cryptosporidium	Beta-Poisson with unit dose threshold: Prob infection $=1-(1+dose/beta)^{-alpha}$	alpha= 0.115 beta=0.176	0.001796683	Teunis *et al.* (2002)
Campylobacter		alpha=0.024 beta=0.011	0.002082368	Van den Brandhof *et al.*(2003) Evans *et al.*(1996)

Rotavirus		alpha = 0.253 beta = 0.422	0.00086413	Teunis *et al.*(2002) Ward *et al.*(1986)
Adenovirus	Adenovirus 4 Exponential $P=1-e^{(-k.dose)}$	k 2.397	-	Fewtrell and Bartram (2001)

Note:
1. Adenovirus is included here as it was considered as an alternative index virus pathogen to Rotavirus.

5.4 Health Risk Benchmarks

The aim of this report was to estimate risks of exposure and assess how these compared with Benchmarks developed historically and overseas or for which a consensus appears to exist within the expert community.

There are as yet no legislated 'acceptable risk' probability values for recycled water in Australia. However various work from overseas and Australia has identified possible 'benchmark' values for drinking water, which might be used as default values. A good example, in the Australian context, is that proposed in the AWT (1997) study of shellfish risks. Two risk thresholds for gastroenteritis identified were infection risk probabilities of 10^{-4} person^{-1}. y^{-1} which has been proposed for drinking water by the USEPA (Macler, 1993) for *Giardia* and elsewhere (Fewtrell and Hunter 2001) and 6 x 10^{-3} person^{-1}. y^{-1} proposed by AWT (1997).

As noted above the limitation with infection rate probabilities as Benchmarks is that they do not account for the varying severity of disease caused by different pathogens. The latter issue is being dealt with using disability life adjusted years (DALY). One μDALY is a possible benchmark (see WHO 2004, Chapter 3). The DALY is a population health summary measure that integrates years of life lost by premature mortality with years lived with a disability standardised by means of severity weights.

Another Benchmark pertinent to the present study is the epidemiology based threshold of 1% per swimming/immersion event proposed in the WHO (2003) and NH&MRC (2005) guidelines which correspond to high quality bathing waters.

6 Exposure Assessment

This section details aspects of Exposure Assessment developed for the specific exposure pathways modelled based on the potential hazard locations and exposed populations identified in section 3.2.3.

6.1 Barrier Classes

In modeling exposure to risks a range of "barriers" and pathways were combined in different exposure scenarios. These barriers are listed in Table 6-1. It is important to note that not all are physical barriers. Management actions can act as barriers as well as environmental processes. All have been used in modeling exposure pathways where applicable and quantifiable. Parameters describing each barrier are based on the data described in Section 5.

Table 6-1. "Barriers" Considered in Modelling Pathogen Risks from Replacement Water in the Hawkesbury-Nepean River

Barrier (Class)	Contaminants Applicable to	Elaboration	Comments
Monitoring of STP Operation	All	STPs periodically malfunction *e.g.* during hydraulic overload. These impacts can be limited by not supplying the MF-RO with water during periods	An agreed assumption at the project's commencement was that water would not be supplied to the MF-RO plant when an STP was malfunctioning.
Microfiltration	Bacterial and Protozoan Pathogens, Some of the virus load solids, chemicals adhering to large particles	Microfiltration will remove larger particulate material.	
Reverse Osmosis	All pathogens, most chemicals, Phosphate	Reverse osmosis conceptually removes all contaminant units > a few hundred Daltons and a range of smaller chemicals	smaller chemicals depending on their shape, charge and hydrophobicity
Dilution	All	Dilution reduces the contaminant concentrations to which users are exposed or which challenge river and land based inactivation processes	
River Processes (Microbiological)	Pathogens	Entrainment and settling of particles and particle bound pathogens, solar radiation, natural cell death enhanced by temperature, predation, mixing	Entrainment provides an opportunity for further inactivation or degradation away from exposure pathways. Mixing transports pathogens to the surface where radiation is most intense.
River Processes (Chemical)	Chemicals	Includes chemical decomposition and various partitioning mechanisms	
Human Behaviour Relating to Exposure Route	All	People are not exposed continually to all pathways *e.g.* bathing is uncommon in winter	Used to construct conceptually rational exposure pathway assumptions *e.g.* frequency food consumption or bathing exposure

Barrier (Class)	Contaminants Applicable to	Elaboration	Comments
Water Treatment Processes	All	North Richmond Water Treatment Plant is designed to reduce the concentration of pathogen and chemical contaminants	Includes Dry Air Flotation (DAF), Rapid Sand Filtration (RSF) and chlorination
Terrestrial Processes	Pathogens, chemicals	Analogous to river processes	*e.g.* inactivation through desiccation, collection of limited volume of contaminated water on lettuce lead by virtue of vegetable morphology
(Bioaccumulation)	Pathogens	Processes involve increase in effective concentration to which a person is expose. Mitigated in part by the relatively small quantity of material consumed.	Applies to foods consumed raw. Considered especially in regard to shellfish consumption.
Exposure frequency and volume or other quantity	All	Risk is reduced by limiting the volume of material that comes in close contact.	For example while contact with pathogens during primary contact recreation may seem more physically intimate, risks are greatly limited by the relatively small volume of water ingested
Cooking	Pathogens, some chemicals	Foods considered in detail are those with higher risk *e.g.* foods eaten raw. Used as basis for selecting raw shellfish.	Applies to residual contaminants in food. Not considered specifically but would provide in many instanced further protection to user populations.
Dose Response	Pathogens, Chemicals	The risk from a disease from ingesting a certain number of pathogens is considered to be defined by an exponential or beta Poisson algorithm	Varies greatly. Model pathogens were selected in part because they are infectious at low doses.

Important barriers NOT included in the risk modeling were:

- Breakpoint chlorination used for ammonium stripping;
- Public education regarding drinking of untreated river water;
- Warnings from utility operators in the event of plant breakdown (example of a management-based barrier as compared to a physical barrier); and
- Management of access immediately downstream of the replacement water discharge point.

These were omitted because quantitative data for modeling risks was too limited. But in practice they would provide additional protection from hazards and hence reduce risk further. And they can still be accounted for in final decision-making regarding the process.

6.2 Exposure Routes and Pathways

Conceptually there are many possible exposure pathways and pathway steps, indeed far to many to model. So for assessment purposes five high priority pathways were selected for

modeling (Table 6-2). The rationale for their selection varied but mainly they were selected on the following basis:

- They are the best documented most clearly hazardous pathways;
- These pathways are based on historical experience of exposure to water (illness from drinking of contaminated water, food poisoning);
- Brief consideration shows that many other pathways would involve less exposure, and risks estimated for the 5 major pathways will provide sufficient indication of the risks involved;
- There is too little data at present to undertake a quantitative assessment and no clear evidence of significant infection risk greater than risk by one of the selected pathways.

These different exposure pathways were identified in initial discussions with SW and NSW Health and a preliminary qualitative risk assessment. They are also illustrated graphically in Figure 6-1 (see Figure 3-4 for template diagram showing all possible pathways). Consumption of raw water during recreation and via domestic use occur via the same pathway (a.). The consumption volumes however are treated as being different (compare Table 5-16 and Table 5-17).

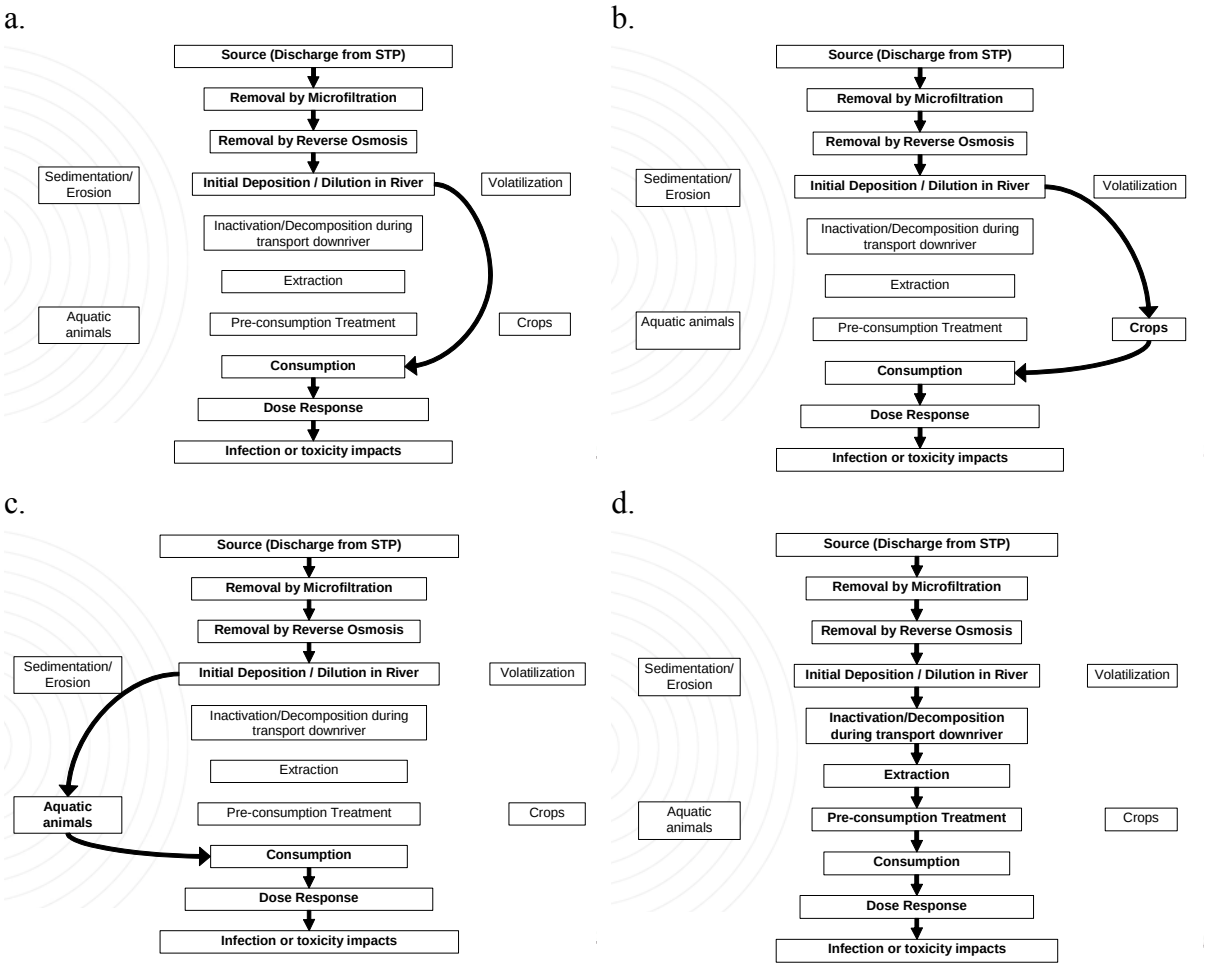


Figure 6-1. Exposure pathways

Notes:

1. Consumption in pathway a. can be deliberate as a result of the use of untreated drinking water for potable domestic use, or incidental during primary contact recreation.

2. The exposure pathways shown relate to:
    a. Accidental consumption of pathogens through primary contact recreation and deliberate consumption through use of untreated river water for normal domestic purposes;
    b. Consumption of pathogens via irrigated crops;
    c. Consumption of pathogens via eating of aquatic animals;
    d. Consumption of pathogens via reticulated water after transport downstream and treatment.

Table 6-2. Barriers Modelled for Quantitative Microbial Risk Assessment

Barrier (Class)	**Exposure Pathway**				
	Consumption of Water During Primary Contact Recreation	***Deliberate Consumption of Raw Drinking as a Domestic Supply***	***Drinking of Treated Reticulated Water***	***Consumption of raw vegetables***	***Consumption of raw fish***
Monitoring of STP Operation	+	+	+	+	+
Microfiltration	+	+	+	+	+
Reverse Osmosis	+	+	+	+	+
Breakpoint chlorination	Not included due to limited data suitable for modeling	Not included due to limited data suitable for modeling	Not included due to limited data suitable for modeling	Not included due to limited data suitable for modeling	Not included due to limited data suitable for modeling
Dilution	+	+	+	+	+
River Processes (Microbiological)	Not included in base case scenarios (consumption at Penrith)	Not included in base case scenarios (consumption at Penrith)	+	Not included in base case scenarios (consumption at Penrith)	Not included in base case scenarios (consumption at Penrith)
Human Behaviour Relating to Exposure Route	+ (frequent primary contact recreation)	+ (consumption rates for cold water from surveys)	+ (consumption rates for cold water from surveys)	+ (model raw vegetable, high consumption, no washing assumed)	+ (model raw shellfish, high consumption, no purging assumed)
Water Treatment Processes	Not applicable	Not applicable	+ (effectiveness of WTP Richmond using literature)	Not applicable	Not applicable
Terrestrial Processes	Not applicable	Not applicable	Not applicable	+ (retention worst case of river water on raw lettuce)	Not applicable
(Bioaccumulation)	Not applicable	Not applicable	Not applicable	Not included raw contaminated greater concern	+ (based on estimates for oyster)
Exposure frequency + wet weight of volume	+ (based on primary recreation figures)	+ (based on cold tap water consumption)	+ (based on primary recreation figures)	+ (based on maximum consumption rates)	+ (based on primary recreation figures)
Cooking	Not applicable	+ (cold water only no hot beverages)	+ (cold water only no hot beverages)	+ (no cooking assumed)	+ (no cooking assumed)
Dose Response	+ (literature infectivity algorithms)	+ (literature infectivity algorithms)	+ (literature infectivity algorithms)	+ (literature infectivity algorithms)	+ (literature infectivity algorithms)

Notes:
1. '+' = included.

6.3 Pathway Specific Assumptions

Several assumptions used for risk estimation were common for all pathways. These were:

- Initial concentrations of pathogens;
- MF-RO effectiveness;
- Dilution/flow regimes; and
- Model pathogens and their dose-responses.

In addition each scenario had a number of specific assumptions.

6.3.1 Intake of Water (raw drinking water consumption, primary contact accidental ingestion)

Data was available for cold drinking water consumption in Australia and generically for recreational water consumption. The selected modeling functions were:

- For drinking water (treated and raw), the Poisson distribution developed for Melbourne was used which had a gamma coefficient of 3.368 and gave an average daily consumption of *ca* 0.75 L per person; and
- For recreational consumption a triangular distribution having 10, 30 and 50 mL as the minimum, most likely and maximum consumption volumes was used. A second assumption necessary was the number of visits. It was assumed that the river was used for bathing once per week during the summer months *i.e.* 26 times.

6.3.2 Consumption via Reticulated Water

For treated reticulated water a number of barrier functions were added reflecting treatment stages at the Richmond Water Treatment Plant. These described pathogen removal functions from the literature and obtained in the MicroRisk project:

- Flocculation/sedimentation;
- Rapid Sand Filtration; and
- Chlorination.

The PDFs describing pathogen removal at the Water Treatment Plant can be found in Table 5-8.

6.3.3 Raw vegetable consumption

Exposure to pathogens associated with raw vegetables was based on assumptions proposed in the recycled water guidelines (NH&MRC/NRMMC, 2005). In summary it was assumed that one 100g serving of lettuce was consumed every day of the year and the maximum volume of raw water which could be retained was retained and there was no washing.

6.3.4 Raw 'fish'

In this instance it was assumed that raw mussels were consumed after the same number of visits to the river as occurred with recreation *i.e.* once per week during the summer months when access would be comfortable *i.e.* 26 times per year. Consumption serving size of mussels used assumptions developed by Cox (1996) for oysters.

6.4 Microbial Risk Estimation

This section describes how exposure concentration and intake were calculated. The calculation process is part of the QMRA modelling whose final products are the infection

probabilities and μDALYs presented in the section 7.1. The latter use a range of inputs presented previously in sections 5.1 and 5.2. The actual inputs on a scenario-by-scenario basis are detailed in Appendix 2 (Section 23.2).

6.4.1 Input Data Assumptions

From the data assembled in the review process, Probability Density Functions (PDFs) were selected for modeling which mathematically describe the contaminant concentrations in the treated sewage, the effects of barriers and likely human responses. In many instances functions describing Nominal and Hazardous Event situations were also defined. The list of those selected for model construction is given in Table 23-1 in Appendix 2.

The PDFs took the form of:

- Point values (*e.g.* percentile flow values);
- Simple triangular or uniform distribution functions (*e.g.* virus concentrations in treated sewage); and
- Functions reflecting the distribution fitted to a relevant available data of significant size (*e.g.* Nominal DR functions for bacterial cell removal derived from the Singapore MF-RO plant).

Our simulations of pathogen risks assumed that no disinfection of the tertiary treated wastewater occurred. Thus the risk estimates are necessarily conservative. The rationale for using data on un-disinfected wastewater was that the MF-RO process is generally much more effective at eliminating pathogens than chemical disinfection.

Other sources of pathogens and chemicals exist which could impact on the Hawkesbury-Nepean River and hence the population under consideration, which are at most only indirectly related to the proposed replacement water. Such related sources include:

- stormwater run-off;
- bather shedding;
- domestic and wild animal and bird inputs;
- agricultural run-off;
- sewerage overflows; and
- discharges from other STPs.

Assessing their individual relative impacts was beyond the scope or resources of this study.

6.4.2 Scenario Selection

The pathogen exposure scenarios for each pathway are summarised in Table 6-3. Each scenario integrates between seven and twenty-two PDFs. The details of each scenario simulated can be obtained by comparing Table 23-1 and Table 23-2 in Appendix 2.

These scenario PDFs include details of the assumptions under normal operation and high-risk conditions.

The exposure worst-case scenarios that were considered initially assumed the following:

- Drinking of untreated river water;
- On a regular basis (= as domestic supply); and
- Exposure at Penrith immediately after dilution.

Scenarios considered were:

- Nominal risk arising under the three flow regimes; and
- Hazardous Event Risk (MF and/or RO malfuction) arising under low flow when microfiltration and/or reverse osmosis were malfunctioning for a total duration of 5.3 days per year (for origin of this figure see Sections 5.1.2.3 and 5.1.2.4).

These scenarios were selected as worst cases because they involved consumption of the contaminants at their most concentrated and consumption was likely to be greatest.

Table 6-3. Exposure Scenarios

Exposures Pathway	Exposure Point	Flow	Scenario	Notes
Direct consumption of untreated river water as a result of its use for domestic uses	Penrith	Median Flow	Nominal average potable use exposure (Nominal MF-RO Function, consumption of *ca* 0.75 L of cold water per day)	Worst Base Case due to low dilution
		High (20%ile) Flow		
		Low (80%ile) Flow		
		Low (80%ile) flow	MF breakdown (5.3 days.y^{-1})	Nominal average exposure outside of breakdown period
		Low (80%ile) flow	RO Breakdown (5.3 days.y^{-1})	
		Low (80%ile) Flow	RO+MF concurrent breakdown (5.3 days.y^{-1})	Nominal average exposure outside of breakdown period Scenario used to assess worst case
Oral intake as a result of accidental ingestion during primary recreation	Penrith	Median Flow	Nominal average recreational ingestion exposure (Nominal MF-RO Function, ingestion of *ca* 0.03 L of river water per visit, 26 visits.y^{-1})	
		High (20%ile) Flow		
		Low (80%ile) Flow		
		Low (80%ile) Flow	RO+MF concurrent breakdown (5.3 days.y^{-1})	Nominal average exposure outside of breakdown period. Scenario used to assess worst case
Eating of uncooked mussels	Penrith	Low (80%ile) Flow	1 meal per visit, 26 visits.y^{-1}	Discussions with local freshwater mussel expert indicate little if any consumption takes place – included because there are historical middens
Eating of raw lettuce irrigated with river water	Penrith	Low (80%ile) Flow	Three hundred and sixty five 100g gram servings of lettuce in one year	Direct consumption of pathogens in lettuce water
Direct drinking consumption of untreated river water	North Richmond	High (20%ile) Flow	Potable use exposure, untreated water (Nominal MF-RO Function, microbial reductions due to environmental inactivation, consumption of *ca* 0.75 L of cold untreated water per day)	The largest population exposed continually to Hawkesbury-Nepean River water are the residents of the Macquarie Towns (*e.g.* Richmond, Nth Richmond) who obtain reticulated water supply from a high performance treatment plant at North Richmond
		Low (80%ile) Flow		
Direct drinking consumption of treated river water	North Richmond	High (20%ile) Flow	Potable use exposure, treated water (Nominal MF-RO Function, microbial reductions due to environmental inactivation, treatment by DAF, RSF and Cl_2, consumption of *ca* 0.75 L of cold treated water per day)	
		Low (80%ile) Flow		

6.4.3 Risk Calculation

Risk estimation for pathogens was undertaken using by constructing barrier models in MS Excel. Monte Carlo sampling of each probability distribution function was undertaken using @Risk Add-in (Palisade) V4.5.

Hazardous Events were modeled by running a Nominal and Hazardous Event (*e.g.* malfunction) models side by side and sampling the risk estimates from one model or the other in proportion to the time spent in the Nominal or Event state.

6.5 Hazardous Event Scenario Modeling

6.5.1 Hazardous Event Modeling

Within the drinking water industry increasing emphasis is being placed on understanding the risks arising during hazardous events of relatively short duration but high impact (Nadebaum *et al.* 2004). Extending this concept to recycled water it follows that assessments of risk should be undertaken for high risk periods as well as under 'nominal' conditions *i.e.* all barriers are operating at their typically observed effectiveness.

Conceptually it is straightforward to model events quantitatively provided estimates of event duration, frequency and severity can be obtained or developed (see for example Westrell *et al.* 2003). However, such event duration, frequency and severity data is not readily available in the water industry literature. From CWWT-UNSW's experience with drinking water supply systems this appears to be the case for several reasons:

- Compliance monitoring has dominated data collection in the past and there is no clear driver in such schemes to collect event data.
- Data collected historically tends to be extremely diverse, and not yet in a quantitative form suited to quantitative analysis (see case studies in Nadebaum *et al.* 2004).
- Analysis of on-line monitoring data which might provide some frequency + duration data is still limited in part because of the size of the data sets, in part because of the challenge involved in identifying events, known as the 'Change Point' problem.
- Institutionally water utilities are not well designed yet for documenting and analysing hazardous events in that the management of such events tends to fall within the activities of day-to-day operational management rather than long term research.

These data limitations, the range of malfunction scenarios and situations where suboptimal removal or high infection rates might occur (*e.g.* sensitive populations, low dilution during drought, elevated pathogen levels, sudden popularity in river sports) and the limitations implicit in a desk top study meant that it was not currently feasible to estimate all the risks from all hazardous event scenarios. The feasible alternative was to identify and simulate those hazardous events of most concern and assess their impact on each of the key pathways. If these were found to be tolerable then it would follow that other less hazardous pathways would also be tolerable under most conditions.

Consideration of the literature data, input assumptions and sensitivity analyses indicated that the potentially most severe events in respect to pathogens would be the loss of micro-filtration or reverse osmosis removal capacity because of the very high removal achieved under nominal operating conditions. Accordingly a set of common scenarios for MF and/or RO failure was developed and assessed for its impact of risk via each of the 5 pathways.

6.5.2 MF-RO Plant Malfunction

Investigations into the literature on water recycling and MF-RO, and discussions with Sydney Water indicated that in the wastewater treatment field as well, useful hazardous event information for large-scale system management and operation is scarce. This had two implications for risk estimation in the present instance:

- Risk estimates would necessarily have a high associated uncertainty; and
- Hazardous events for a Screening Level/Desk Top assessment would need to be constructed conceptually and the concepts would have to be defensible as far as practicable.

Accordingly the hazardous event scenarios constructed were designed so as to explore credible worst cases so that estimated risks would be conservative. Modelling such events, though based on literature and information provided by Sydney Water, proved difficult because:

- Failure modes reported were largely induced rather that natural (*e.g.* creation of pin hole, cut O rings);
- Such studies were usually undertaken on small to pilot plant scale systems;
- Though detection of filter failure is operationally possible it is unclear what magnitude of failure is required before they are detectable; and
- Because of the effectiveness of microfiltration in removing microorganisms, operation monitoring from Singapore did not provide good data on the reliability of the Reverse Osmosis stage.

From the data available, and presented in the literature review, the following were the best conservative estimates of what would constitute an MF or RO membrane failure event:

1. No major failures were evident in monitoring data for the Microfilters so filtration failure duration X no. of events was estimated at < 5 days per year (Singapore data).
2. Removal effectiveness (Decimal Reduction) during microfiltration failure was for:
    a. bacteria and protozoa - DR=2;
    b. viruses - DR =1 (poorer removal by relatively large pores); and
3. Removal effectiveness (Decimal Reduction) during Reverse Osmosis for all pathogens would be *ca* DR=2.

These event attributes were seen as most likely to be conservative and generate ‘worst case’ failure rates for several reasons:

- no recognisable failure was actually seen with the Singapore data (potentially poorer performance measurements in the microfiltration step were incorporated into the DR probability density function for each group of indicators for nominal operating conditions);
- failure in MF or RO would not happen to the whole plant at once, but rather to one in a number of sub-modules mitigating the impact *e.g.* if one of ten RO modules achieving DRs of *ca* 6 malfunctioned such that it only achieved a decimal reduction of 2, the overall performance of the plant would still have a DR of *ca* 3; and
- the modular design of MF-RO plants means that there should be little problem with taking the malfunctioning unit off line while maintaining the operation of the majority of the treatment plant.

6.6 Illustrative Examples of Microbial Risk Probability Calculation

Table 6-4 illustrates how the infection risk probability and μDALY values reported in the Risk Characterisation Section were estimated. A scenario is first developed for the exposure pathway operating and the effectiveness of each stage/barrier is defined quantitatively. In the case shown an initial concentration of a pathogen was estimated in the form of a probability density function based on literature or local data. Then the sequential effect of each barrier is estimated. The PDFs are based on the information presented in Section 5. This allows PDFs of the dose consumed by each person to be simulated. Then using literature dose response curves the probability of infection is calculated on a per day and per year basis. Finally using further literature information the infection rate is converted to a Disability Life Adjusted Year figure. Features of note are that:

- The probability of infection relationship in the case of *Campylobacter* reduced to the maximum risk curve for most simulations. As a result the infection probability estimates are likely to be conservative;
- The arithmetic average of risk simulation runs (n=1000 to n= 10,000) is routinely reported instead of the 95th percentile. Because the PDFs tend to be log normally distributed the arithmetic averages of the simulated risk probabilities tend to be more conservative than 95th percentiles;
- The simulations capture variability mainly through the use of probability density functions, and hazardous event simulation rather with an arbitrary statistic;

In Table 6-5 the inputs and outputs from a Monte Carlo simulated scenario are shown where suboptimal MF-RO removal (MF and RO effectiveness reduced to a decimal reduction of 2 $\log_{10}$ units at a rate equivalent to 5 days per 365 days in a year). In this simulation two models, nominal conditions and malfunction (*i.e.* hazardous event) conditions are run side by side. The final infection statistics are estimated by sampling from one or other model in proportion to the time in that state. The procedure is shown diagrammatically in Figure 6-2.

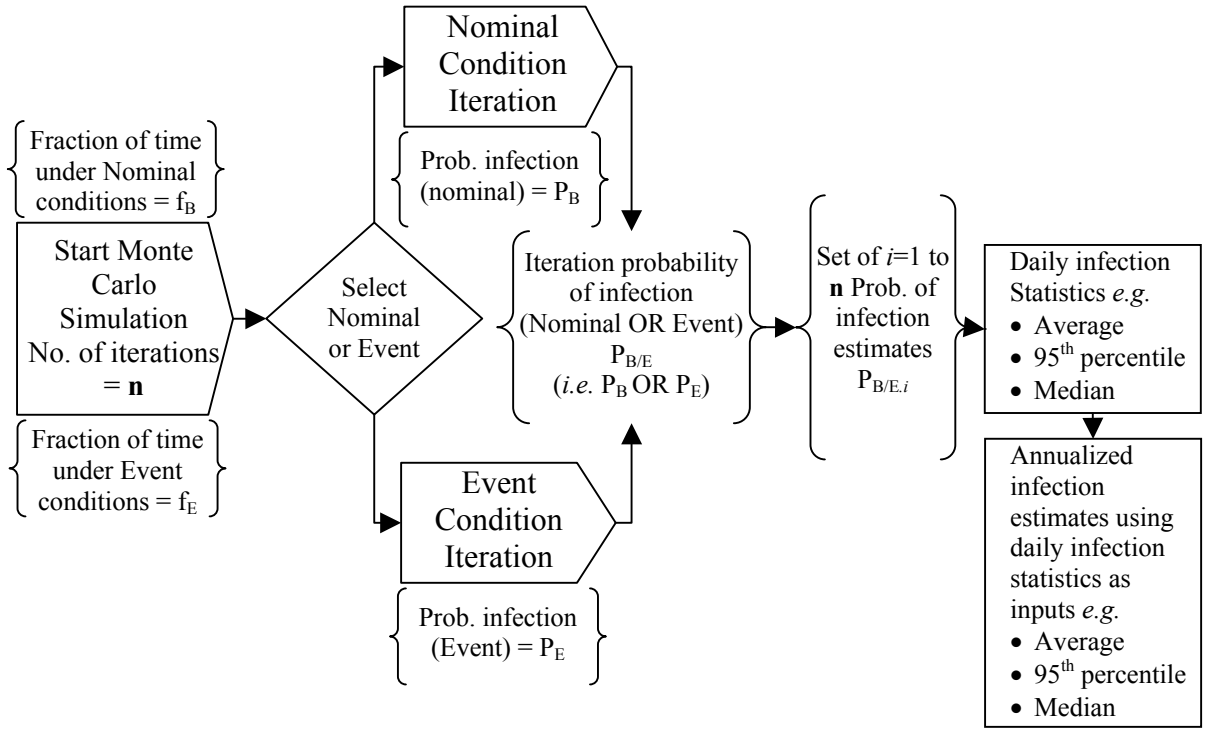


Figure 6-2. Procedure for Simulating the Risk Arising from Baseline+ Hazardous Event **Conditions**

Table 6-4. Reductions in, and final risk from, *Campylobacter* simulated for Nominal Conditions

Stage Barrier	Description	Probability Density Function Type	Units	Output Parameter	Data Source/ Reference	Risk Calculation Output (Average)
Initial Concentration	*Campylobacter* concentration in treated effluent modelled using Campylobacter data	Triangular	$mpn.L^{-1}$	Minimum=30, Mode =1000, Maximum = 10000	Koenraad *et al.* 1994	3676 $orgs.L^{-1}$
Microfiltration	*Campylobacter* removal by Microfiltration modelled using Thermotolerant coliforms data	Normal	log_{10} reduction	Mu=7.916, sigma =2.116 for DR	Singapore Microfiltration thermotolerant coliform PDF	0.60 $orgs.L^{-1}$
Reverse Osmosis	*Campylobacter* removal by Reverse Osmosis modelled using Various indicators data	Point estimate	log_{10} reduction	Modal value for DR = 6.5	Various	1.90 $x10^{-7}$ $orgs.L^{-1}$
Dilution	All removal by Dilution at Penrith Weir modelled using particle dilution data from Sydney Water	Point estimate	log_{10} reduction	Modal value for DR =0.565	Sydney Water Model	5.17 $x10^{-8}$ $orgs.L^{-1}$
Consumption	Melbourne Overall 0.25 L glass Poisson	Poisson	Litres/day	Gamma = 3.3684	Mons *et al.* 2005	6.71 $x10^{-8}$ orgs
Probability of infection (daily)	Probability of infection based on Outbreak data for *Campylobacter jejuni*	P=1-(1+dose/beta)^-alpha	Prob. Of infection	Alpha=0.024, beta = 0.011, Prob. if dose is algorithm output = 6.28E-12, Maximum risk probability, 2.88E-12	Van den Brandhof *et al.* (2003) Evans *et al.* (1996)	**$6.71\ x10^{-8}$. $person^{-1}.day^{-1}$**
Probability of infection (annualised)	Annualised Risk Probability	P= 1-(1-Daily Probability)^365	prob. Of infection		Haas *et al.* (1999)	**$2.45x10^{-5}$ $person^{-1}.year^{-1}$**
Disability Weighted Risk Estimate	Risk expressed as DALY	Point Estimate	DALY per infection	Daly per infection 0.00208	Havelaar and others (see 3 references in Part A table)	**0.051 µDALY**

1. Simulation corresponds to dry weather (80^{th} percentile) flow.

Table 6-5. Reductions in, and final risk from, *Campylobacter* simulated for Illustrattve Nominal + Event Conditions

Stage Barrier	Description	Probability Density Function Type	Units	Output Parameter	Data Source/ Reference	% of Simulations	Risk Calculation Output (Average)
Initial Concentration	*Campylobacter* concentration in treated effluent modelled using Campylobacter data	Triangular distribution	$mpn.L^{-1}$	Minimum=30, Mode =1000, Maximum = 10000	Koenraad *et al.* 1994	100	3676 $orgs.L^{-1}$
Microfiltration	*Campylobacter* nominal removal by Microfiltration modelled using Thermotolerant coliforms data	Normal distribution	log_{10} reduction	Mu=7.916, sigma =2.116 for DR	Singapore MF THC removal PDF	98.5	0.60 $orgs.L^{-1}$
	Campylobacter suboptimal removal by Microfiltration modelled using Thermotolerant coliforms data	Point Estimate	log_{10} reduction	Modal value for DR = 2	Kitis *et al.* (2003)	1.5	36.8 $orgs.L^{-1}$
Reverse Osmosis	*Campylobacter* nominal removal by Reverse Osmosis modelled using Various indicators data	Point estimate	log_{10} reduction	Modal value for DR = 6.5	Various	98.5	1.90 $x10^{-7}$ $orgs.L^{-1}$
	Campylobacter suboptimal removal by Reverse Osmosis modelled using Various indicators data	Point estimate	log_{10} reduction	Modal value for DR = 2	Kitis *et al.* (2003)	1.5	3.68 $x10^{-1}$ $orgs.L^{-1}$
Dilution	All removal by dilution at Penrith Weir modelled using particle dilution data from Sydney Water	Point estimate	log_{10} reduction	Modal value for DR =0.565	Sydney Water Model	98.5	5.17 $x10^{-8}$ $orgs.L^{-1}$ nominal conditions
						1.5	1.00 $x10^{-1}$ $orgs.L^{-1}$ event simulation)
Consumption	Melbourne Overall 0.25 L glass Poisson	Poisson distribution	Litres/day	Gamma = 3.3684	Mons *et al.* 2005	98.5	6.71 $x10^{-8}$ orgs nominal conditions
						1.5	8.48 $x10^{-2}$ $orgs.L^{-1}$ (event simulation)
Probability of infection (daily)	Probability of infection based on outbreak data for *Campylobacter jejuni*	P=1-(1+dose/beta)^-alpha	Prob. Of infection	Alpha=0.024, beta = 0.011, Prob. if dose is algorithm output = 6.28E-12, Maximum risk probability, 2.88E-12	Van den Brandhof *et al.* (2003) Evans *et al.* (1996)	100	**$3.03\ x10^{-4}$. $person^{-1}.day^{-1}$** combined simulation
P. of infection (annualised)	Annualised Risk Probability	P= 1-(1-Daily Probability)^365)	Prob. Of infection		Haas *et al.* (1999)	100	**$1.05x10^{-1}$ $person^{-1}.year^{-1}$** combined simulation
Disability Weighted Risk Estimate	Risk expressed as DALY	Point Estimate	DALY per infection	DALY per infection 0.00208	Havelaar and others (see Part A table)	100	**217 µDALYs** combined probability

7 Risk Characterisation

7.1 Quantitative Microbial Risk Estimation

7.1.1 Use of River Water for Drinking without Treatment at Penrith Weir

Table 7-1 summarises the risks from drinking raw river water from the organisms emitted from the MF-RO plant immediately downstream of the Penrith Weir. The first three scenarios show the risks arising during Nominal MF-RO removal under 3 flow regimes. It can be seen than risks are less that the 10^{-4} infections per person per year probability and the 1 µDALY benchmarks.

The main Hazardous Events identified were from breakdown involving the RO system. This reflected the decline in assumed DR from 6.5 to 2 (*i.e.* 4.5 orders of magnitude). None of the other Barrier Hazardous Events or PDF High Values (Table 23-1) had the potential to reduce the DR mode by more than 1-2 $\log_{10}$ units. No data were identified indicating rates of breakdown so the upper limit of failure incidence indicated by the Singapore data (5-6 days per year) was used in the simulations. Even under this high failure rate scenario, infections only seemed likely to exceed the benchmark values in the initial mixing zone when the RO malfunctioned for this extended period of time.

Table 7-1. Estimated Risks for Untreated Drinking Water Consumption immediately after dilution of Replacement Flows in the river at Penrith

Statistic	Microorganism	High Flow	Median Flow	Low Flow	Low Flow MF Breakdown	Low Flow RO Breakdown	Low Flow MF-RO Concurrent Breakdown
Average Daily risk .person^{-1}.day^{-1}	*Cryptosporidium*	5.00E-13	6.58E-12	5.88E-12	6.22E-12	8.24E-11	1.31E-08
	Campylobacter	4.12E-09	2.54E-08	6.71E-08	6.92E-08	8.47E-08	3.04 E-04
	Rotavirus	1.93E-09	2.62E-08	3.98E-08	7.81E-08	1.51E-05	1.35E-03
Average Annualised Risk .person^{-1}. year^{-1}	*Cryptosporidium*	1.83E-10	2.40E-09	2.15E-09	2.27E-09	3.01E-08	4.78E-06
	Campylobacter	1.50E-06	9.28E-06	2.45E-05	2.53E-05	3.09E-05	**1.05E-01**[1]
	Rotavirus	7.03E-07	9.55E-06	1.45E-05	2.85E-05	**5.49E-03**[1]	**3.90E-01**[1]
Average µDALYs	*Cryptosporidium*	3.80E-07	5.00E-06	3.86E-06	4.08E-06	5.40E-05	8.59E-03
	Campylobacter	3.13E-03	1.93E-02	5.10 E-02	5.26E-02	6.44E-02	**2.17E+02**[1]
	Rotavirus	6.08E-04	8.25E-03	1.25E-02	2.46E-02	**4.74E+00**[1]	**3.37E+02**[1]

Note: Those risk estimates in bold exceed the 1E-04 and 1 µDALY benchmarks.

7.1.2 Primary Recreation at Penrith Weir

Table 7-2 shows the estimated Enterococci concentration immediately after discharge. It can be seen that all concentration statistics are well below the recreational water 95th percentile recommended in the NH&MRC (2005). A similar very small residual concentration of *E. coli* can be expected.

Such low concentrations indicate that the MF-RO product would generally comply with traditional coliform guideline concentrations for drinking water as well (NWQMS 2004).

Table 7-2. Simulated Concentrations of Enterococci in Recreation Water Immediately after dilution in the river without any treatment

Statistic	Concentration in Water Enterococci .L^{-1}					
	Median Flow	High Flow	Low Flow	Highest Risk (low) flow, MF breakdown,	Highest Risk (low) Flow RO Breakdown	Low Flow MF-RO Concurrent Breakdown
Average	1.89E-08	5.42E-09	3.03E-08	1.53E-06	9.92E-04	4.85E-02
Median	3.17E-12	2.44E-13	4.93E-12	1.41E-06	1.53E-07	4.47E-02
95th percentile[1]	4.26E-09	3.35E-10	6.53E-09	3.04E-06	2.20E-04	9.61E-02

Note:

1. By way of comparison the 95th percentile benchmark target for Microbial Class A water in the NH&MRC (2005) guidelines is 400.L^{-1}.

Table 7-3 shows that the risk to recreators from the index pathogens is very low under nominal conditions (first 3 simulations). The fourth scenario assumes 26 days per year concurrent failure and indicates some risk in this unlikely event. The combined daily risk probability of *ca* 7 x 10^{-3} person^{-1}.d^{-1} is still below overall 1% risk probability proposed in the recreational guidelines for 'Class A' recreational waters.

Table 7-3. Primary Recreation Risks immediately after dilution in the river at Penrith Weir

Statistic	Microorganism	Median Flow Nominal Recreation Scenario	High Flow Nominal Recreation Scenario	Low Flow Nominal Recreation Scenario	Low Flow Recreation Nominal Recreation Scenario with 0.015 probability of MF-RO failure
Average Daily risk probability .person^{-1}.day^{-1}	*Cryptosporidium*	2.10E-13	1.13E-14	2.43E-13	3.17E-08[1]
	Campylobacter	1.79E-09	9.27E-11	2.03E-09	2.99E-03[1]
	Rotavirus	9.24E-10	6.73E-11	1.45E-09	3.64E-03[1]
Average Annualised Risk .person^{-1}.year^{-1}	*Cryptosporidium*	5.47E-12	2.94E-13	6.31E-12	8.24E-07
	Campylobacter	4.66E-08	2.41E-09	5.29E-08	**7.49E-02**
	Rotavirus	3.37E-07	2.46E-08	5.30E-07	**9.05E-02**
Average µDALYs	*Cryptosporidium*	9.83E-09	5.29E-10	1.13E-08	1.48E-03
	Campylobacter	9.71E-05	5.02E-06	1.10E-04	**1.56E+02**
	Rotavirus	2.92E-04	2.12E-05	4.58E-04	**7.82E+01**

7.1.3 Consumption of Shellfish and Irrigated Vegetables

Under nominal conditions both lettuce grown and mussels collected hypothetically at Penrith would have a very low probability of containing pathogens from the MF-RO plant (Table 7-4).

The daily risks from consuming water from the MF-RO plant on lettuce are such that they it is unlikely that the benchmark risk would ever be exceeded even where RO loss occurred.

The main uncertainty here is the risk posed by concurrent MF-RO failure and shellfish consumption. This was not simulated because there was judged to be so much uncertainty in both the scale and timing of bioaccumulation and the real likelihood of MF-RO failure going unrecongised, that quantification of this risk would not be useful.

Table 7-4. Risks estimated for Raw Food Consumption Scenarios of High Concern at Penrith Weir

Statistic	Microorganism	Low Flow Nominal Mussel Consumption Scenario[1]	Low Flow Nominal Irrigation and Consumption of Lettuce Scenario[1]
Average Daily risk probability .person^{-1} .day^{-1}	*Cryptosporidium*	4.94E-10	4.99E-14
	Campylobacter	2.59E-06	2.24E-10
	Rotavirus	2.88E-06	2.37E-10
Average Annualised Risk .person^{-1}.year^{-1}	*Cryptosporidium*	1.29E-08	1.82E-11
	Campylobacter	6.74E-05	8.16E-08
	Rotavirus	7.48E-05	8.66E-08
Average µDALYs	*Cryptosporidium*	2.31E-05	3.28E-08
	Campylobacter	1.40E-01	1.70E-04
	Rotavirus	6.46E-02	7.49E-05

Notes:
1. See Table 6-3 for further explanation of modelling assumptions.

7.1.4 Consumption of Water from North Richmond Reticulated Supply

Though it is a long way downstream and the water supply is extensively treated, risk assessment of the North Richmond drinking water supply was essential because of the large population served (daily demand = 50 ML).

Table 7-5 shows that as expected the risk to consumers from MF-RO plant discharge is negligible even compared to the Penrith untreated water situation. This is because:

- The treatment plant provides a barrier sufficient to reduce pathogens by a further 5 to 6 orders of magnitude;
- There will have been some further dilution;
- There will be have been significant inactivation under low to median flow conditions (compare Table 5-9 and Table 5-10).

These risks were so low that modeling of Hazardous Event scenarios was seen as unnecessary.

Table 7-5. Risks Estimated for Special Scenarios of High Concern for North Richmond

Statistic	Microorganism	High Flow - drinking w/o treatment	Low Flow - drinking w/o treatment	High Flow drinking with WTP	Low Flow drinking with WTP
Average Daily risk probability .person^{-1} .day^{-1}	*Cryptosporidium*	8.70E-13	1.25E-12	6.96E-19	1.12E-17
	Campylobacter	1.75E-10	1.42E-14	5.35E-16	2.53E-20
	Rotavirus	5.38E-10	2.30E-14	5.40E-14	2.00E-18
Average Annualised Risk .person^{-1}. year^{-1}	*Cryptosporidium*	3.17E-10	4.57E-10	2.54E-16	4.10E-15
	Campylobacter	6.38E-08	5.19E-12	1.95E-13	9.25E-18
	Rotavirus	1.96E-07	8.39E-12	1.79E-11	7.31E-16
Average µDALYs	*Cryptosporidium*	5.70E-07	8.21E-07	4.57E-13	7.36E-12
	Campylobacter	1.15E-04	9.32E-09	3.51E-10	1.66E-14
	Rotavirus	3.53E-04	1.51E-08	3.22E-08	1.31E-12

7.1.5 Daily Risks from Consumption during MF of RO malfunction at Penrith Weir

The greatest concern would probably be deliberate consumption or accidental ingestion on the day of a breakdown. Table 7-6 indicates a breakdown in the MF would probably not be a concern but a breakdown in the RO with or without MF function would be were the water to be used as a potable supply.

Similarly for ingestion during primary recreation and the failure scenario described, the average infection probabilities were estimated to be 5.0E-08, 3.0E-03, and 1.8E-03 person^{-1}.d^{-1} for *Cryptosporidium*, *Campylobacter* and Rotavirus respectively. The latter two are slightly lower than the benchmark for Class A recreational waters (risk probability = 1% or 1E-02 person^{-1}.d^{-1} for all gastroenteritis).

Table 7-6. Daily Risks from Potable Consumption During Plant Malfunction

Statistic	Microorganism	Highest Risk (low) flow, MF breakdown	Highest Risk (low) Flow RO Breakdown	Low Flow MF-RO Concurrent Breakdown
Average Daily risk. person^{-1}. day^{-1}	*Cryptosporidium*	2.82E-11	2.49E-07	9.00E-07
	Campylobacter	2.68E-06	4.50E-04	**4.25E-02**
	Rotavirus	3.25E-06	**1.29E-03**	**7.73E-02**

7.2 Interpreting Risk Probability Estimates

The final step in the risk assessment process involves interpretation and communication of risk assessment findings in a form that will aid decision-making. Qualitative Risk Assessment methods, provide a useful precedent because the risk assessments this process generates are in an easily understandable format. Particularly useful is the practice/framework where Consequences (Table 7-7) and Likelihood (Table 7-8) are estimated and combined to determine the 'level of risk' (Table 7-9).

The main limitations of the qualitative approach are that the assessments are based on 'expert opinion' and impact assessment categories are somewhat vague and subject to the perception of the assessor. This leaves the assessments open to concerns of bias on the part of those not involved in the process irrespective of how reasonable these assessments are.

Quantitative Risk Analysis differs in that it generates risk estimates that are based to a large extent on independently collected quantitative scientific data. The risk probability estimates are in theory proportional to the scale of risk faced *i.e.* the magnitude of the consequence or impact. And the process of scenario definition also defines the perceived Likelihood.

What remains is to standardise the interpretation of risk probability estimates in terms of consequences. There are currently no standards for interpreting Quantitative Microbial Risk probabilities in terms of qualitative consequence or impact descriptors. However efforts to move in this direction are promoted by current guidelines (*e.g.* WHO 2003).

The Benchmark value of 1 µDALY provides an initial point. What remains is to define the size of ranges equivalent to interpretations such as 'insignificant', 'minor' *etc.* For the purposes of the current assessment the approach taken has been to:

1. Use ten fold increases as the basis for assessing consequence magnitude. So the maximum µDALY value for each scenario as the measure of risk consequence and increasing

consequence classes be assigned according to the order of magnitude of the DALY value where:

a. < 1 μDALY is taken as being 'insignificant/undetectable'
b. 1-10 μDALY = 'minor'
c. 10 -100 μDALY = 'moderate'
d. 100-1000 μDALY = 'major'
e. > 1000 μDALY = 'catastrophic'

2. Adapt and apply qualitative risk assessment (Table 7-9) to assess the risk posed by each scenario so that:
    a. The specific risk posed by each scenario is assessed using the scheme above – effectively the impact or consequence – in effect the μDALY replaced for the scenario a qualitative Likelihood X Consequence product;
    b. The overall risk posed by a particular exposure pathway is assessed for each scenario where:
        i. Overall risk is based on Likelihood X Consequence;
        ii. The Likelihood of the scenarios is assessed using the criteria in Table 7-8 listed above; and
        iii. The Consequence is assessed from the maximum DALY value for the scenario.

The rationale for this scheme is that:

- It defines clearly what its meant here by 'moderate', 'possible' *etc.*;
- 1 μDALY is already seen as a potential benchmark where the level of infection is virtually undetectable with any current surveillance or analysis technologies;
- Categories based on order of magnitude increases reflect the wider range of possible risks, are unequivocally so different from one another that minor uncertainties do not impact on the reliability of the category assigned; and
- There are precedents for order of magnitude risk categories based on consequence, which show this approach to be useful, the best known being the Richter Scale used for earthquakes.

It is emphasised that the assignment of DALY ranges while 'reasonable' is still based on the authors' value judgments. As the form is transparent however, it may be revised easily in the future.

Table 7-7. Qualitative measures of consequence or impact

Descriptor	Example description
Insignificant	Insignificant impact or not detectable
Minor	Health – Minor impact for small population Environment – Potentially harmful to local ecosystem with local impacts contained to site
Moderate	Health – Minor impacts for large population Environment – Potential harmful to regional ecosystem with local impacts primarily contained to on-site
Major	Health – Major impacts for small population Environment – Potentially lethal to local ecosystem. Predominantly local, but potential for off-site impacts
Catastrophic	Health – Major impacts for large population Environment – Potentially lethal to regional ecosystem or threatened species. Widespread on-site and off-site impacts.

Table 7-8. Qualitative measures of likelihood as provided in the draft National Guidelines for water recycling

Descriptor	Example description
Rare	May occur only in exceptional circumstances. May occur once in 100 years
Unlikely	Could occur within 20 years or in unusual circumstances
Possible	Might occur or should be expected to occur within a 5 to 10 year period

Likely	Will probably occur within the next 1 to 5 year period
Almost certain	Is expected to occur with a probability of multiple occurrences within a year

Table 7-9. Qualitative risk analysis matrix: level of risk (from draft National Guidelines for Water Recycling)

Likelihood	**Consequences**				
	Insignificant	Minor	Moderate	Major	Catastrophic
Rare	Low	Low	Low	Low	High
Unlikely	Low	Low	Moderate	High	Very High
Possible	Low	Moderate	High	Very High	Very High
Likely	Low	Moderate	High	Very High	Very High
Almost certain	Low	Moderate	High	Very High	Very High

So risk probabilities were used in two ways:

1. The individual risk probabilities provided a means of assessing whether a given scenario was in need of management.
2. By assessing the likelihood of a number of scenarios associated with a particular exposure pathway it was possible to assess the overall consequences of the exposure pathway and their implications for management of the exposure pathway.

To illustrate, in the present study the scenario of concurrent MF and RO failure + consumption of untreated water as a potable supply yielded *Campylobacter* and Rotavirus disease burdens of 220 and 340 μDALYs respectively indicating a major impact or consequence which is in line with commonsense. This indicates that this scenario needs to be managed. More generally this example illustrates how the quantitative risk estimation process can identify operating scenarios whose risks are acceptable or unacceptable.

Because of its severity the scenario cannot be dismissed in an *ad hoc* manner given the current limited long term performance data for MF and RO. However, based on the data available from Singapore and limited literature this scenario also seemed 'very unlikely'. So the overall risk posed by it would seem based on Table 7-9, to be 'Low' and hence not a reason for rejecting the replacement water scheme.

7.3 Overall Risk Assessment

To assess the general level of risk to Hawkesbury-Nepean river water users from the proposed flow replacement scheme the various scenarios were assessed (Table 7-10) using the scenario assessment scheme proposed above. Consequences were assessed as described above using the maximum μDALY estimate approach. The Likelihood assessments of scenarios with higher than insignificant consequences are shown in Table 7-11.

Firstly it can be seen that:

1. The baseline scenarios where the plant it operating nominally pose a very low risk such that:
    - Direct consumption of pathogens from the MF-RO plant on a long-term basis at Penrith Weir itself would pose an 'insignificant' risk;
    - Similarly eating of shellfish or raw vegetables or primary contact at this point would pose an 'insignificant' risk; and
    - Most importantly the MF-RO replacement water would pose such an 'insignificant' risk to consumers of water extracted at North Richmond that it can be also discounted.
2. The only scenarios of concern identified where consequences were more than 'insignificant' were those associated with consumption of large volumes of river water during large scale/extended duration breakdown in the RO system.

When the Likelihood and Consequences were compared although some scenarios were 'almost certain' (exposure to contaminants from the replacement flow releases from drinking water extracted at North Richmond) or had 'Major' consequences, all scenarios generated a 'Low' risk rating when Likelihood is balanced against consequence.

As indicated in the Introduction the endpoint of this assessment was not to generate management options but only to inform (risk) management. In respect to this latter need the following general conclusions have been made:

- There is no evidence of severe risk that would preclude the replacement water scheme.
- Drinking of raw water on a continuous basis was seen as a worst case and a very unlikely one; and even it appears to pose a low risk.
- The main uncertainties related to RO performance. These did not reflect poor data on performance but a lack of complete information on failure modes. The latter derived in part from a lack of available data and a lack of design information on the proposed RO plant.
- This limitation should be possible to address by:
    - Collection of RO performance data relevant to the ability of these systems to remove pathogens under suboptimal operating conditions.
    - Use of this data to model performance under more realistic failure modes than was possible in this study.
    - Development of Critical Limits on RO performance and a management system able to achieve water quality sufficient to achieve a 'Low' risk for downstream water users.

Table 7-10. Summary of Microbial Risks Scenarios

Exposures Pathway	**Assessment Point**	**Scenario**	**Highest Risk**		**Subjective Assessment of Scenario occurring**		
			Pathogen	µDALYs	Consequences[1]	Likelihood[2]	Risk Rating
Direct drinking consumption of untreated river water as a result of its use for domestic uses	Penrith	High (20%ile) Flow	*Campylobacter*	0.003	Insignificant	Possible	Low
		Median Flow	*Campylobacter*	0.02	Insignificant	Possible	Low
		Low (80%ile) Flow	*Campylobacter*	0.05	Insignificant	Possible	Low
		Low (80%ile) Flow MF breakdown (5.3 days.y^{-1})	*Campylobacter*	0.05	Insignificant	Unlikely	Low
		Low (80%ile) Flow RO Breakdown (5.3 days.y^{-1})	Rotavirus	**4.7**	**Minor**	Unlikely	Low
		Low (80%ile) Flow RO+MF concurrent breakdown(5.3 days.y^{-1})	Rotavirus	**340**	**Major**	Rare	Low
Direct accidental ingestion during primary recreation (26 days.y^{-1})		High (20%ile) Flow	Rotavirus	0.0002	Insignificant	Likely	Low
		Median Flow;	Rotavirus	0.00002	Insignificant	Likely	Low
		Low (80%ile) Flow	Rotavirus	0.0004	Insignificant	Likely	Low
		Low (80%ile) Flow +MF-RO failure (26 days)	Rotavirus	**78**	**Moderate**	Rare	Low

			Highest Risk		Subjective Assessment of Scenario occurring		
Direct consumption of mussels		Low (80%ile) Flow; 1 meal per day, 26 meals in one year	*Campylobacter*	0.1	Insignificant	Unlikely - Possible	Low
Direct consumption of irrigated lettuce		Low (80%ile) Flow; 365 normal serving of lettuce in one year)	*Campylobacter*	0.0002	Insignificant	Possible	Low
Direct drinking consumption of untreated river water	North Richmond	High (20%ile) Flow	*Rotavirus*	0.0001	Insignificant	Almost certain	Low
		Low (80%ile) Flow	*Crypto-sporidium*	8×10^{-7}	Insignificant	Almost certain	Low
Direct drinking consumption of treated river water		High (20%ile) Flow	*Rotavirus*	3×10^{-8}	Insignificant	Almost certain	Low
		Low (80%ile) Flow	*Crypto-sporidium*	7×10^{-12}	Insignificant	Almost certain	Low

Notes:

1. μDALYs were use to assign ratings as follows:
    a. < 1 = insignificant/undetectable
    b. 1-10 = minor
    c. 10 -100= moderate
    d. 100-1000 = major
    e. > 1000 = catastrophic
2. Likelihood ratings for the scenarios are as follows:
    a. Scenario **rare** – only in exceptional circumstances or > 100 year recurrence interval
    b. Scenario **unlikely** – could occur in exceptional circumstances or within 20 years
    c. Scenario **possible** – might occur or should be expected with 5 to 10 year recurrence
    d. Situation will **probably** occur in the next few years
    e. Situation is **almost certain** to occur frequently

Table 7-11. Rationale for Assignment of Likelihood Ratings where Consequences Greater than Insignificant were encountered

Exposures Pathway	Assess-ment Point	Scenario	Consequence and Likelihood Ratings		Rationale for Likelihood Rating
			Conse-quences[1]	Like-lihood[2]	
Direct drinking consumption of untreated river water as a result of its use for domestic uses	Penrith	Low (80%ile) Flow RO Breakdown (5.3 days.y^{-1})	Minor	Unlikely	Breakdown prevention or minimisation of malfunction periods should be possible using real-time monitoring pressure decay and diffusive air testing. The DR values were obtained for small units rather than the large multi unit modules planned.
		Low (80%ile) Flow RO+MF concurrent breakdown(5.3 days.y^{-1})	Major	Rare	As above except scenario even less likely because it would require both MF and RO to fail simultaneously and for this situation to go unchecked for several days each year.

			Consequence and Likelihood Ratings		
Ingestion during primary recreation scenario		Low (80%ile) Flow +MF-RO failure (26 days)	Moderate	Rare	As above

8 Uncertainties

There are various uncertainties associated with the pathogen assessment. Some approaches used to take them into account are introduced briefly in sections 3.2.2 and 3.2.3. Some further examples are outlined in Table 8-1. The remainder of this section outlines in further detail aspects of those uncertainties associated with the core risk assessment process steps seen as most of concern in the decision making process.

In addition to these there are other generic uncertainties relating to the risk assessment process as a whole, which are identified and discussed in Part E.

Table 8-1. Summary of types and sources of uncertainty in the risk assessment

Type of Uncertainty	How Addressed	Notes
Uncertainty generally	• Use of Monte Carlo quantitative barrier simulation • Use of probability density functions in place of point estimates where practicable	Models of risk as applied here must always be recognised as models and not reality
Source water data quality variability	• Use of Monte Carlo quantitative barrier simulation • Use of probability density functions in place of point estimates where practicable	Could be improved with local data. But this is not necessarily justified as maximum risks would be unlikely to greatly increase.
Source water data quality uncertainty	• Strict estimation of uncertainty impacts not assessed.	Not practical in desktop survey
Hazardous Events	• Simulation of hazardous event scenarios	Hazardous Event scenarios considered are conservative.
Dose Response relationships vary between pathogens	• Use of index pathogens with high infectivity	Further pathogen dose response relationships can be assessed if necessary
Use of point estimates for input modelling	• Testing of various scenarios	Further worst case scenarios can be assessed if necessary.
Other pathogens may be a concern	• Use of 3 quite different and relatively recalcitrant pathogens	Further pathogen dose response relationships can be assessed if necessary
Severity of illness	• Inclusion of DALYs	
Different exposure pathways and situations	• Consideration of worst cases and different pathways	Further scenarios can be assessed if necessary.
At risk populations	• Consideration of worst case scenarios	Further scenarios can be assessed if necessary.
Public acceptability	• Not addressed directly; indirectly addressed by undertaking various worst case simulations.	Public not consulted. However report findings provide basis for discussing risks with public.

8.1 Hazard Identification

There are numerous other pathogens whose risks was not estimated because of a lack of sufficient data, poor detection methods or time and resource limitations for example Hepatitis A virus (HAV) (Conaty *et al*. 2000). Dose-response data is available for HAV and MF-RO removal and inactivation in the environment probably follows a similar pattern to other Enteroviruses. However, despite the availability of quantitative assay methods (*e.g.* Morace *et al.* 2002) the data available on its abundance in sewage and surface waters is limited and somewhat equivocal (*e.g.* Lodder and deRodda Husman 2005; Griffin *et al.* 2003). Reports cited by Lodder and deRodda Husman (2005) suggest HAV is rare compared to other viruses. And the study of Conaty *et al*. (2000) suggests that in Australia Hepatitis A virus is substantially less abundant than the other viruses. The work of Jiang and Chu (2005) and Pusch *et al.* (2005) suggest it may be more common in the US but the latter references only report presence or absence.

Provisionally it is concluded that the HAV appears less abundant in water than rotavirus, which may balance the somewhat greater disease severity of disease caused by HAV (*e.g.* mortality if *ca* 10 times that of Rotavirus; Bosch, 1998).

Also poorly documented was how high the concentrations of viruses were in the tertiary treated Western Sydney STPs. This uncertainty was allowed for by assuming starting concentrations more consistent with secondary treated sewage whose concentrations could be expected to be higher.

8.2 Dose Response Assessment

Dose responses for pathogens vary greatly as do the severity of disease in those infected (Bosch 2000). Infection rate variability was allowed for in part by using recently derived dose response curve coefficient estimates, which assumed high infectivity and estimating both infection rate and DALYs. But this does not allow for the high variability in disease severity following infection.

There is also the matter of variability in infection severity and outcome between different populations. Rotavirus for example is seen as more of a hazard for children.

8.3 Exposure Assessment

8.3.1 Hazard Locations

There were no significant geographic uncertainties in the hazard locations because the impacted area was well defined.

8.3.2 Exposure Pathways

There were a number of exposure pathways, which were not assessed. The risks from these other secondary pathways or pathway variations (Table 8-2), were seen as largely being addressed by the assessments of the primary pathways of concern whose risk is expected to be greater than those of secondary pathways.

Table 8-2. Alternative Pathways or Pathway Variations Not Simulated

Alternate Pathway / Pathway Variation	How Accounted For
Secondary and Tertiary Contact Recreation	Will be less than for primary contact recreation and therefore covered by the latter assessment
Recreation, raw drinking water, food consumption contact at sites downstream of Penrith	Will be less than or comparable to exposure via these pathways at Penrith.
Aerosol inhalation	Aerosol inhalation during recreation would involve much less volume than direct consumption. No basis for inferring that STP effluent will have major aerosol pathogens (*e.g. Nagleria*, Legionellae).
Dermal contact	Not a major route of exposure to model enteric pathogens of STP origin expected in Australia compared to ingestion.
Bioaccumulation	Covered by model vegetable ingestion. Main pathway believed currently to be via attachment to plant surfaces rather than via root uptake.
Shedding	Included in NH&MRC (2005) guideline risk assessment

A full exposure path assessment was beyond the scope of this project. To provide useful risk assessment and management recommendations a wide range of exposure scenarios varying in application method, locality, season and wind conditions, would probably have to be developed.

Some indication of the risks arising from exposure to aerosols can be gleaned from the study of Höglund *et al.* (2002). This work estimated the risk arising from the untreated aerosolised diluted urine and containing much higher environmental concentrations of viruses than predicted for Hawkesbury-Nepean River water post MF-RO treatment (Table 8-3).

In Table 8-3 we have reproduced the key input assumptions (concentrations of pathogens in the urine before aerosolisation, under the worst model conditions i.e disease outbreak in the community) and the maximum risks estimated to arise via this exposure route. For comparison the concentrations of the same pathogens predicted for the river water at Penrith are shown alongside.

It can be seen that:

- even with urine irrigation only rotavirus posed a high infection risk due to its high infectivity and initial concentration of the virus;
- the pathogen concentrations predicted for river water at Penrith are over 1 million fold lower than in the urine in all cases indicating that under even the worst situation for the Hawkesbury-Nepean River the infection risk probability should be less than 1E-06.person^{-1}.expsoure^{-1} in the worst case of suboptimal MF-RO performance.

Table 8-3. Comparison of Pathogen Concentrations in Aerosolised Urine and Risks Arising with Pathogen Concentration in Hawkesbury-Nepean River Water

Pathogen	***Risk Probability (.person^{-1}.expsoure^{-1}) of Infection for Worst Case Urine Aerosol[1,2]***	Mean Pathogen Density		
		Urine[1]	**Nominally Treated MF-RO water diluted during Low Flow Scenarios[3]**	**Concurrent MF-RO Suboptimal Performance during Low Flow[3]**
Cryptosporidium	***1.2E-04***	*2.1E+01. L^{-1}*	2.78E-11. L^{-1}	1.6E-06. L^{-1}
Campylobacter	*2.0E-05*	*4.6E+03. L^{-1}*	1.64E-07. L^{-1}	1.0E-01. L^{-1}
Rotavirus	***4.2E-01***	*2.4E+05. L^{-1}*	8.11E-08. L^{-1}	2.1E-01. L^{-1}

1. Data from Höglund *et al.* (2002) Exposure Scenario group 3 – inhalation of aerosols while fertilising crops with urine, 100m downwind of application point.
2. These assume epidemic levels of infection in the community.
3. Concentrations calculated for the mixing zone at Penrith.

8.3.3 Exposure Concentrations

Uncertainty arose from the need to simulate a series of barriers. Such barriers each vary in their effectiveness at controlling pathogen exposure. To allow for this the simulations used probability density functions and Monte Carlo style simulations rather than point estimates of exposure reductions. But some of these barrier functions had limitations such as:

- The parameter values were conceptual at full-scale (RO during breakdown); and
- The data was not based on local measurements (Rotavirus in sewage).

8.3.4 Contaminant Intake

Variability in contaminant intact was allowed for by the use of probability density functions and the use of what were considered conservative intake estimates. For basic physiological reasons it is unlikely that drinking water consumption rates which relate to the two most important pathways (potable drinking use and primary recreation) differed much from those adopted for modeling.

8.3.5 Hazardous Event/MF-RO Plant Failure modes

There was uncertainty in the modeled failure rates. As far as it was possible hazardous event simulation assumptions were all conservative. But such data is still needed.

8.3.6 Scenarios modeled

The principle uncertainties in the scenarios were seen as:

- The number of recreation or fishing visits per year;
- The quantity of mussels consumed;
- The amount of lettuce consumed and whether there might be any pathogens taken up by plants.

These were considered likely to be conservative worst-case assumptions and hence uncertainties were unlikely to pose a problem for the following reasons:

- Direct consumption in recreation would be far less than via the raw drinking water route and thus the latter estimates would identify whether there was a major risk.
- It was unclear if anyone currently consumes raw mussels.
- It is normal good hygiene practice that raw vegetables are washed before consumption and this would provide a large degree of additional protection not accounted for here.

Two scenarios classes, not modeled in detail because they were seen as being of secondary concern when the scope of the Screening assessment tasks was agreed to, but which might be quantified in a fuller (*i.e.* non-screening level) risk assessment, were:

- Aerosol inhalation associated with open space watering and crop irrigation;
- The combination of contaminants in the replacement water with those from other sources.

The potential aerosol infection from recreation is discussed above in relation to irrigation.

Aerosols are also thought important where there is primary contact (WHO, 2003; NH&MRC 2005). While the risk from aerosols during recreation was not specifically modelled the extent of risks of "Acute Febrile Respiratory Illness" is incorporated into the recreation guidelines more generally. And the extent of Enterococci removal suggests the risk from the MF-RO water would be tolerable (see Section 7.1.2 for assessment against NH&MRC 2005 water quality guidelines).

The issue of other contaminants is dealt with further under the generic uncertainty section 20.3.

8.4 Risk Characterisation

Risks estimated by simulating pathogen exposure pathways were so low that it would be impossible to independently verify their accuracy by any currently available technology. Epidemiological studies are the only theoretical means but their sensitivity is far to poor to be able to detect pathogen risks of the order of 1 μDALY.

However the risks arising from water borne pathogen exposure are now based on well-developed theories on infection pathways and an understanding of pathogen ecology. A range of information and scientific studies attests to the soundness of 'Barrier Theory' in particular:

- The success of water treatment processes and catchment protection policies indicated by the low level of disease in the Australian community;
- Epidemiological studies of water recreation which show a correspondence between faecal contamination and disease incidence;
- That periodic outbreaks of disease associated with water can be linked with hazardous events of the kind considered here (*e.g.* poor management of sewage disposal at Wallis Lake led to contamination of shellfish and ultimately infection of consumers; the Walkerton drinking water contamination incident associated with poor barrier performance and analysis of exposure pathways).

The issue of what are appropriate Benchmarks in the Australian context remains unresolved. In this report we discussed risk by reference to the 1 μDALY, an infection probability of 1E-04.person^{-1}.y^{-1} and 1% per recreational exposure.

9 Management

It was not seen as a major function of the project to recommend specific management regimes for the replacement water scheme as:

- the role of a Screening Assessment was seen as to determine if a full risk assessment was needed; and
- only limited details of the MF-RO specifications were available.

Nevertheless the exposure analysis process showed a range of data gaps, uncertainties and possible exposure situations whose significance might be assessed in subsequent studies as a matter of priority. This section identifies and discusses a range of such management issues and identifies options that may be feasible or appropriate.

9.1 Elaboration of MF-RO Plant Failure Modes, Rates, Detection and Scale

MF-RO plant function would need to be maintained at a appropriate degree of functionality with any suspected malfunction triggering rapid shut down, if only to assure the community of the safety of this novel use of wastewater. This is probably feasible because of the modular design of MF-RO plants that should allow removal from the treatment process of any malfunctioning sub-units.

The total risk should be very small from any such malfunctions because of the high quality of the feedwater. In any case estimation of the risks arising from a module breakdown should be possible to model easily along with the risks arising to confirm this perception. **Thus it is recommended that a computer-based model of failure modes, their impact, their detection and management actions triggered should be developed as one basis for developing testing system management protocols.**

One approach to gaining more understanding of MF-RO failure modes would be to construct a small test MF-RO system. The benefits gained from such a pilot plant though would likely be very limited because:

- It is already planned to undertake a range of tests on the MF-RO plant membrane performance as part of its commissioning;
- It is already clear that MF-RO systems are very effective at removing pathogen and chemical contaminants when under operating nominal conditions. This is supported by such information as the Singapore MF-RO monitoring data. A small pilot test unit would be unlikely to provide any more useful data in regard to nominal performance;
- The risk assessment undertaken indicated that risk under nominal conditions was low based on the 1 μDALY benchmark.
- It is not the risk under nominal conditions that is uncertain. It is the affect of failure conditions on risk, which needs additional data.

Thus it is considered that testing would be more appropriate on the full-scale constructed system with a view to suspending its operation when a malfunction was detected. Such testing would be most useful after a system had been operating for a period of time (some months). The modular structure of MF-RO plants would probably allow the following to be carried out:

- Confirm performance at full-scale operation and assess actual plan operating characteristics;
- Confirm the capacity of failure detection systems (*e.g.* pressure data measurement and analysis) to work effectively; and

- Undertake challenge testing of an operational part of the treatment train using safe surrogate microorganisms (*e.g.* bacteriophage) and chemicals (*e.g.* fluorescent dyes) after it has been taken off line.

Such work could address data gaps such as how good are pressure sensors monitoring arrays of filters and their proposed arrangement at detecting problems in single modules?

Such work would also probably be much more operationally and cost effective at protecting the public than high frequency end point testing as it would allow more powerful hypothesis testing to be undertaken.

9.2 Validation of Risk Assumptions and Data

Another desirable activity is confirmation of the assumptions underlying the current risk assessment. The key assumptions that could be better quantified as follows:

- **Measurement of selected pathogens and chemicals in the proposed feedwater (alternatively measurement of contaminants in raw sewage and the effectiveness of upstream STP barriers might be a more effective way of obtaining above detection limit measurements);**
- **In depth discussions with membrane manufacturers and acquisition of membrane performance and failure data such that their performance can be expressed probabilistically and used in models;**
- **An onground survey of Hawkesbury-Nepean River user behaviour patterns pertinent to risk to determine such relevant behaviours as:**
    - **Where raw water is actually consumed as the primary drinking source (caravan parks have been identified);**
    - **Whether mussels are consumed at all;**
    - **Where irrigation takes place and what crops are irrigated and what their fate is.**
    - **Recreation frequency and location between Penrith and Richmond now and in the future (given the Penrith Lakes development effects);**
    - **Any other risk-related activity such as exposure to aerosols.**
- **The protective effect of key natural processes *e.g.* sunlight driven disinfection, chemical volatilisation.**

It is probably unnecessary to reassess or measure:

- water consumption rates;
- dose response assumptions; and
- pathway risk if new data indicates the risk is much the same as estimated here.

End point monitoring or extensive 'monitoring' of the river would probably not be useful because of the low levels of analytes much of the time. Though assessment of sediment accumulation of contaminants and microcosm experiments to confirm process rates might for auditing purposes immediately above and below the emission zone.

9.3 Other Management Options

Other management options that might be considered are:

- **Advisory signs and other communication aimed at reducing any residual exposure near the main release point as a precautionary measure;**
- **Adapting/Reviewing/Modifying existing STP exception response protocols (*e.g.* warnings to the community);**

- **Quantitative Risk Assessment of aersol risks; and**
- **Reporting performance data in refereed journals and other literature to ensure it is peer reviewed and the risk assessments credible**.

9.4 Public Consultation

The information being gathered here would appear to be relevant not only to the current project but to future water recycling generally.

Thus public consultation in the near future is seen as warranted which presents the both the benefits and limitations of MF-RO together within the context of a large working project. Such consultation would also be useful for identifying any further risk pathways which have been somehow overlooked or which the community feels need assessing so that they can be reassured. For example discussion with irrigators and other water extractors about the MF-RO plant's aims could help improve understanding of actual exposure pathways in the Hawkesbury-Nepean River catchment generally.

Part C. Chemical Risk Assessment

10 Issue Identification

A summary of the full listing of possible chemical of concerns is presented in Appendix 3.

The principal available relevant data was that acquired by sewage treatment effluent monitoring undertaken by Sydney Water. This data is known as "Schedule 10 data" and consists of measurements of 111 organic and inorganic chemical parameters that had been identified in previous risk assessments as being of concern (*e.g.* Sydney Water 1996). Schedule 10 data were combined for the three relevant sewage treatment plants (Penrith STP, Quakers Hill STP and St Marys STP) for the years 2000-2004. This provided a minimum of 25 data points for each of the 111 chemical parameters.

The Schedule 10 list includes numerous classes of chemicals that have been associated with human health concerns. Examples include some heavy metals, pesticides, industrial chemicals, solvents, polyaromatic hydrocarbons and polychlorinated biphenyls.

A number of chemicals that are not included in the Schedule 10 list were also considered for risk assessment. These additional chemicals were considered based on the recognised public concerns for some chemicals (endocrine disrupting chemicals, EDCs) and the potential for formation during the advanced treatment process (disinfection and biofouling control by-products – NDMA and halogenated organics). The antiseptic agent, triclosan was also identified as a potential contaminant of concern for consideration.

11 Hazard Assessment

The hazard assessment process was undertaken in two main stages. These are described in the 'Hazard Identification' Section (11.1) and the 'Dose-Response assessment' Section (11.1.5) .

11.1 Hazard Identification

Hazard identification was undertaken in two steps. The first was to match the list of hazardous chemicals with the available historical data and then undertake a hazard screening step to eliminate chemicals of minimal concern and in so doing identify those warranting more detailed attention. For the most part 'Screening' involved comparison of chemical concentrations in tertiary treated STP water with guideline values and removal of chemicals from further consideration whose concentrations not of concern even before MF-RO treatment.

This process of hazard identification is illustrated in Figure 11-1.

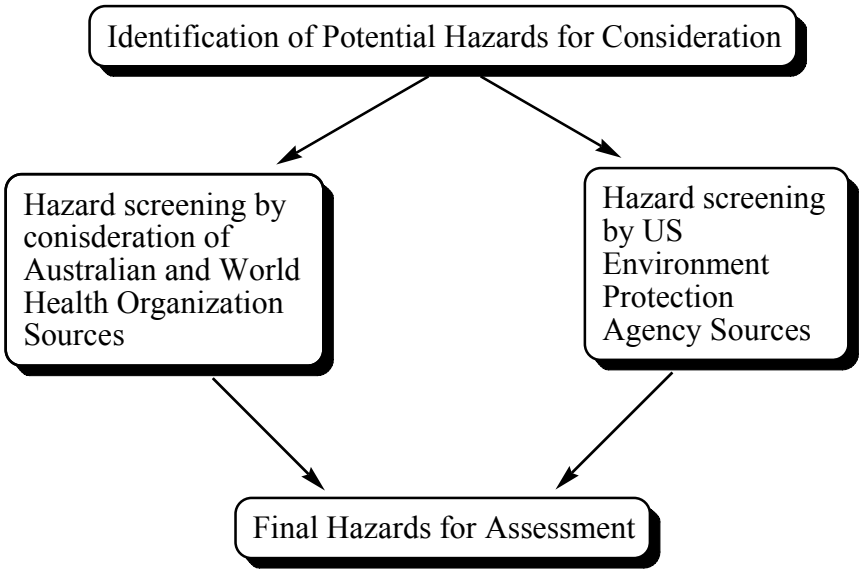


Figure 11-1. Process used for the identification of hazards for assessment

The first step of 'hazard identification' in the current assessment was to provide a list of potential chemical contaminants in water, which should be (at least preliminarily) considered.

11.1.1 Schedule 10 chemicals

An initial list of chemical parameters was selected for consideration matching Schedule 10 of the Sydney Water Act 1994. The original purpose of the Schedule 10 list is described in Section 23 of the Act. Schedule 10 monitoring data was not collected for the specific purpose of undertaking chemical risk assessments for treated effluent.

The Schedule 10 list comprises a range of single chemicals, as well as some broad categories such as "polyaromatic hydrocarbons, including chlorinated naphthylenes, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs)".

The Schedule 10 data used in this assessment included 111 organic and inorganic chemical parameters. Monitoring data from Penrith STP, Quakers Hill STP and St Marys STP, for the years

2000-2004 were combined. This provided a minimum of 25 data points for each of the 111 chemical parameters.

The chemical hazards identified by Sydney Water Schedule 10 during 2000-2004 are provided in Table 11-1. The number of data points recorded during that period is denoted "n". In a large number of cases, chemical concentrations were below analytical detection limits. The number of these is identified in Table 11-1 as 'n<LOD'. In such cases, the analytical detection limit was used for screening in place of the maximum possible value and used as a conservative surrogate of the actual 95th percentile concentrations. Accordingly, care must be taken when interpreting Table 11-1 since the presence of a 95th percentile concentration does not necessarily imply that the chemical was ever measured at such a high concentration, but only that it could not be confirmed to be less than that concentration due to analytical technique limitations.

Table 11-1. Chemical hazards identified by Sydney Water Schedule 10, 2000-2004

Analyte	95th percentile (µg.L^{-1})	n	n<LOD
2,4-D	0.9	25	25
Acenaphthene	0.1	25	24
Acenaphthylene	0.1	25	25
Acrylonitrile	5	25	25
Aldrin	0.01	25	25
Aluminium	391.6	93	3
Ammonia	1270	761	208
Anthracene	0.1	25	25
Arsenic	1	28	25
Atrazine	0.5	25	25
Barium	10.2	25	1
Benz(a)anthracene	0.1	25	25
Benzene	1	25	25
Benzene Hexachloride (Alpha)	0.01	25	25
Benzene Hexachloride (Beta)	0.01	25	25
Benzene Hexachloride (Gamma) - Lindane	0.01	67	67
Benzidine	5	25	25
Benzo(a)pyrene	0.1	25	25
Benzo(b)fluoranthene	0.1	25	25
Benzo(e)pyrene	0.1	25	25
Benzo(ghi)perylene	0.1	25	25
Benzo(k)fluoranthene	0.1	25	25
Boron	138	25	0
Bromoform	2.8	25	20
Cadmium	0.24	73	45
Carbaryl	1	25	25
Carbon Tetrachloride	1	25	25
Chlordane (Total)	0.01	25	25
Chloride	190450	72	0
Chlorobenzene	0.5	25	25
Chloroform	7	67	9
Chloronaphthalene	0.1	25	25
Chlorophenol (2)	1	25	25
Chlorpyrifos	0.07	133	110
Chromium	1	28	22
Chrysene	0.1	25	25
Cobalt	1.2	31	0
Copper	7.8	125	11

Analyte	95th percentile (µg.L^{-1})	n	n<LOD
Coronene	0.1	25	25
Cresol (m)	1	25	25
Cresol (o)	1	25	25
Cresol (p)	1	25	25
DDD	0.01	25	25
DDE	0.01	25	25
DDT	0.01	25	25
Demeton (Dem S-Methyl)	0.1	25	25
Diazinon	0.2	147	121
Dibenz(ah)anthracene	0.1	25	25
Dibromochloromethane	9	25	10
Dichlorobenzene (1,2)	0.5	25	25
Dichlorobenzene (1,3)	0.5	25	25
Dichlorobenzene (1,4)	0.5	25	25
Dichlorobenzidine	5	25	25
Dichloroethane (1,1)	1	25	25
Dichloroethane (1,2)	1	25	25
Dichloroethene (1,1)	1	25	25
Dichloromethane	5	25	25
Dichlorophenol (2,4)	0.1	42	41
Dieldrin	0.01	99	98
Diphenylhydrazine	5	25	25
Endosulphan	0.01	42	42
Endrin	0.01	25	25
Ethylbenzene	1	25	25
Fluoranthene	0.1	25	25
Fluorene	0.1	25	25
Free Chlorine Residual	154	174	14
Glyphosate	10	25	25
Guthion (Methyl Azinphos)	0.1	25	25
Heptachlor	0.005	25	25
Heptachlor-epoxide	0.01	25	25
Hexachlorobenzene	0.01	25	25
Hydrogen Sulphide (un-ionised)	20	108	92
Indeno(1,2,3-cd)pyrene	0.1	25	25
Iron	605	31	0
Lead	1	42	40
Malathion	0.1	25	25
Manganese	85	70	0
Mercury	0.02	67	63
Methoxychlor	0.01	25	25
Methylene Blue Active Substances	226	25	1
Molybdenum	24.65	28	0
Naphthalene	0.1	25	25
Nickel	31.85	34	0
Nonyl Phenol Ethoxylate	5	25	24
Octyl Phenol Ethoxylate	5	25	25
Parathion	0.1	25	25
Pentachlorophenol	0.1	25	25
Perylene	0.1	25	25
Phenanthrene	0.1	25	25
Phenol	1	25	25
Polychlorinated Biphenyls	0.1	25	25

Analyte	95th percentile (µg.L^{-1})	n	n<LOD
Pyrene	0.1	25	25
Selenium	5	25	25
Silver	0.1	59	57
Styrene	1	25	25
Sulphate	87000	25	0
Tetrachloroethene	1	25	25
Tetrachlorophenol	0.1	25	25
Tin	1	25	22
Toluene	1	25	25
Total Chloramines	319.5	102	39
Total Chlorine Residual	50	488	465
Total Cyanide	43.5	34	12
Total Polycyclic Aromatic Hydrocarbons	0.1	25	25
Trichloroethane (1,1,1)	1	25	25
Trichloroethene	1	25	25
Trichlorophenol (2,4,5)	0.1	25	25
Vanadium	10	25	25
Xylene (m+p)	1	25	25
Xylene (o)	1	25	25
Zinc	59.5	51	0

11.1.2 Endocrine disrupting chemicals (EDCs)

Endocrine disrupting chemicals (EDCs) are chemicals that may have a deleterious impact on the endocrine (hormonal) system of any species. During the last decade, EDCs have risen in profile to such a degree that concern regarding their impacts, or the lack of knowledge regarding impacts, has begun to have major influences on the ways in which water is managed.

Much attention has been devoted to natural and synthetic steroidal hormones, which are shown to induce biological effects on some organisms at part per trillion concentrations. Other chemicals exhibiting similar effects and known to be present in sewages include some plasticisers, pesticides and degradation products of some detergents. The presence and implications of endocrine disrupters in sewage and the environment has been previously discussed in an Australian context by Ying and Kookana (2002).

Numerous endogenous steroidal hormones are excreted via urine into sewage. Predominant among these is 17β-estradiol. During metabolism, 17 β -estradiol is primarily converted to estrone and further to oestriol. A variety of sulphate and glucuronide conjugates are also excreted. These excreted conjugates may be hydrolysed to the parent compounds in wastewater. Because of their increased oral potency, synthetic estrogens are employed in hormone replacement therapy and in contraceptive formulations. The most common of the synthetic contraceptive estrogens is ethynylestradiol. These natural and synthetic steroids are the most significant of the environmental EDCs in terms of hormonal potency (Metcalfe *et al.*, 2001). A principal route of these compounds to the environment is via the discharge of treated municipal sewage effluent (de Mes *et al.* 2005).

In addition to natural steroidal estrogens, a number of non-steroidal chemicals have been observed to mimic the action of estrogen by virtue of key features of their molecular structures. Alkylphenol-polyethoxylates are an important class of non-ionic surfactants that are widely used in many household and industrial detergent formulations. While the alkylphenol-polyethoxylates are known to be eliminated efficiently during sewage treatment, a range of major biodegradation products including nonylphenol and octylphenol are known to persist, sometimes in high concentrations (Ying *et al.* 2002). These compounds have been demonstrated to be estrogenic to fish, birds and

mammals by a variety of bioassays. However, the relative estrogenic potencies are many orders of magnitude less than that of the steroidal estrogenic hormones (Jobling & Sumpter 1993).

11.1.3 Disinfection and biofouling control by-products

Most modern membrane-based advanced water treatment plants require some form of biofouling control to protect the membranes. This is normally undertaken by chlorine-based disinfection (usually chloramine) prior to membrane contact.

Information received from Sydney Water indicated that biofouling would be controlled by monochloramine: "A concentration of 2 $mg.L^{-1}$ of monochloramine is required in the feed. This represents 0.54 $mg\ L^{-1}$ of nitrogen as monochloramine. There will be a slight excess of ammonia to prevent residual chlorine attacking the membranes. After single pass RO the Chloramine-N would be 0.27 $mg.L^{-1}$. This will produce 0.09 $mg.L^{-1}$ of ammonia nitrogen." (*pers. com.* Adam Lovell 2006). Accordingly, by-products that may be formed from such disinfection (or biofouling control) processes represent potential human health risks.

Chlorine disinfectants may react with organic matter in water to produce halogenated organics, most notably trihalomethanes (THMs) (Adams *et al.* 2005). Current Australian Drinking Water Guidelines (ADWG) note the following health considerations (NWQMS, 2004).

> *"In animals, the trihalomethanes are central nervous system depressants and liver and kidney toxicants. Chloroform and bromoform are also known to cause central nervous system depression in humans. Some epidemiological studies have reported associations between the ingestion of chlorinated drinking water (which typically contains THMs) and increased cancer mortality rates. The International Agency for Research on Cancer has concluded that the available data for chlorinated water provide inadequate evidence of carcinogenicity in humans (Group 3, inadequate evidence in humans and limited evidence in animals)".*

Recent attention in the USA and Canada has been given to the detection of the carcinogen, nitrosodimethylamine (NDMA) in chloraminated waters intended for reuse. NDMA is believed to be formed as a by-product of the chloramination disinfection process (Mitch & Sedlak 2002b; Mitch *et al.* 2003).

The US EPA has allocated NDMA a 'weight of evidence' toxicity classification B2 (probable human carcinogen). This classification was made on the basis of induction of tumors at multiple sites in both rodents and nonrodent mammals exposed by various routes (US Environmental Protection Agency 2006b). NDMA is not currently regulated in Australia and no public health guideline concentrations are available.

11.1.4 Additional emerging chemicals of concern

Additional emerging chemicals of concern were broadly considered for inclusion in the risk assessment. Chemicals that were considered include pharmaceutically active compounds (PhACs), and personal care products (including that antiseptic agent triclosan).

11.1.5 Hazard identification screening assessment

The chemical hazards that were initially identified were then subject to a hazard identification screening assessment. The purpose of this assessment was to eliminate chemicals that do not present significant (or determinable) health risks so as to allow prioritised consideration of the remainder.

For Schedule 10 chemicals, this hazard identification screening process was undertaken by comparison of chemical concentrations (95th percentile) in tertiary-treated STP effluent (the source water to the proposed advanced water treatment plant) to some widely accepted health-based guideline values and calculations. These values and concentrations were sourced from Australian Government and World Health Organization sources, as well as US Environmental Protection Agency Sources. These various sources and the data gleaned from them are described in the following sections.

Chemicals which were shown to be present in tertiary treated effluent at concentrations that would be considered unacceptable for drinking water (according to the following sources) were selected as identified hazards for more detailed consideration (dose response assessment and exposure assessment).

11.1.5.1 Australian Government and World Health Organization Sources

A number of Australian Government and World Health Organization sources were identified as useful collations of risk-based data for the determination of acceptable daily drinking water concentrations of discrete chemical substances. These sources were:

- The ADI List (Office of Chemical Safety 2005a);
- ARfD List (Office of Chemical Safety 2005b);
- Australian Drinking Water Guidelines (National Water Quality Management Strategy 2004)
- Guidelines for Managing Risks in Recreational Water (NH&MRC 2005);
- Guidelines for Drinking Water Quality (WHO 2004).

A brief description of these sources, the data provided within them and how this data was applied in the hazard identification screening assessment is provided below.

11.1.5.2 ADI List

The Australian Government maintains a document titled the ADI List (Office of Chemical Safety 2005a). This provides a useful collation of acceptable daily intakes (ADI) for agricultural and veterinary chemicals. The ADI for humans is considered to be a level of intake of a chemical that can be ingested daily over an entire lifetime without any appreciable risk to health.

For this assessment, ADI data have been converted to 'acceptable daily drinking water concentrations' by application of Equation 11-1.

$$C\,(\mu g.L^{-1}) = \frac{ADI\,(mg.kg^{-1}.day^{-1}) \times BW\,(kg) \times F \times 10^{3}\ (\mu g.mg^{-1})}{IRW\,(L.day^{-1}) \times SF}$$

Equation 11-1. Calculation of acceptable drinking water concentrations (C) from Acceptable daily intake (ADI)

Table 11-2. Parameters used in calculation of acceptable drinking water concentrations from ADI

Parameter	Description	Assigned value	Justification of assigned value
C	Acceptable drinking water concentration	-	
ADI	Acceptable daily intake	From ADI List (Office of Chemical Safety, 2005a)	
BW	Body weight	70 kg	Consistent with Australian Drinking Water Guidelines (National Water Quality Management Strategy 2004)
F	Fraction of intake attributable to consumption of water	0.1	Consistent with Australian Drinking Water Guidelines (National Water Quality Management Strategy 2004)
IRW	Drinking water ingestion (daily)	2 L	Consistent with Australian Drinking Water Guidelines (National Water Quality Management Strategy 2004)
SF	Safety factor (normally for extrapolation of animal studies to humans or other sources of toxicity uncertainty)	1	Safety factors have already been applied in the derivation of ADI values (Office of Chemical Safety 2005a)

Acceptable daily drinking water concentrations calculated using ADI data were used for hazard identification screening assessment and are presented in Table 11-4.

11.1.5.3 ARfD List

The Australian Government maintains a further document called the ARfD List (Office of Chemical Safety 2005b). This provides a tabulation of toxicity reference doses for agricultural and veterinary chemicals.

The ARfD data are provided in units of milligrams per kilogram of body weight. Therefore, it is appropriate to calculate acceptable daily drinking water concentrations in terms of 24-hour ARfD by dividing the ARfD by one day and applying drinking water consumption rates equally for one day. Accordingly, ARfD data have been converted 'acceptable daily drinking water concentrations' by application of Equation 11-2.

$$C\,(\mu g.L^{-1}) = \frac{ARfD\,(mg.kg^{-1}.day^{-1}) \times BW\,(kg) \times F \times 10^{3}\ (\mu g.mg^{-1})}{IRW\,(L.day^{-1}) \times SF}$$

Equation 11-2. Calculation of acceptable drinking water concentrations (C) from acute reference doses (ARfD)

Table 11-3. Parameters used in calculation of acceptable drinking water concentrations from ADI

Parameter	Description	Assigned value	Justification of assigned value
C	Acceptable drinking water concentration	-	
ARfD	Acute reference dose	From ARfD List (Office of Chemical Safety 2005b)	
BW	Body weight	70 kg	Consistent with Australian Drinking Water Guidelines (National Water Quality Management Strategy, 2004)
F	Fraction of intake attributable to consumption of water	0.1	Consistent with Australian Drinking Water Guidelines (National Water Quality Management Strategy, 2004)
IRW	Drinking water ingestion (daily)	2 L	Consistent with Australian Drinking Water Guidelines (National Water Quality Management Strategy 2004)

Parameter	Description	Assigned value	Justification of assigned value
SF	Safety factor (normally for extrapolation of animal studies to humans or other sources of toxicity uncertainty)	1	Safety factors have already been applied in the derivation of ARfD values (Office of Chemical Safety 2005b).

11.1.5.4 Australian Drinking Water Guidelines (2004)

Current Australian Drinking Water Guidelines (ADWG) were published by the National Health and Medical Research Council in partnership with the Natural Resource Management Ministerial Council (National Water Quality Management Strategy, 2004).

This document provides guideline concentrations for a number of potential chemical contaminants in drinking water.

For most contaminants, two guideline values are provided, one based on health considerations and a generally higher value based on aesthetic concentrations. In such cases, only the value based on health concentrations is of significance to a human heath risk assessment.

The data provided for pesticides are slightly different to the data for other contaminants. In these cases, guideline values are provided, but these are generally based on analytical limits of determination. It is recommended that if pesticides are reliably detected at these low guideline concentrations, the source should be identified and action taken to prevent further contamination. An additional health value is provided in most cases and this is based on 10 per cent of acceptable daily intake (ADI).

The health-based concentration data in the ADWG have been derived based on calculations generally consistent with those provided in Equation 11-1 and Equation 11-2. Accordingly, the ADWG Guideline numerical values for chemical concentrations were used directly for hazard identification screening assessment and are presented in Table 11-4.

11.1.5.5 Guidelines for Managing Risks in Recreational Water

The National Health and Medical Research Council provide Guidelines for Managing Risks in Recreational Water (GMRRW) (NH&MRC 2005).

For the management of chemical contaminants, the GMRRW refer predominantly to the Australian drinking water guidelines (see above). They indicate that the ADWG values are applicable to drinking water quality and are based on the daily consumption of 2L. Accordingly, the GMRRW indicate that the ADWG values should only be used as a guide to deriving chemical values applicable to recreational water bodies. They state that a "consumption factor of 2L will result in very conservative health guidelines in recreational water". The GMRRW indicates that when applying the ADWG values to recreational exposure, consumption of 100-200 mL per day should be taken into consideration.

Given the direct relationship between the GMRRW and current ADWG, and considering that ADWG will provide the most conservative data, it is therefore not considered necessary to provide a full analysis based on the GMRRW.

11.1.5.6 World Health Organization Guidelines for Drinking Water Quality

The World Health Organization (WHO) publishes Guidelines for Drinking Water Quality (WHO 2004). The Guidelines state that they are 'intended to support the development and implementation of risk-management strategies that will ensure the safety of drinking-water supplies through the control of hazardous constituents in water'.

Chapter 8 of the WHO Guidelines deal with 'chemical aspects' and provides numerical concentration limits for many substances. These limits are purported to be derived from health-based risk assessment considerations accounting for 'no-observed adverse effect levels' (NOAEL), tolerable daily intakes (TDI), body weight, fraction TDI allocated to drinking water, and daily drinking water consumption.

The WHO Guideline numerical values for chemical concentrations were used directly for hazard identification screening assessment and are presented in Table 11-4.

11.1.5.7 Collation of hazard identification data from Australian Government and World Health Organization sources

The numerical hazard identification data gleaned from the Australian Government and World Health Organization sources are presented in Table 11-4.

Table 11-4. Hazard identification data from Australian Government and World Health Organization sources (μg.L^{-1})

	Schedule 10 monitoring 2000-2004		Risk-based concentrations (μg.L^{-1})			
Chemical	**No. Times reported**	**95th percentile (μg.L^{-1})**	**From ADI**	**From ARfD**	**From ADWG**	**From WHO**
2,4-D	25	0.9	35	n	30	30
Acenaphthene	25	0.1	n	n	n	n
Acenaphthylene	25	0.1	n	n	n	n
Acrylonitrile	25	5	n	n	n	n
Aldrin	25	0.01	0.35	n	0.3	n
Aluminium	93	391.6	n	n	n	NE
Ammonia N	761	1270	n	n	n	NE
Anthracene	25	0.1	n	n	n	n
Arsenic	28	1	n	n	7	10
Atrazine	25	0.5	17.5	n	40	2
Barium	25	10.2	n	n	700	700
Benz(a)anthracene	25	0.1	n	n	n	n
Benzene	25	1	n	n	1	10
Benzene Hexachloride (Alpha)	25	0.01	n	n	n	Ex
Benzene Hexachloride (Beta)	25	0.01	n	n	n	Ex
Benzene Hexachloride (Gamma) - Lindane	67	0.01	n	n	n	Ex
Benzidine	25	5	n	n	n	n
Benzo(a)pyrene	25	0.1	n	n	0.01	0.7
Benzo(b)fluoranthene	25	0.1	n	n	n	n
Benzo(e)pyrene	25	0.1	n	n	n	n
Benzo(ghi)perylene	25	0.1	n	n	n	n
Benzo(k)fluoranthene	25	0.1	n	n	n	n
Boron	25	138	n	n	4000	500
Bromoform	25	2.8	n	n	250	100
Cadmium	73	0.24	n	n	2	3
Carbaryl	25	1	28	35	30	n
Carbon Tetrachloride	25	1	n	n	3	4
Chlordane (Total)	25	0.01	1.75	n	1	0.2
Chloride	72	190450	n	n	n	NE
Chlorobenzene	25	0.5	n	n	300	n
Chloroform	67	7	n	n	250	200
Chloronaphthalene	25	0.1	n	n	n	n

	Schedule 10 monitoring 2000-2004		Risk-based concentrations ($\mu g.L^{-1}$)			
Chemical	**No. Times reported**	**95th percentile ($\mu g.L^{-1}$)**	**From ADI**	**From ARfD**	**From ADWG**	**From WHO**
Chlorophenol (2)	25	1	n	n	n	NE
Chlorpyrifos	133	0.07	10.5	350	10	30
Chromium	28	1	n	n	50	50
Chrysene	25	0.1	n	n	n	n
Cobalt	31	1.2	n	n	n	n
Copper	125	7.8	n	n	2000	2000
Coronene	25	0.1	n	n	n	n
Cresol (m)	25	1	n	n	n	n
Cresol (o)	25	1	n	n	n	n
Cresol (p)	25	1	n	n	n	n
DDD	25	0.01	n	n	n	1
DDE	25	0.01	n	n	n	1
DDT	25	0.01	7	n	20	1
Demeton (Dem S-Methyl)	25	0.1	1.05	n	n	n
Diazinon	147	0.2	3.5	35	3	Ex
Dibenz(ah)anthracene	25	0.1	n	n	n	n
Dibromochloromethane	25	9	n	n	250	100
Dichlorobenzene (1,2)	25	0.5	n	n	1500	1000
Dichlorobenzene (1,3)	25	0.5	n	n	n	NE
Dichlorobenzene (1,4)	25	0.5	n	n	40	300
Dichlorobenzidine	25	5	n	n	n	n
Dichloroethane (1,1)	25	1	n	n	n	NE
Dichloroethane (1,2)	25	1	n	n	3	30
Dichloroethene (1,1)	25	1	n	n	30	30
Dichloromethane	25	5	n	n	4	20
Dichlorophenol (2,4)	42	0.1	n	n	n	NE
Dieldrin	99	0.01	0.35	n	0.3	n
Diphenylhydrazine	25	5	n	n	n	n
Endosulphan	42	0.01	21	70	30	NE
Endrin	25	0.01	0.7	n	n	0.6
Ethylbenzene	25	1	n	n	300	n
Fluoranthene	25	0.1	n	n	n	NE
Fluorene	25	0.1	n	n	n	n
Free Chlorine Residual	174	154	n	n	5000	5000

	Schedule 10 monitoring 2000-2004		Risk-based concentrations ($\mu g.L^{-1}$)			
Chemical	**No. Times reported**	**95th percentile ($\mu g.L^{-1}$)**	**From ADI**	**From ARfD**	**From ADWG**	**From WHO**
Glyphosate	25	10	1050	n	1000	NE
Guthion (Methyl Azinphos)	25	0.1	87.5	262.5	3	n
Heptachlor	25	0.005	1.75	n	0.3	NE
Heptachlor-epoxide	25	0.01	n	n	0.3	NE
Hexachlorobenzene	25	0.01	n	n	n	NE
Hydrogen Sulphide (un-ionised)	108	20	n	n	n	NE
Indeno(1,2,3-cd)pyrene	25	0.1	n	n	n	n
Iron	31	605	n	n	n	NE
Lead	42	1	n	n	10	10
Malathion	25	0.1	n	n	n	NE
Manganese	70	85	n	n	500	400
Mercury	67	0.02	n	n	1	1
Methoxychlor	25	0.01	35	n	300	20
Methylene Blue Active Substances	25	226	n	n	n	n
Molybdenum	28	24.65	n	n	50	70
Naphthalene	25	0.1	n	n	n	n
Nickel	34	31.85	n	n	20	20
Nonyl Phenol Ethoxylate	25	5	n	n	n	n
Octyl Phenol Ethoxylate	25	5	n	n	n	n
Parathion	25	0.1	17.5	35	10	NE
Pentachlorophenol	25	0.1	n	n	n	9
Perylene	25	0.1	n	n	n	n
Phenanthrene	25	0.1	n	n	n	n
Phenol	25	1	n	n	n	n
Polychlorinated Biphenyls	25	0.1	n	n	n	n
Pyrene	25	0.1	n	n	n	n
Selenium	25	5	n	n	10	10
Silver	59	0.1	n	n	10	NE
Styrene	25	1	n	n	30	20
Sulphate	25	87000	n	n	500000	NE
Tetrachloroethene	25	1	n	n	n	40
Tetrachlorophenol (2,3,4,6)	25	0.1	n	n	n	n
Tin	25	1	n	n	n	n
Toluene	25	1	n	n	800	700

	Schedule 10 monitoring 2000-2004		Risk-based concentrations (μg.L^{-1})			
Chemical	**No. Times reported**	**95th percentile (μg.L^{-1})**	**From ADI**	**From ARfD**	**From ADWG**	**From WHO**
Total Chloramines (as monochloramine)	102	319.5	n	n	3000	3000
Total Chlorine Residual	488	50	n	n	5000	5000
Total Cyanide	34	43.5	n	n	80	70
Total Polycyclic Aromatic Hydrocarbons	25	0.1	n	n	n	n
Trichloroethane (1,1,1)	25	1	n	n	n	NE
Trichloroethene	25	1	n	n	n	70
Trichlorophenol (2,4,5)	25	0.1	n	n	n	n
Vanadium	25	10	n	n	n	n
Xylene (m+p)	25	1	n	n	600	500
Xylene (o)	25	1	n	n	600	500
Zinc	51	59.5	n	n	n	NE

n: not listed.
NE: WHO guideline value not established (on the basis of absence of health concerns in drinking water or insufficient data to permit value derivation).
Ex: Excluded from WHO guideline value derivation (on the basis of being unlikely to occur in drinking water).
Unknown: Not previously analysed by Sydney Water.

11.1.6 Chemicals identified from Australian Government and World Health Organization sources

Three chemical parameters were identified from the hazard identification screening assessment using Australian Government and World Health Organization risk-based data sources. These will be considered further in terms of dose-response assessment and exposure assessment. A brief description of the relationship between the Schedule 10 monitoring data and the Australian Government & World Health Organization risk-based data is presented for each of these three chemical parameters below.

11.1.6.1 Dichloromethane

The WHO recommends a limit of 20 $\mu g.L^{-1}$ and the ADWG require a maximum of 4 $\mu g.L^{-1}$. Dichloromethane was not detected during treated effluent monitoring, however the analytical detection limit of 5 $\mu g.L^{-1}$ is not sufficiently low to ensure that the ADWG value was not exceeded.

11.1.6.2 Nickel

Both the WHO recommendation and the ADWG maximum are 20 $\mu g.L^{-1}$. Nickel was detected at a 95^{th} percentile concentration of 31.85 $\mu g.L^{-1}$ during treated effluent monitoring.

11.1.6.3 Benzo(a)pyrene

The WHO recommends a limit of 0.7 $\mu g.L^{-1}$ and the ADWG require a maximum of 0.01 $\mu g.L^{-1}$. Benzo(a)pyrene was not detected during treated effluent monitoring, however the analytical detection limit of 0.1 $\mu g.L^{-1}$ is not sufficiently low to ensure that the ADWG value was not exceeded.

11.1.7 US EPA Sources

The Californian EPA makes use of an environmental chemicals concentration list referred to as Preliminary Remediation Goals (PRG) for Superfund (US Environmental Protection Agency, 2004b; US Environmental Protection Agency, 2004c).

PRG concentrations are maintained for the preliminary assessment of contaminated sites (US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991). They combine current human health toxicity values with standard exposure factors to estimate contaminant concentrations in environmental media (soil, air, water) that are considered by the US EPA to be health protective of human exposures (including sensitive groups), over a lifetime.

Chemical concentrations above PRG levels do not automatically indicate a significant risk, but suggest that further evaluation is appropriate. Further evaluation may include additional sampling, consideration of ambient levels in the environment, or a reassessment of the assumptions contained in these screening-level estimates (*e.g.* appropriateness of route-to-route extrapolations, appropriateness of using chronic toxicity values to evaluate childhood exposures, appropriateness of generic exposure factors for a specific site *etc.*).

PRGs are chemical concentrations that correspond to fixed levels of risk. These are:

- A benchmark cancer risk (lifetime average probability) of 10^{-6}; or
- A noncarcinogenic hazard quotient of 1.

In cases where a substance causes cancer and noncancer effects, the more stringent concentration criteria have been adopted. In most cases, this corresponds to the 10^{-6} cancer risk.

The equations used to calculate PRGs for carcinogenic and non-carcinogenic contaminants are published by the US EPA (2004c) and presented in Equation 11-3 and Equation 11-4. They are an

update of the equations provided by the US EPA Risk Assessment Guidance for Superfund (US Environmental Protection Agency, 1991).

$$PRG\ (\mu g.L^{-1}) = \frac{TR \times AT_c \times 1000 \mu g/mg}{EF_r\ [(IFW_{adj} \times CSF_o) + (VF_w \times InhF_{adj} \times CSF_i)]}$$

Equation 11-3. Ingestion and inhalation exposures to carcinogenic contaminants in water

$$PRG\ (\mu g.L^{-1}) = \frac{THQ \times BW_a \times AT_n \times 1000 \mu g/mg}{EF_r \times ED_r\ [(\frac{IRW_a}{RfD_o}) + (\frac{VF_w \times IRA_a}{RfD_i})]}$$

Equation 11-4. Ingestion and inhalation exposures to noncarcinogenic contaminants in water

The standard default values used for PRG calculation are provided in Table 11-5.

Table 11-5. Standard default factors (US Environmental Protection Agency, 2004c).

Symbol	Definition (units)	Default	References
CSF_o	Cancer slope factor oral (mg^{-1}.kg.day)	-	(US Environmental Protection Agency, 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency, 2006b; US Environmental Protection Agency, 2006c; US Environmental Protection Agency, 2006d)
CSF_i	Cancer slope factor inhaled (mg^{-1}.kg.day)	-	(US Environmental Protection Agency, 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency, 2006b; US Environmental Protection Agency, 2006c; US Environmental Protection Agency, 2006d)
RfD_o	Reference dose oral ($mg.kg^{-1}.day^{-1}$)	-	(US Environmental Protection Agency, 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency, 2006b; US Environmental Protection Agency, 2006c; US Environmental Protection Agency, 2006d)
RfD_i	Reference dose inhaled ($mg.kg^{-1}.day^{-1}$)	-	(US Environmental Protection Agency, 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency, 2006b; US Environmental Protection Agency, 2006c; US Environmental Protection Agency, 2006d)
TR	Target cancer risk	10^{-6}	(US Environmental Protection Agency, 2004c)
THQ	Target hazard quotient	1	(US Environmental Protection Agency, 2004c)
BW_a	Body weight, adult (kg)	70	(US Environmental Protection Agency, 1989)
BW_c	Body weight, adult (kg)	15	(US Environmental Protection Agency, 2004c)
AT_c	Averaging time – carcinogens (days)	25550	(US Environmental Protection Agency, 1989)
AT_n	Averaging time – noncarcinogens (days)	ED*365	(US Environmental Protection Agency, 1989)
IRA_a	Inhalation rate – adult ($m^3.day^{-1}$)	20	(US Environmental Protection Agency, 2004c)
IRW_a	Drinking water ingestion – adult ($L.day^{-1}$)	2	(US Environmental Protection Agency, 1989)
EF_r	Exposure frequency – residential ($day.year^{-1}$)	350	(US Environmental Protection Agency, 2004c)
ED_r	Exposure duration – residential (years)	30	(US Environmental Protection Agency, 2004c)
$InfF_{adj}$	Age-adjusted inhalation factor, air ([m^3-year].[kg-day]$^{-1}$)	11	(US Environmental Protection Agency, 2004c)
IFW_{adj}	Age-adjusted ingestion factor, water ([L-year].[kg-day]$^{-1}$)	1.1	(US Environmental Protection Agency, 2004c)

Symbol	Definition (units)	Default	References
VF_w	Volatilisation factor for water ($L.m^{-3}$)	0.5	(US Environmental Protection Agency, 2004c)

Human toxicity values known as cancer slope factors (SF) or non-cancer reference doses (RfDs) form the basis of the PRG calculations. There is a hierarchy of sources to be used for the collation of these data. The current EPA hierarchy is as follows (Cook, 2003):

- Tier 1- Integrated Risk Information System (US Environmental Protection Agency, 2006b),
- Tier 2 - EPA's Provisional Peer Reviewed Toxicity Values (PPRTVs) (US Environmental Protection Agency, 2006d), and
- Tier 3 - Other Toxicity Values. Tier 3 includes additional EPA sources (*e.g.* current HEAST (US Environmental Protection Agency, 2006a) and NCEA (US Environmental Protection Agency, 2006c) provisional values) and non-EPA sources of toxicity information.

Current IRIS and NCEA databases do not present RfDs or SFs for the inhalation route. These criteria have been replaced with reference concentrations (RfC) for noncarcinogenic effects and unit risk factors (URF) for carcinogenic effects. However, for purposes of estimating risk and calculating risk-based concentrations, inhalation reference doses (RfDi) and inhalation slope factors (SFi) are preferred (US Environmental Protection Agency, 2004c). This is not a problem for most chemicals because the inhalation toxicity criteria are easily converted. To calculate an RfDi from an RfC, the following equation and assumptions may be used for most chemicals:

$$\mathrm{RfDi\ (mg.kg^{-1}day^{-1})} = \mathrm{RfC\ (mg.m^{-3})} \times \frac{20\ \mathrm{m^3}}{\mathrm{day}} \times \frac{1}{70\ \mathrm{kg}}$$

Equation 11-5. Calculation of RfDi from RfC data (US Environmental Protection Agency, 2004c)

Likewise, to calculate an SFi from an inhalation URF, the following equation and assumptions may be used:

$$\mathrm{SFi\ (kg.day.mg^{-1})} = \mathrm{URF\ (m^3.\mu g^{-1})} \times \frac{\mathrm{day}}{20\ \mathrm{m^3}} \times 70\ \mathrm{kg} \times \frac{10^3\ \mu\mathrm{g}}{\mathrm{mg}}$$

Equation 11-6. Calculation of SFi from inhalation URF data (US Environmental Protection Agency, 2004c)

Route-to-route extrapolations ("r") were frequently used when there were no toxicity values available for a given route of exposure. Oral cancer slope factors ("SFo") and reference doses ("RfDo") were used for both oral and inhaled exposures for organic compounds lacking inhalation values. Inhalation slope factors ("SFi") and inhalation reference doses ("RfDi") were used for both inhaled and oral exposures for organic compounds lacking oral values (US Environmental Protection Agency, 2004c). Route extrapolations were not performed for inorganics due to portal of entry effects and known differences in absorption efficiency for the two routes of exposure (US Environmental Protection Agency, 2004c).

The US EPA toxicity data and Preliminary Remediation Goals (PRG) calculated for tap water are presented in Table 11-6. Tier 1 toxicity values from IRIS are listed as "i" and Tier 2 toxicity values known as PPRTVs as "p". Tier 3 toxicity values were obtained from California EPA databases "c", historic HEAST tables "h" and NCEA provisional values "n".

Table 11-6. US EPA Toxicity data and Preliminary Remediation Goals (PRG) for tap water (µg.L^{-1}) (US Environmental Protection Agency, 2004b).

Chemical	n	95th percentile (µg.L^{-1})	Sfo	RfDo	Sfi	RfDi	Vo	PRG (µg.L^{-1})	ca/nc
2,4-D	25	0.9		1.0E-02 i		1.0E-02 r		3.7E+02	nc
Acenaphthene	25	0.1		6.0E-02 i		6.0E-02 r	y	3.7E+02	nc
Acenaphthylene	25	0.1					y	nil	nil
Acrylonitrile	25	5	5.4E-01 i	1.0E-03 h	2.4E-01 i	5.7E-04 i	y	3.8E-02	ca
Aldrin	25	0.01	1.7E+01 i	3.0E-05 i	1.7E+01 i	3.0E-05 r		3.9E-03	ca
Aluminium	93	391.6		1.0E+00 p		1.4E-03 p		3.7E+04	nc
Ammonia N	761	1270				2.9E-02 i		nil	nil
Anthracene	25	0.1		3.0E-01 i		3.0E-01 r	y	1.8E+03	nc
Arsenic[a]	28	1	1.5E+00 i	3.0E-04 i	1.5E+01 i			4.4E-02	ca
Atrazine	25	0.5	2.2E-01 h	3.5E-02 i	2.2E-01 r	3.5E-02 r		3.0E-01	ca
Barium	25	10.2		7.0E-02 i		1.4E-04 h		2.6E+03	nc
Benz(a)anthracene	25	0.1	7.3E-01 n		7.3E-01 r			9.1E-02	ca
Benzene	25	1	5.5E-02 i	4.0E-03 i	2.7E-02 i	8.6E-03 i	y	3.5E-01	ca
Benzene Hexachloride (Alpha)	25	0.01	6.3E+00 i	5.0E-04 n	6.3E+00 i	5.0E-04 r		1.1E-02	ca
Benzene Hexachloride (Beta)	25	0.01	1.8E+00 i	2.0E-04 n	1.8E+00 i	2.0E-04 r		3.7E-02	ca
Benzene Hexachloride (Gamma) - Lindane	67	0.01	1.3E+00 h	3.0E-04 i	1.3E+00 r	3.0E-04 r		5.1E-02	ca
Benzidine	25	5	2.3E+02 i	3.0E-03 i	2.3E+02 i	3.0E-03 r		2.9E-04	ca
Benzo(a)pyrene	25	0.1	7.3E+00 i		7.3E+00 r			9.1E-03	ca
Benzo(b)fluoranthene	25	0.1	7.3E-01 n		7.3E-01 r			9.1E-02	ca
Benzo(e)pyrene	25	0.1						nil	nil
Benzo(ghi)perylene	25	0.1						nil	nil
Benzo(k)fluoranthene	25	0.1	7.3E-02 n		7.3E-02 r			9.1E-01	ca
Boron	25	138		2.0E-01 i		5.7E-03 h		7.3E+03	nc
Bromoform	25	2.8	7.9E-03 i	2.0E-02 i	3.9E-03 i	2.0E-02 r		8.4E+00	ca
Cadmium	73	0.24		5.0E-04 i	6.3E+00 i			1.8E+01	nc
Carbaryl	25	1		1.0E-01 i		1.1E-01 r		3.7E+03	nc
Carbon Tetrachloride	25	1	1.3E-01 i	7.0E-04 i	5.3E-02 i	7.0E-04 r	y	1.7E-01	ca
Chlordane (Total)	25	0.01	3.5E-01 i	5.0E-04 i	3.5E-01 i	2.0E-04 i		1.9E-01	ca
Chloride	72	190450						nil	nil
Chlorobenzene	25	0.5		2.0E-02 i		1.7E-02 n	y	1.1E+02	nc
Chloroform	67	7	1.0E-02 i	1.0E-02 i	8.1E-02 i	1.4E-02 n	y	1.6E-01	ca
Chloronaphthalene	25	0.1		8.0E-02 i		8.0E-02 r	y	4.9E+02	nc
Chlorophenol (2)	25	1		5.0E-03 i		5.0E-03 r	y	3.0E+01	nc

Chemical	n	95th percentile (µg.L^{-1})	Sfo	RfDo	Sfi	RfDi	Vo	PRG (µg.L^{-1})	ca/nc
Chlorpyrifos	133	0.07		3.0E-03 i		3.0E-03 r		1.1E+02	nc
Chromium	28	1		3.0E-03 i	2.9E+02 i	2.2E-06 i		1.1E+02	nc
Chrysene	25	0.1	7.3E-03 n		7.3E-03 r			9.1E+00	ca
Cobalt	31	1.2		2.0E-02 p	9.8E+00 p	5.7E-06 p		7.3E+02	nc
Copper	125	7.8		4.0E-02 h				1.5E+03	nc
Coronene	25	0.1						nil	nil
Cresol (m)	25	1		5.0E-02 i		5.0E-02 r		1.8E+03	nc
Cresol (o)	25	1		5.0E-02 i		5.0E-02 r		1.8E+03	nc
Cresol (p)	25	1		5.0E-03 h		5.0E-03 r		1.8E+02	nc
DDD	25	0.01	2.4E-01 i		2.4E-01 r			2.8E-01	ca
DDE	25	0.01	3.4E-01 i		3.4E-01 r			2.0E-01	ca
DDT	25	0.01	3.4E-01 i	5.0E-04 i	3.4E-01 i	5.0E-04 r		2.0E-01	ca
Demeton (Dem S-Methyl)	25	0.1		4.0E-05 i		4.0E-05 r		1.5E+00	nc
Diazinon	147	0.2		9.0E-04 h		9.0E-04 r		3.3E+01	nc
Dibenz(ah)anthracene	25	0.1	7.3E+00 n		7.3E+00 r			9.1E-03	ca
Dibromochloromethane	25	9	8.4E-02 i	2.0E-02 i	8.4E-02 r	2.0E-02 r		7.9E-01	ca
Dichlorobenzene (1,2)	25	0.5		9.0E-02 i		5.7E-02 h	y	3.7E+02	nc
Dichlorobenzene (1,3)	25	0.5		3.0E-02 n		3.0E-02 r	y	1.8E+02	nc
Dichlorobenzene (1,4)	25	0.5	2.4E-02 h	3.0E-02 n	2.2E-02 n	2.3E-01 i	y	5.0E-01	ca
Dichlorobenzidine	25	5	4.5E-01 i		4.5E-01 r			1.5E-01	ca
Dichloroethane (1,1)	25	1		1.0E-01 h		1.4E-01 h	y	8.1E+02	nc
Dichloroethane (1,2)	25	1	9.1E-02 i	2.0E-02 n	9.1E-02 i	1.4E-03 n	y	1.2E-01	ca
Dichloroethene (1,1)	25	1		5.0E-02 i		5.7E-02 i	y	3.4E+02	nc
Dichloromethane	25	5	7.5E-03 i	6.0E-02 i	1.6E-03 i	8.6E-01 h	y	4.2E+00	ca
Dichlorophenol (2,4)	42	0.1		3.0E-03 i		3.0E-03 r		1.1E+02	nc
Dieldrin	99	0.01	1.6E+01 i	5.0E-05 i	1.6E+01 i	5.0E-05 r		4.1E-03	ca
Diphenylhydrazine	25	5	8.0E-01 i		8.0E-01 i			8.3E-02	ca
Endosulphan	42	0.01		6.0E-03 i		6.0E-03 r		2.2E+02	nc
Endrin	25	0.01		3.0E-04 i		3.0E-04 r		1.1E+01	nc
Ethylbenzene	25	1		1.0E-01 i		2.9E-01 i	y	1.3E+03	nc
Fluoranthene	25	0.1		4.0E-02 i		4.0E-02 r		1.5E+03	nc
Fluorene	25	0.1		4.0E-02 i		4.0E-02 r	y	2.4E+02	nc
Free Chlorine Residual	174	154		1.0E-01 i		5.7E-05		3.7E+03	nc
Glyphosate	25	10		1.0E-01 i		1.0E-01 r		3.7E+03	nc
Guthion (Methyl Azinphos)	25	0.1						nil	nil

Chemical	n	95th percentile (µg.L^{-1})	Sfo		RfDo		Sfi		RfDi		Vo	PRG (µg.L^{-1})	ca/nc
Heptachlor	25	0.005	4.5E+00	i	5.0E-04	i	4.6E+00	i	5.0E-04	r		1.5E-02	ca
Heptachlor-epoxide	25	0.01	9.1E+00	i	1.3E-05	i	9.1E+00	i	1.3E-05	r		7.3E-03	ca
Hexachlorobenzene	25	0.01	1.6E+00	i	8.0E-04	i	1.6E+00	i	8.0E-04	r		4.1E-02	ca
Hydrogen Sulphide (un-ionised)	108	20			3.0E-03	i			2.9E-04	i	y	2.0E+00	nc
Indeno(1,2,3-cd)pyrene	25	0.1	7.3E-01	n			7.3E-01	r				9.1E-02	ca
Iron	31	605			3.0E-01	n						1.1E+04	nc
Lead[b]	42	1										nil	nc
Malathion	25	0.1			2.0E-02	i			2.0E-02	r		7.3E+02	nc
Manganese	70	85			2.4E-02	i			1.4E-05	i		8.8E+02	nc
Mercury	67	0.02			3.0E-04	i						1.1E+01	nc
Methoxychlor	25	0.01			5.0E-03	i			5.0E-03	r		1.8E+02	nc
Methylene Blue Active Substances	25	226										nil	nil
Molybdenum	28	24.65			5.0E-03	i						1.8E+02	nc
Naphthalene	25	0.1			2.0E-02	i			8.6E-04	i	y	6.2E+00	nc
Nickel	34	31.85			2.0E-02	i						7.3E+02	nc
Nonyl Phenol Ethoxylate	25	5										nil	nil
Octyl Phenol Ethoxylate	25	5										nil	nil
Parathion	25	0.1			6.0E-03	h			6.0E-03	r		2.2E+02	nc
Pentachlorophenol	25	0.1	1.2E-01	i	3.0E-02	i	1.2E-01	r	3.0E-02	r		5.5E-01	ca
Perylene	25	0.1										nil	nil
Phenanthrene	25	0.1									y	nil	nil
Phenol	25	1			3.0E-01	i			3.0E-01	r		1.1E+04	nc
Polychlorinated Biphenyls	25	0.1	4.0E-01	i			3.5E-01	i				1.7E-01	ca
Pyrene	25	0.1			3.0E-02	i			3.0E-02	r		1.1E+03	nc
Selenium	25	5			5.0E-03	i						1.8E+02	nc
Silver	59	0.1			5.0E-03	i						1.8E+02	nc
Styrene	25	1			2.0E-01	i			2.9E-01	i	y	1.6E+03	nc
Sulphate	25	87000										nil	nil
Tetrachloroethene	25	1	5.4E-01	c	1.0E-02	i	2.1E-02	c	1.0E-02	c	y	1.0E-01	ca
Tetrachlorophenol (2,3,4,6)	25	0.1			3.0E-02	i			3.0E-02	r		1.1E+03	nc
Tin	25	1			6.0E-01	h						2.2E+04	nc
Toluene	25	1			2.0E-01	i			1.1E-01	i	y	7.2E+02	nc
Total Chloramines (as monochloramines)	102	319.5			1.0E-01	i			1.0E-01	r	y	6.1E+02	nc
Total Chlorine Residual	488	50										nil	nil
Total Cyanide[c]	34	43.5										nil	nil

Chemical	n	95th percentile (µg.L^{-1})	Sfo	RfDo	Sfi	RfDi	Vo	PRG (µg.L^{-1})	ca/nc
Total Polycyclic Aromatic Hydrocarbons	25	0.1						nil	nil
Trichloroethane (1,1,1)	25	1		2.8E-01 n		6.3E-01 p	y	3.2E+03	nc
Trichloroethene	25	1	4.0E-01 n	3.0E-04 n	4.0E-01 n	1.0E-02 n	y	2.8E-02	ca
Trichlorophenol (2,4,5)	25	0.1		1.0E-01 i		1.0E-01 r		3.7E+03	nc
Vanadium	25	10		1.0E-03 n				3.7E+01	nc
Xylene (m+p)	25	1		2.0E-01 i		2.9E-02 i	y	2.1E+02	nc
Xylene (o)	25	1		2.0E-01 i		2.9E-02 i	y	2.1E+02	nc
Zinc	51	59.5		3.0E-01 i				1.1E+04	nc

Arsenic[a]:The two primary forms of arsenic in water are trivalent arsenic (As+3, arsenite (III), CAS number 22569-72-8) and pentavalent arsenic (As+5, arsenate (V), CAS number 17428-41-0). Arsenic as a free element (0-oxidation state) is rarely encountered in nature.
Lead[b] : PRG requires calculation by Integrated Exposure Uptake Biokinetic Model for Lead in Children: www.epa.gov/superfund/programs/lead/products.htm#ieubk
SFo,i=Cancer Slope Factor oral, inhalation
RfDo,i=Reference Dose oral, inhalation
i: Data from IRIS (US Environmental Protection Agency, 2006b)
p: Data from PPRTV (US Environmental Protection Agency, 2006d)
c: Data from California EPA (US Environmental Protection Agency, 2004b)
n: Data from NCEA (US Environmental Protection Agency, 2006c)
h: Data from Health Effects Summary Table (HEAST) (US Environmental Protection Agency, 2006a)
r: Route-extrapolation (US Environmental Protection Agency, 2004c)
y: Classified as volatile substance (Henrys Law const > 10^{-5} atm.m^3.mol^{-1} and mw < 200 g/mole) and inhalation pathway included in PRG calculation
ca: PRG based on cancer risk calculation.
nc: PRG based on non-cancer risk calculation.
nil: No PRG value assigned due to lack of data

11.1.7.1 Chemicals identified from US EPA sources

27 chemical parameters were identified from the hazard identification screening assessment using US EPA risk-based data sources. These chemicals are provided in Table 11-7 along with the ratio of their 95th percentile concentration from Schedule 10 monitoring to the PRG value. These chemicals were considered further by dose-response assessment and exposure assessment.

Table 11-7. Chemicals identified by hazard identification screening assessment using US EPA risk-based data sources

Chemical parameter	Monitoring conc/PRG
Total Chloramines (as monochloramines)	1
Polychlorinated Biphenyls	1
Benzene Hexachloride (Alpha)	1
Dichlorobenzene (1,4)	1
Benz(a)anthracene	1
Benzo(b)fluoranthene	1
Indeno(1,2,3-cd)pyrene	1
Dichloromethane	1
Heptachlor-epoxide	1
Atrazine	2
Dieldrin	2
Aldrin	3
Benzene	3
Carbon Tetrachloride	6
Dichloroethane (1,2)	8
Tetrachloroethene	10
Hydrogen Sulphide (un-ionised)	10
Benzo(a)pyrene	11
Dibenz(ah)anthracene	11
Dibromochloromethane	11
Arsenic	23
Dichlorobenzidine	34
Trichloroethene	36
Chloroform	44
Diphenylhydrazine	60
Acrylonitrile	130
Benzidine	17329

11.1.7.2 Elimination of benzidine (source control)

Benzidine was identified as having a high hazard quotient. Benzidine was also identified during the Issue Identification Screening Assessment on account of the relevant method detection limit being lower than the PRG value. Despite having tested for and never positively identified by Sydney Water it was seen as essential to determine if its potential risks might be discounted on other grounds, in particular source control.

Benzidine is an industrial chemical used mainly in pulp & paper industries as well as in dye houses. Investigation of Sydney Waters' trade-waste customers revealed three potential sources within the wastewater catchment:

1. A Carton and Cardboard Manufacturer
2. A Paper/Pulp Manufacturer/Processor
3. A Drum Washer/Reconditioner

By visiting each one of these companies, Sydney Water confirmed no use, production, or discharge of benzidine. A catchment survey undertaken for this risk assessment reported:

> *"Benzidine was not detectable in any samples collected for Sydney Water's Ecological and Human Health Risk Assessment (1995). Benzidine dyes are actively avoided because of their well-known health hazards, according to a survey of customers (undertaken in May 2006) in the study area who might be expected to either dyestuffs or re-process recycled containers containing dyestuffs. Benzidine is not a reportable substance under the National Pollutant Inventory. Benzidine is listed under the synonym [1,1'-Biphenyl]-4,4'-diamine on the Australian Inventory of Chemical Substances".*

The full survey findings are included as Appendix 4.

Accordingly, benzidine was not considered to pose a public health risk during any realistic circumstances. It is therefore not further considered in the risk assessment.

11.1.8 Chemicals excluded from quantitative risk assessment

Chemicals that were not identified during the Hazard Identification Screening Assessment were excluded from quantitative risk assessment. This included a large majority of chemicals on the Schedule 10 monitoring list as well as most of the additional identified chemicals.

Consideration of endocrine disrupting chemicals, pharmaceuticals and personal care products was limited by a lack of accepted human-health toxicity data considered to be relevant for the low concentrations of these compounds known to be present in wastewaters.

Toxicity data exists for many disinfection by-products including trihalomethanes and NDMA. However, a lack of available detail regarding design and operating conditions of the proposed treatment plant prevents the identification of reasonable anticipated concentration ranges.

All of these excluded chemicals contribute to the uncertainties associated with the risk assessment (and are further discussed in the uncertainties section).

11.2 Dose-response assessment of identified hazards

The final list of chemicals of concern (drawn from WHO, Australian Government and USEPA sources) is provided in Table 11-8.

Table 11-8. Final chemicals of concern for dose-response assessment

Chemical	
Acrylonitrile	Dichlorobenzidine
Aldrin	Dichloroethane (1,2)
Arsenic	Dichloromethane
Atrazine	Dieldrin
Benz(a)anthracene	Diphenylhydrazine
Benzene	Heptachlor-epoxide
Benzene Hexachloride (Alpha)	Hydrogen Sulphide (un-ionised)
Benzo(a)pyrene	Indeno(1,2,3-cd)pyrene
Benzo(b)fluoranthene	Nickel
Carbon Tetrachloride	Polychlorinated Biphenyls
Chloroform	Tetrachloroethene
Dibenz(ah)anthracene	Total Chloramines (as monochloramines)
Dibromochloromethane	Trichloroethene

Chemical	
Dichlorobenzene (1,4)	

These chemicals were subject to further assessment of the hazards posed. Dose-response assessments of the various identified chemical hazards are presented in the following sections.

Tables are presented in this section showing chronic cancer risk data (cancer slope factors) and threshold-based toxicity data (reference doses). These data are used subsequently in risk characterisation calculations (Section 13).

11.2.1 Dichloromethane

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (WHO 2004):

> *Dichloromethane is of low acute toxicity. An inhalation study in mice provided conclusive evidence of carcinogenicity, whereas drinking-water studies in rats and mice provided only suggestive evidence. IARC has placed dichloromethane in Group 2B; however, the balance of evidence suggests that it is not a genotoxic carcinogen and that genotoxic metabolites are not formed in relevant amounts in vivo.*

The US EPA has allocated dichloromethane a 'weight of evidence' toxicity classification B2 (probable human carcinogen). The basis given for this classification is as follows (US Environmental Protection Agency, 2006b):

> *Based on inadequate human data and sufficient evidence of carcinogenicity in animals; increased incidence of hepatocellular neoplasms and alveolar/bronchiolar neoplasms in male and female mice, and increased incidence of benign mammary tumors in both sexes of rats, salivary gland sarcomas in male rats and leukemia in female rats. This classification is supported by some positive genotoxicity data, although results in mammalian systems are generally negative*

Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-9.

Table 11-9. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for dichloromethane

	Sfo		RfDo		Sfi		RfDi	
Dichloromethane	7.5E-03	I	6.0E-02	i	1.6E-03	i	8.6E-01	h

i: Data from IRIS (US Environmental Protection Agency, 2006b)
h: Data from Health Effects Summary Table (HEAST) (US Environmental Protection Agency, 2006a)

11.2.2 Nickel

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (WHO 2004):

> *IARC concluded that inhaled nickel compounds are carcinogenic to humans (Group 1) and metallic nickel is possibly carcinogenic (Group 2B). However, there is a lack of evidence of a carcinogenic risk from oral exposure to nickel. Dose-related increases in perinatal mortality were observed in a carefully conducted two-generation study in rats, but variations in response between successive litters make it difficult to draw firm conclusions from this study.*

The U.S. EPA has not evaluated soluble salts of nickel, as a class of compounds, for potential human carcinogenicity. (US Environmental Protection Agency, 2006b).

Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-10.

Table 11-10. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for nickel

	Sfo		RfDo		Sfi		RfDi	
Nickel			2.0E-02	i				

i: Data from IRIS (US Environmental Protection Agency, 2006b)

11.2.3 Total chloramines

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

> *Although monochloramine has been shown to be mutagenic in some in vitro studies, it has not been found to be genotoxic in vivo. IARC has classified chloramine in Group 3, and the US EPA has classified monochloramine in group D (not classifiable as to human carcinogenicity, as there is inadequate human and animal evidence). In the NTP bioassay in two species, the incidence of mononuclear cell leukaemias in female F344/N rats was increased, but no other increases in tumour incidence were observed. IPCS (2000) did not consider that the increase in mononuclear cell leukaemia was treatment-related.*

The US EPA has allocated monochloramine a 'weight of evidence' toxicity classification D (not classifiable as to human carcinogenicity). The basis given for this classification is as follows (US Environmental Protection Agency, 2006b):

> *Based on inadequate human data and equivocal evidence of carcinogenicity from animal bioassays. A 2-year bioassay showed a marginal increase in mononuclear cell leukemia in female F344/N rats. No evidence of carcinogenic activity was reported in male rats or in male or female B6C3F1 mice. Genotoxicity studies, both in vitro and in vivo, gave negative results.*

Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-10.

Table 11-11. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for monochloramine

	Sfo		RfDo		Sfi		RfDi	
Monochloramine			1.0E-01	i			1.0E-01	r

i: Data from IRIS (US Environmental Protection Agency, 2006b)

11.2.4 Polycyclic aromatic hydrocarbons (PAH) (incl. Benzo(a)pyrene (BaP), Benz(a)anthracene, Benzo(b)fluoranthene, Indeno(1,2,3-cd)pyrene, Dibenz(ah)anthracene

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

> *Evidence that mixtures of PAHs are carcinogenic to humans comes primarily from occupational studies of workers following inhalation and dermal exposure. No data are available for humans for the oral route of exposure. There are few data on the oral toxicity of PAHs other than BaP, particularly in drinking-water. Relative potencies of carcinogenic PAHs have been determined by comparison of data from dermal and other studies. The order*

of potencies is consistent, and this scheme therefore provides a useful indicator of PAH potency relative to BaP.

A health-based value of 4µg/litre can be calculated for fluoranthene on the basis of a NOAEL of 125 mg/kg of body weight per day for increased serum glutamate– pyruvate transaminase levels, kidney and liver pathology, and clinical and haematological changes in a 13-week oral gavage study in mice, using an uncertainty factor of 10 000 (100 for inter- and intraspecies variation, 10 for the use of a subchronic study and inadequate database and 10 because of clear evidence of cocarcinogenicity with BaP in mouse skin painting studies). However, this health-based value is significantly above the concentrations normally found in drinking-water. Under usual conditions, therefore, the presence of fluoranthene in drinking-water does not represent a hazard to human health. For this reason, the establishment of a guideline value for fluoranthene is not deemed necessary.

The US EPA has allocated each of benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene, indeno(1,2,3-cd)pyrene, and dibenz(ah)anthracene a 'weight of evidence' toxicity classification B2 (probable human carcinogen). The basis given for this classification is as follows (US Environmental Protection Agency, 2006b):

Benzo(a)pyrene: Human data specifically linking benzo[a]pyrene (BAP) to a carcinogenic effect are lacking. There are, however, multiple animal studies in many species demonstrating BAP to be carcinogenic following administration by numerous routes. BAP has produced positive results in numerous genotoxicity assays.

Benz(a)anthracene: Based on no human data and sufficient data from animal bioassays. Benz[a]anthracene produced tumors in mice exposed by gavage; intraperitoneal, subcutaneous or intramuscular injection; and topical application. Benz[a]anthracene produced mutations in bacteria and in mammalian cells, and transformed mammalian cells in culture.

Benzo(b)fluoranthene: Based on no human data and sufficient data from animal bioassays. Benzo[b]fluoranthene produced tumors in mice after lung implantation, intraperitoneal (i.p.) or subcutaneous (s.c.) injection, and skin painting.

Indeno(1,2,3-cd)pyrene: Based on no human data and sufficient data from animal bioassays. Indeno[1,2,3-cd]pyrene produced tumors in mice following lung implants, subcutaneous injection and dermal exposure. Indeno[1,2,3-cd]pyrene tested positive in bacterial gene mutation assays.

Dibenz(ah)anthracene: Based on no human data and sufficient data from animal bioassays. Dibenz[a,h]anthracene produced carcinomas in mice following oral or dermal exposure and injection site tumors in several species following subcutaneous or intramuscular administration. Dibenz[a,h]anthracene has induced DNA damage and gene mutations in bacteria as well as gene mutations and transformation in several types of mammalian cell cultures.

Cancer slope factors (mg^{-1}.kg.day) sourced from US EPA data are provided in Table 11-12.

Table 11-12. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for polycyclic aromatic hydrocarbons

	Sfo		RfDo		Sfi		RfDi	
Benzo(a)pyrene	7.3E+00	i			7.3E+00	r		
Benz(a)anthracene	7.3E-01	n			7.3E-01	r		
Benzo(b)fluoranthene	7.3E-01	n			7.3E-01	r		
Indeno(1,2,3-cd)pyrene	7.3E-01	n			7.3E-01	r		
Dibenz(ah)anthracene	7.3E+00	n			7.3E+00	r		

i: Data from IRIS (US Environmental Protection Agency, 2006b)
n: Data from NCEA (US Environmental Protection Agency, 2006c)
r: Route-extrapolation (US Environmental Protection Agency, 2004c)

11.2.5 Benzene Hexachloride (Alpha)

"Benzene hexachloride" isomers (or Hexachlorocyclohexane isomers), were noted in the development of the World Health Organization Guidelines for Drinking-water Quality, but were excluded from guideline value derivation. This was on the basis that these chemicals were considered to be unlikely to occur in drinking-water (World Health Organization, 2004).

The US EPA has allocated Benzene hexachloride (alpha) a 'weight of evidence' toxicity classification B2 (probable human carcinogen). The basis given for this classification is as follows (US Environmental Protection Agency, 2006b):

> *Dietary alpha-HCH has been shown to cause increased incidence of liver tumors in five mouse strains and in Wistar rats.*

Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-13.

Table 11-13. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for benzene hexachloride (alpha)

	Sfo		RfDo		Sfi		RfDi	
Benzene hexachloride (alpha)	6.3E+00	i	5.0E-04	n	6.3E+00	i	5.0E-04	r

i: Data from IRIS (US Environmental Protection Agency, 2006b)
n: Data from NCEA (US Environmental Protection Agency, 2006c)
r: Route-extrapolation (US Environmental Protection Agency, 2004c)

11.2.6 Dichlorobenzene (1,4)

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

> *1,4-DCB is of low acute toxicity, but there is evidence that it increases the incidence of renal tumours in rats and of hepatocellular adenomas and carcinomas in mice after long-term exposure. IARC has placed 1,4-DCB in Group 2B. 1,4-DCB is not considered to be genotoxic, and the relevance for humans of the tumours observed in animals is doubtful.*

1,4-Dichlorobenzene has not undergone a complete evaluation and determination under US EPA's IRIS program for evidence of human carcinogenic potential. (US Environmental Protection Agency, 2006b).

Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-14.

Table 11-14. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for dichlorobenzene

	Sfo		RfDo		Sfi		RfDi	
Dichlorobenzene	2.4E-02	h	3.0E-02	n	2.2E-02	n	2.3E-01	i

i: Data from IRIS (US Environmental Protection Agency, 2006b)
n: Data from NCEA (US Environmental Protection Agency, 2006c)
h: Data from Health Effects Summary Table (HEAST) (US Environmental Protection Agency, 2006a)

11.2.7 Heptachlor-epoxide

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

> *Prolonged exposure to heptachlor has been associated with damage to the liver and central nervous system toxicity. In 1991, IARC reviewed the data on heptachlor and concluded that the evidence for carcinogenicity was sufficient in animals and inadequate in humans, classifying it in Group 2B. A health-based value of 0.03µg/litre can be calculated for heptachlor and heptachlor epoxide on the basis of a PTDI of 0.1µg/kg of body weight, based on a NOAEL for heptachlor of 0.025 mg/kg of body weight per day from two studies in the dog, taking into consideration inadequacies of the database and allocating 1% of the PTDI to drinking-water. However, because heptachlor and heptachlor epoxide occur at concentrations well below those at which toxic effects are observed, it is not considered necessary to derive a guideline value. It should also be noted that concentrations below 0.1µg/litre are generally not achievable using conventional treatment technology.*

The US EPA has allocated heptachlor-epoxide a 'weight of evidence' toxicity classification B2 (probable human carcinogen). The basis given for this classification is as follows (US Environmental Protection Agency, 2006b):

> *Sufficient evidence exists from rodent studies in which liver carcinomas were induced in two strains of mice of both sexes and in CFN female rats. Several structurally related compounds are liver carcinogens.*

Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-15.

Table 11-15. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for heptachlor-epoxide

	Sfo		RfDo		Sfi		RfDi	
Heptachlor-epoxide	9.1E+00	i	1.3E-05	i	9.1E+00	i	1.3E-05	r

i: Data from IRIS (US Environmental Protection Agency, 2006b)
r: Route-extrapolation (US Environmental Protection Agency, 2004c)

11.2.8 Aldrin and Dieldrin

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

> *Both compounds are highly toxic in experimental animals, and cases of poisoning in humans have occurred. Aldrin and dieldrin have more than one mechanism of toxicity. The target organs are the central nervous system and the liver. In long-term studies, dieldrin was shown to produce liver tumours in both sexes of two strains of mice. It did not produce an increase in*

tumours in rats and does not appear to be genotoxic. IARC has classified aldrin and dieldrin in Group 3. It is considered that all the available information on aldrin and dieldrin taken together, including studies on humans, supports the view that, for practical purposes, these chemicals make very little contribution, if any, to the incidence of cancer in humans.

The US EPA has allocated aldrin and dieldrin a 'weight of evidence' toxicity classification B2 (probable human carcinogen). The basis given for this classification is as follows (US Environmental Protection Agency, 2006b):

Aldrin: Orally administered aldrin produced significant increases in tumor responses in three different strains of mice in both males and females. Tumor induction has been observed for structurally related chemicals, including dieldrin, a metabolite.

Dieldrin: Dieldrin is carcinogenic in seven strains of mice when administered orally. Dieldrin is structurally related to compounds (aldrin, chlordane, heptachlor, heptachlor epoxide, and chlorendic acid) which produce tumors in rodents.

Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-16.

Table 11-16. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for aldrin and dieldrin

	Sfo		RfDo		Sfi		RfDi	
Aldrin	1.7E+01	i	3.0E-05	i	1.7E+01	i	3.0E-05	r
Dieldrin	1.6E+01	i	5.0E-05	i	1.6E+01	i	5.0E-05	r

i: Data from IRIS (US Environmental Protection Agency, 2006b)
r: Route-extrapolation (US Environmental Protection Agency, 2004c)

11.2.9 Atrazine

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

The weight of evidence from a wide variety of genotoxicity assays indicates that atrazine is not genotoxic. There is evidence that atrazine can induce mammary tumours in rats. It is highly probable that the mechanism for this process is nongenotoxic. No significant increase in neoplasia has been observed in mice. IARC has concluded that there is inadequate evidence in humans and limited evidence in experimental animals for the carcinogenicity of atrazine (Group 2B).

A 'weight of evidence' US EPA toxicity classification is not currently available for atrazine (US Environmental Protection Agency, 2006b).

Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-17.

Table 11-17. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for atrazine

	Sfo		RfDo		Sfi		RfDi	
Atrazine	2.2E-01	h	3.5E-02	i	2.2E-01	r	3.5E-02	r

i: Data from IRIS (US Environmental Protection Agency, 2006b)
h: Data from Health Effects Summary Table (HEAST) (US Environmental Protection Agency, 2006a)
r: Route-extrapolation (US Environmental Protection Agency, 2004c)

11.2.10 Benzene

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

> *Acute exposure of humans to high concentrations of benzene primarily affects the central nervous system. At lower concentrations, benzene is toxic to the haematopoietic system, causing a continuum of haematological changes, including leukaemia. Because benzene is carcinogenic to humans, IARC has classified it in Group 1.Haematological abnormalities similar to those observed in humans have been observed in animal species exposed to benzene. In animal studies, benzene was shown to be carcinogenic following both inhalation and ingestion. It induced several types of tumours in both rats and mice in a 2-year carcinogenesis bioassay by gavage in corn oil. Benzene has not been found to be mutagenic in bacterial assays, but it has been shown to cause chromosomal aberrations in vivo in a number of species, including humans, and to be positive in the mouse micronucleus test.*

Benzene is classified by the US EPA as a "known" human carcinogen (Category A). The basis given for this classification is as follows (US Environmental Protection Agency, 2006b):

> *Epidemiologic studies and case studies provide clear evidence of a causal association between exposure to benzene and acute nonlymphocytic leukemia (ANLL) and also suggest evidence for chronic nonlymphocytic leukemia (CNLL) and chronic lymphocytic leukemia (CLL). Other neoplastic conditions that are associated with an increased risk in humans are hematologic neoplasms, blood disorders such as preleukemia and aplastic anemia, Hodgkin's lymphoma, and myelodysplastic syndrome (MDS). These human data are supported by animal studies. The experimental animal data add to the argument that exposure to benzene increases the risk of cancer in multiple species at multiple organ sites (hematopoietic, oral and nasal, liver, forestomach, preputial gland, lung, ovary, and mammary gland). It is likely that these responses are due to interactions of the metabolites of benzene with DNA. Recent evidence supports the viewpoint that there are likely multiple mechanistic pathways leading to cancer and, in particular, to leukemogenesis from exposure to benzene.*

Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-18.

Table 11-18. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for benzene

	Sfo		RfDo		Sfi		RfDi	
Benzene	5.5E-02	i	4.0E-03	i	2.7E-02	i	8.6E-03	i

i: Data from IRIS (US Environmental Protection Agency, 2006b)

11.2.11 Carbon Tetrachloride

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

> *The primary targets for carbon tetrachloride toxicity are liver and kidney. In experiments with mice and rats, carbon tetrachloride proved to be capable of inducing hepatomas and hepatocellular carcinomas. The doses inducing hepatic tumours were higher than those inducing cell toxicity. It is likely that the carcinogenicity of carbon tetrachloride is secondary to its hepatotoxic effects. On the basis of available data, carbon tetrachloride can be*

considered to be a non-genotoxic compound. Carbon tetrachloride is classified by IARC as being possibly carcinogenic to humans (Group 2B): there is sufficient evidence that carbon tetrachloride is carcinogenic in laboratory animals, but inadequate evidence in humans.

The US EPA has allocated carbon tetrachloride a 'weight of evidence' toxicity classification B2 (probable human carcinogen). The basis given for this classification is as follows (US Environmental Protection Agency, 2006b):

Carcinogenicity in rats, mice, and hamsters.

Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-19.

Table 11-19. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for carbon tetrachloride

	Sfo		RfDo		Sfi		RfDi	
Carbon tetrachloride	1.3E-01	i	7.0E-04	i	5.3E-02	i	7.0E-04	r

i: Data from IRIS (US Environmental Protection Agency, 2006b)
r: Route-extrapolation (US Environmental Protection Agency, 2004c)

11.2.12 Dichloroethane (1,2)

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

IARC has classified 1,2-dichloroethane in Group 2B (possible human carcinogen). It has been shown to produce statistically significant increases in a number of tumour types in laboratory animals, including the relatively rare haemangiosarcoma, and the balance of evidence indicates that it is potentially genotoxic. Targets of 1,2- dichloroethane toxicity in orally exposed animals included the immune system, central nervous system, liver and kidney. Data indicate that 1,2-dichloroethane is less potent when inhaled.

The US EPA has allocated 1,2-dichloroethane a 'weight of evidence' toxicity classification B2 (probable human carcinogen). The basis given for this classification is as follows (US Environmental Protection Agency, 2006b):

Based on the induction of several tumor types in rats and mice treated by gavage and lung papillomas in mice after topical application

Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-20.

Table 11-20. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for 1,2-dichloroethane

	Sfo		RfDo		Sfi		RfDi	
1,2-Dichloroethane	9.1E-02	i	2.0E-02	n	9.1E-02	i	1.4E-03	n

i: Data from IRIS (US Environmental Protection Agency, 2006b)
n: Data from NCEA (US Environmental Protection Agency, 2006c)

11.2.13 Hydrogen Sulphide (un-ionised)

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

> *The acute toxicity to humans of hydrogen sulfide following inhalation of the gas is high; eye irritation can be observed at concentrations of 15–30mg/m3. Although oral toxicity data are lacking, it is unlikely that a person could consume a harmful dose of hydrogen sulfide from drinking water. Consequently, no guideline value is proposed. However, hydrogen sulfide should not be detectable in drinking water by taste or odour.*

The US EPA has not allocated a 'weight of evidence' toxicity classification for hydrogen sulphide (US Environmental Protection Agency, 2006b).

Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-21.

Table 11-21. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for hydrogen sulphide

	Sfo		RfDo		Sfi		RfDi	
Hydrogen sulphide			3.0E-03	i			2.9E-04	i

i: Data from IRIS (US Environmental Protection Agency, 2006b)

11.2.14 Tetrachloroethene

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

> *At high concentrations, tetrachloroethene causes central nervous system depression. Lower concentrations of tetrachloroethene have been reported to damage the liver and the kidneys. IARC has classified tetrachloroethene in Group 2A. Tetrachloroethene has been reported to produce liver tumours in male and female mice, with some evidence of mononuclear cell leukaemia in male and female rats and kidney tumours in male rats. The overall evidence from studies conducted to assess the genotoxicity of tetrachloroethene, including induction of single-strand DNA breaks, mutation in germ cells and chromosomal aberrations in vitro and in vivo, indicates that tetrachloroethene is not genotoxic.*

A 'weight of evidence' US EPA toxicity classification for tetrachlorothene is not currently available (US Environmental Protection Agency, 2006b).

Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-22.

Table 11-22. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for tetrachloroethene

	Sfo		RfDo		Sfi		RfDi	
Tetrachloroethene	5.4E-01	c	1.0E-02	i	2.1E-02	c	1.0E-02	c

i: Data from IRIS (US Environmental Protection Agency, 2006b)
c: Data from California EPA (US Environmental Protection Agency, 2004b)

11.2.15 Chloroform and Dibromochloromethane

Chloroform and Dibromochloromethane are trihalomethanes (THMs). Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

Chloroform

The weight of evidence for genotoxicity of chloroform is considered negative. The weight of evidence for liver tumours in mice is consistent with a threshold mechanism of induction. Although it is plausible that kidney tumours in rats may similarly be associated with a threshold mechanism, there are some limitations of the database in this regard. The most universally observed toxic effect of chloroform is damage to the centrilobular region of the liver. The severity of these effects per unit dose administered depends on the species, vehicle and method by which the chloroform is administered.

Dibromochloromethane (DBCM)

In an NTP bioassay, DBCM induced hepatic tumours in female and possibly in male mice but not in rats. The genotoxicity of DBCM has been studied in a number of assays, but the available data are considered inconclusive. IARC has classified DBCM in Group 3 (not classifiable as to its carcinogenicity to humans).

The US EPA has allocated chloroform a 'weight of evidence' toxicity classification B2 (probable human carcinogen) and dibromochloromethane has been classified C (possible human carcinogen. The basis given for these classifications are as follows (US Environmental Protection Agency, 2006b):

Chloroform: "sufficient evidence" of carcinogenicity in animals.

Dibromochloromethane: Based on inadequate human data and limited evidence of carcinogenicity in animals; namely, positive carcinogenic evidence in B6C3Fl mice (males and females), together with positive mutagenicity data, and structural similarity to other trihalomethanes, which are known animal carcinogens.

Cancer slope factors (mg^{-1}.kg.day) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-23.

Table 11-23. Cancer slope factors (mg^{-1}.kg.day) and Reference doses ($mg.kg^{-1}.day^{-1}$) for chloroform and dibromochloromethane

	Sfo		RfDo		Sfi		RfDi	
Chloroform	1.0E-02	i	1.0E-02	i	8.1E-02	i	1.4E-02	n
Dibromochloromethane	8.4E-02	i	2.0E-02	i	8.4E-02	r	2.0E-02	r

i: Data from IRIS (US Environmental Protection Agency, 2006b)
n: Data from NCEA (US Environmental Protection Agency, 2006c)
r: Route-extrapolation (US Environmental Protection Agency, 2004c)

11.2.16 Arsenic

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

Arsenic has not been demonstrated to be essential in humans. It is an important drinking-water contaminant, as it is one of the few substances shown to cause cancer in humans through consumption of drinking water. There is overwhelming evidence from epidemiological studies that consumption of elevated levels of arsenic through drinking water is causally related to the development of cancer at several sites, particularly skin, bladder and lung. In several parts of the world, arsenic-induced disease, including cancer, is a significant public health problem. Because trivalent inorganic arsenic has greater reactivity and toxicity than pentavalent inorganic arsenic, it is generally believed that the trivalent form is the carcinogen. However, there remain considerable uncertainty and controversy over both the mechanism of carcinogenicity and the shape of the dose–response curve at low intakes. Inorganic arsenic compounds are classified by IARC in Group 1 (carcinogenic to humans) on the basis of sufficient evidence for carcinogenicity in humans and limited evidence for carcinogenicity in animals.

The US EPA has allocated arsenic a 'weight of evidence' toxicity classification A (human carcinogen). The basis given for this classification is as follows (US Environmental Protection Agency, 2006b):

Based on sufficient evidence from human data. An increased lung cancer mortality was observed in multiple human populations exposed primarily through inhalation. Also, increased mortality from multiple internal organ cancers (liver, kidney, lung, and bladder) and an increased incidence of skin cancer were observed in populations consuming drinking water high in inorganic arsenic.

Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-24.

Table 11-24. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for arsenic

	Sfo		RfDo		Sfi		RfDi	
Arsenic	1.5E+00	i	3.0E-04	i	1.5E+01	i		

i: Data from IRIS (US Environmental Protection Agency, 2006b)

11.2.17 Trichloroethene

Chemical fact sheets provided in Chapter 12 of the World Health Organization Guidelines for Drinking-water Quality provide the following toxicological review (World Health Organization, 2004):

The reactive epoxide trichloroethene oxide is an essential feature of the metabolic pathway. Trichloroethene has been classified by IARC in Group 3. It has been shown to induce lung and liver tumours in various strains of mice at toxic doses. However, there are no conclusive data to suggest that this chemical causes cancer in other species. Trichloroethene is a weakly active mutagen in bacteria and yeast.

Trichloroethene is not currently callsified by the US EPA Integrated Risk Information System (IRIS) (US Environmental Protection Agency, 2006b).

Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-25.

Table 11-25. Cancer slope factors ($mg^{-1}.kg.day$) and Reference doses ($mg.kg^{-1}.day^{-1}$) for trichloroethene

	Sfo		RfDo		Sfi		RfDi	

Trichloroethene	4.0E-01	n	3.0E-04	n	4.0E-01	n	1.0E-02	n

n: Data from NCEA (US Environmental Protection Agency, 2006c)

11.2.18 Dichlorobenzidine

Dichlorobenzidine was not included in the World Health Organization Guidelines for Drinking-water Quality (World Health Organization, 2004).

The US EPA has allocated 3,3'-dichlorobenzidine a 'weight of evidence' toxicity classification B2 (probable human carcinogen). The basis given for this classification is as follows (US Environmental Protection Agency, 2006b):

> *Based on statistically significantly increased tumor incidences in rats, mice and dogs. Additional support is provided by positive evidence of genotoxicity and structural relationship to the known human bladder carcinogen benzidine.*

Cancer slope factors (mg^{-1}.kg.day) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-26.

Table 11-26. Cancer slope factors (mg^{-1}.kg.day) and Reference doses ($mg.kg^{-1}.day^{-1}$) for dichlorobenzidine

	Sfo		RfDo		Sfi		RfDi	
Dichlorobenzidine	4.5E-01	i			4.5E-01	r		

i: Data from IRIS (US Environmental Protection Agency, 2006b)
r: Route-extrapolation (US Environmental Protection Agency, 2004c)

11.2.19 Diphenylhydrazine

Diphenylhydrazine was not included in the World Health Organization Guidelines for Drinking-water Quality (World Health Organization, 2004).

The US EPA has allocated 1,2-diphenylhydrazine a 'weight of evidence' toxicity classification B2 (probable human carcinogen). The basis given for this classification is as follows (US Environmental Protection Agency, 2006b):

> *Positive results of studies in both rats and mice form the basis for this classification. Two apparently negative studies lack information on compound purity, experimental design, and statistical treatment.*

Cancer slope factors (mg^{-1}.kg.day) sourced from US EPA data are provided in Table 11-27.

Table 11-27. Cancer slope factors (mg^{-1}.kg.day) and Reference doses ($mg.kg^{-1}.day^{-1}$) for diphenylhydrazine

	Sfo		RfDo		Sfi		RfDi	
Diphenylhydrazine	8.0E-01	i			8.0E-01	i		

i: Data from IRIS (US Environmental Protection Agency, 2006b)

11.2.20 Acrylonitrile

Acrylonitrile was not included in the World Health Organization Guidelines for Drinking-water Quality (World Health Organization, 2004).

The US EPA has allocated acrylinitrile a 'weight of evidence' toxicity classification B1 (probable human carcinogen). The basis given for this classification is as follows (US Environmental Protection Agency, 2006b):

The observation of a statistically significant increase in incidence of lung cancer in exposed workers and observation of tumors, generally astrocytomas in the brain, in studies in two rat strains exposed by various routes (drinking water, gavage, and inhalation) forms the basis for this classification.

Cancer slope factors (mg^{-1}.kg.day) and Reference doses ($mg.kg^{-1}.day^{-1}$) sourced from US EPA data are provided in Table 11-28.

Table 11-28. Cancer slope factors (mg^{-1}.kg.day) and Reference doses ($mg.kg^{-1}.day^{-1}$) for acrylonitrile

	Sfo		RfDo		Sfi		RfDi	
Acrylonitrile	5.4E-01	i	1.0E-03	h	2.4E-01	i	5.7E-04	i

i: Data from IRIS (US Environmental Protection Agency, 2006b)
h: Data from Health Effects Summary Table (HEAST) (US Environmental Protection Agency, 2006a)

12 Exposure Assessment

Exposure assessment comprised the identification of potential exposure pathways and the estimation of exposure concentration for these pathways. These are presented in the following sections.

12.1 Identification of potential exposure pathways

Three principal categories of exposure pathways were identified. These were via consumption of water sourced from the Hawkesbury-Nepean River, recreational exposure to water, soil and air at the Hawkesbury-Nepean River and by exposure via contaminated soils subsequent to intensive irrigation by water sourced from the Hawkesbury-Nepean River.

Drinking water exposures considered the consumption of 2 L per day of water sourced from any section of the Hawkesbury-Nepean River between the point of supplementation (Penrith Weir) and 17.5 km downstream at the Richmond Water Treatment Plant.

Recreational exposures considered possible recreational activities between Penrth Weir and North Richmond that involve accidental ingestion of river water, dermal exposure to water and mud (sediment), and inhalation of air directly above the river.

Contaminated soil exposures were based on an evaluative hypothetical intensive irrigation scenario using water sourced from the Hawkesbury-Nepean River. The risk calculations are based on residential exposure to soils, including exposure by children. Thus they include exposure via oral, inhalation and dermal-contact pathways. They assume the consumption (by children) of 200 mg of soil per day.

The principal exposure scenarios are presented schematically for drinking water consumption (Figure 12-1), recreational activities (Figure 12-2) and irrigation of soils (Figure 12-3).

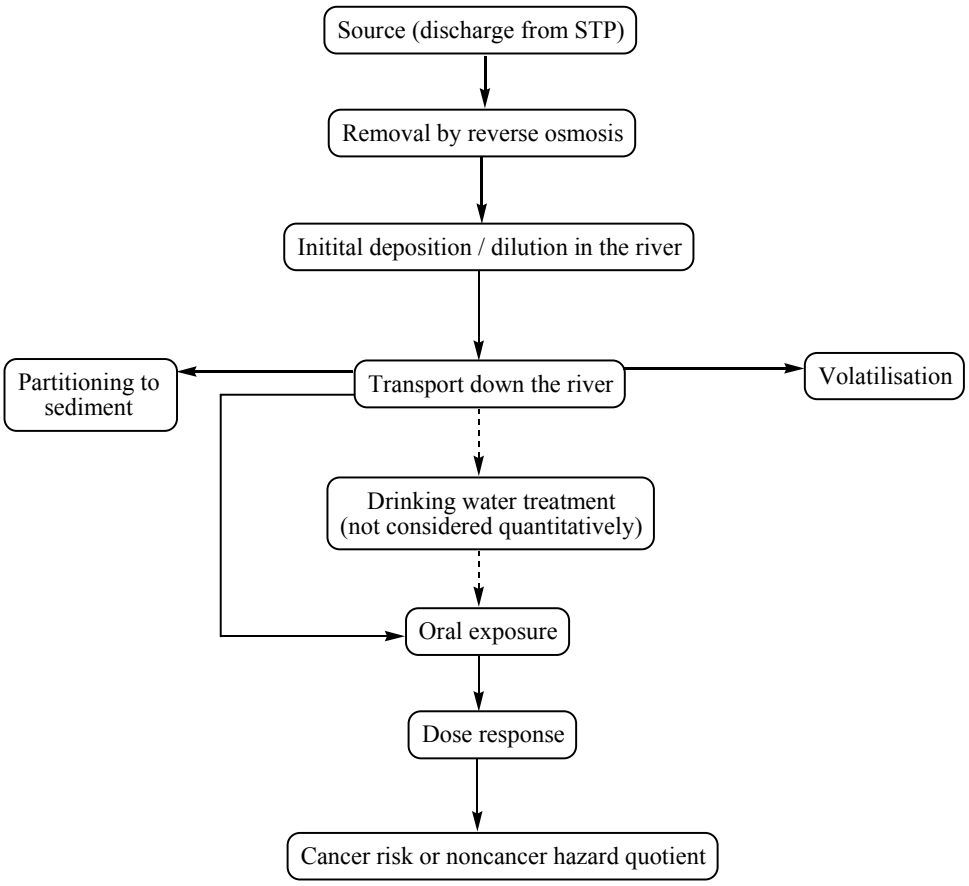


Figure 12-1. Exposure to chemicals via drinking-water consumption

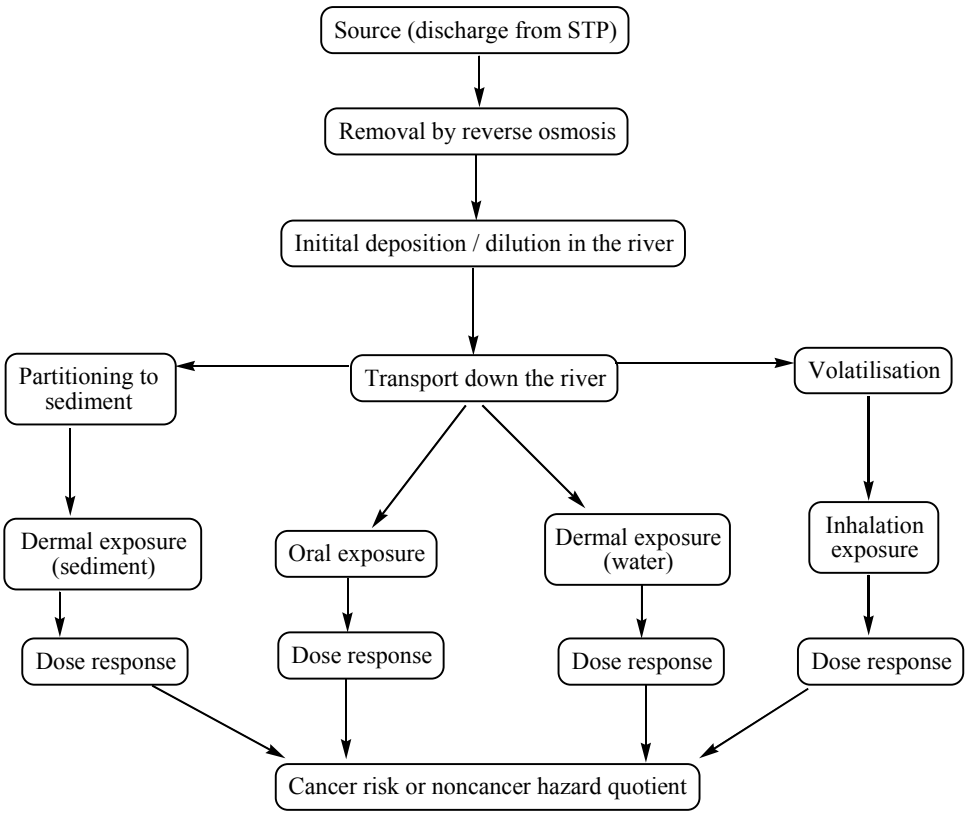


Figure 12-2. Exposure to chemicals via recreational activities

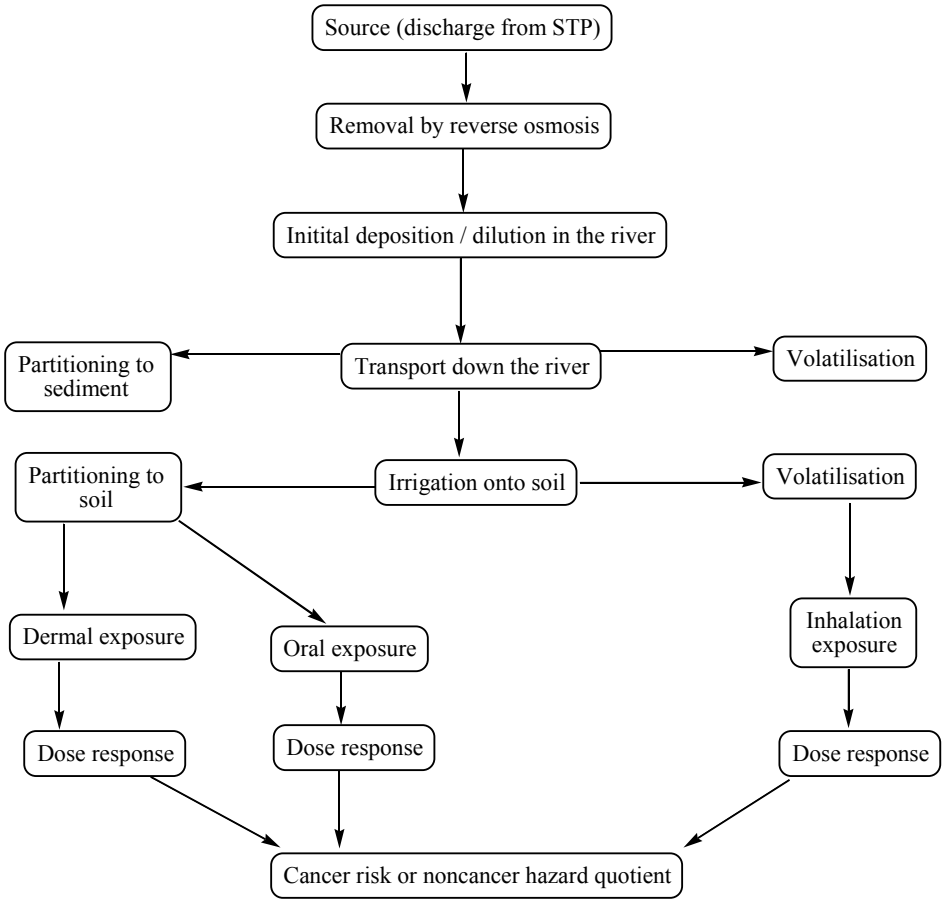


Figure 12-3. Exposure to chemicals via irrigation of soil

12.2 Estimation of exposure concentration for pathways

The estimation of exposure concentrations for pathways was based on 95th percentile concentrations of Schedule 10 data and subsequent chemical removal by various barriers. In situtations where the chemical was not detected, the detection limit was used. The principal barriers considered included advanced water treatment (reverse osmosis), dilution in the river and chemical partitioning (between water, air, sediment and soil). This provided for the calculation of estimated concentrations at key points of exposure as presented in the following sections.

Due to their different physical and chemical attributes and different assessment methods inorganic and organic chemical exposures were assessed by slightly different means.

Though chloramines are strictly inorganic compounds their physical and chemical properties are more typical of organic chemicals and thus they have been grouped and assessed in the 'organic' category.

12.2.1 No barriers

The 'no barriers' situation is hypothetical since it assumes a community sourcing drinking water directly from the tertiary sewage treatment plant source with no further treatment, dilution or environmental residence.

95th percentile concentrations were assumed for concentrations in tertiary treated effluent subjected to no further barriers. These concentrations for the identified chemicals are presented in Table 12-1. In many cases the 95th percentiles values were based on the analytical detection limit.

12.2.2 Advanced water treatment (MF-RO)

The advanced water treatment process can be expected to substantially remove many dissolved organic chemicals principally by the planned reverse osmosis membrane treatment. The actual degree of removal will be dependant on numerous factors including physical/chemical properties of specific solute as well as specific properties of the membranes to be employed (Agenson *et al.* 2003; Drewes *et al.* 2006).

Table 12-1. Ninety fifth percentile 'no barriers' concentrations for chemical hazards (in tertiary treated STP effluent)

Chemical	95th percentile concentration (µg.L^{-1})
Acrylonitrile	5#
Aldrin	0.01#
Arsenic	1
Atrazine	0.5#
Benz(a)anthracene	0.1#
Benzene	1#
Benzene Hexachloride (Alpha)	0.01#
Benzo(a)pyrene	0.1#
Benzo(b)fluoranthene	0.1#
Carbon Tetrachloride	1#
Chloroform	7
Dibenz(ah)anthracene	0.1#
Dibromochloromethane	9
Dichlorobenzene (1,4)	0.5#
Dichlorobenzidine	5#
Dichloroethane (1,2)	1#
Dichloromethane	5#
Dieldrin	0.01 (1 detect of 99 analyses)
Diphenylhydrazine	5#
Heptachlor-epoxide	0.01#
Hydrogen Sulphide (un-ionised)	20
Indeno(1,2,3-cd)pyrene	0.1#
Nickel	31.85
Polychlorinated Biphenyls	0.1#
Tetrachloroethene	1#
Total Chloramines (as monochloramines)	319.5
Trichloroethene	1#

Notes:

1. Concentrations marked # are detection limit values. These are used for chemicals that were never identified at concentrations equal to or greater than this value.

12.2.2.1 Organic chemicals

The removal of organic contaminants is dependant on the precise membrane characteristics as well as operating conditions such as pressure. Furthermore, for some chemicals, membrane-solute interactions are believed to be important (Agenson *et al.* 2003). During bench-top investigations of chemical removals undertaken by Agenson *et al.* (2003), virtually all semi-volatile organic compounds were reduced by at least 90% and most larger organics by 99.9% or more. However,

this was not the case with volatile organic compounds (VOCs), for which in some cases practically nil removal was reported (Table 12-2).

Table 12-2. Retention (%) of VOCs and SVOCs for five membranes at 0.3 MPa (Agenson *et al.* 2003)

Compound	Membrane Material / Description			
	Polyvinylalcohol-polyamide / NTR729HF	Aromatic polyamide/ UTC70	Polyamides / ES10C	Polyvinylalcohol-polyamide / LF10
Benzene	43.7	37.3	54.3	27
Toluene	81.8	67.1	89.2	88
1,1-Dichloroethylene	19.9	1	22.3	1
cis-1,2-Dichloroethylene	37.1	1	23.5	1
trans-1,2-Dichloroethene	42.1	1	19	1
1,2-Dichloroethane	11.4	17.1	35	7
p-Xylene	96.7	93.9	98	98.5
m-Xylene	96.7	93.9	98	98.5
o-Xylene	92.9	94.5	97.7	98.7
1,2-Dichloropropane	42	67.6	67.8	64
Chloroform	23.9	32	44	15.4
Trichloroethylene	74.3	2.1	59.3	26.3
1,1,1-Trichloroethane	70	95.7	95.2	96.8
1,1,2-Trichloroethane	33.8	57.5	55.6	52
2-Isopropyl phenol	80.2	>99.9	98.4	>99.9
4 or 3-Isopropyl phenol	80.5	99.5	97.7	99.5
2-Phenyl-2-propanol	86.6	99.5	97.8	>99.9
2,2,4-Trimethyl-1,3-pentanediol	>99.9	97.1	98	>99.9
1,4-Dichlorobenzene	97.6	95.3	98.8	97
4-tert-Butylphenol	92.3	99.7	>99.9	>99.9
2-Hydroxybenzothiazole	73.6	88.8	92.5	80
Camphor	99	99.2	>99.9	>99.9
Carbontetrachloride	75.3	92.6	92.7	93
Bromodichloromethane	30.1	29.3	44.6	25.1
Tetrachloroethylene	95.6	85.4	96.9	96
Diphenyl amine	>99.9	99.3	>99.9	>99.9
Triethyl phosphate	>99.9	>99.9	>99.9	>99.9
Dimethyl phthalate	95.2	99.5	98.2	99.6
N-Ethyl-p-toluenesulfonamide	94.5	99.8	99.1	>99.9
Dibromochloromethane	42.8	40.2	52.5	43
n-Buthyl benzenesulfonamide	95	99.2	98.5	>99.9
Diethyl phthalate	98.3	96.3	99.4	99.8
Bisphenol A	99.8	99.8	>99.9	>99.9
Bromoform	55.4	57	66	69
Tributhyl phosphate	>99.9	99.7	>99.9	>99.9
Tris(2-chloroethyl) phosphate	>99.9	>99.9	>99.9	>99.9
Chloride	71	98.4	91.1	99.2
Color	99.8	99.8	99.6	99.8

A useful guide for the classification of organic contaminants for removal estimation was recently developed by Drewes *et al.* (2006). This system is based on a limited number of physical/chemical characteristics such as molecular weight (mw), acid dissociation constant (pKa), molecular width (MWd) and octanol-water partitioning coefficients (Log Kow). Removals are determined with respect to system parameters including the nominal molecular weight cut off (MWCO) for the reverse osmosis membrane and the solution pH. The classification system is represented in Figure 12-4 (Drewes *et al.*, 2006).

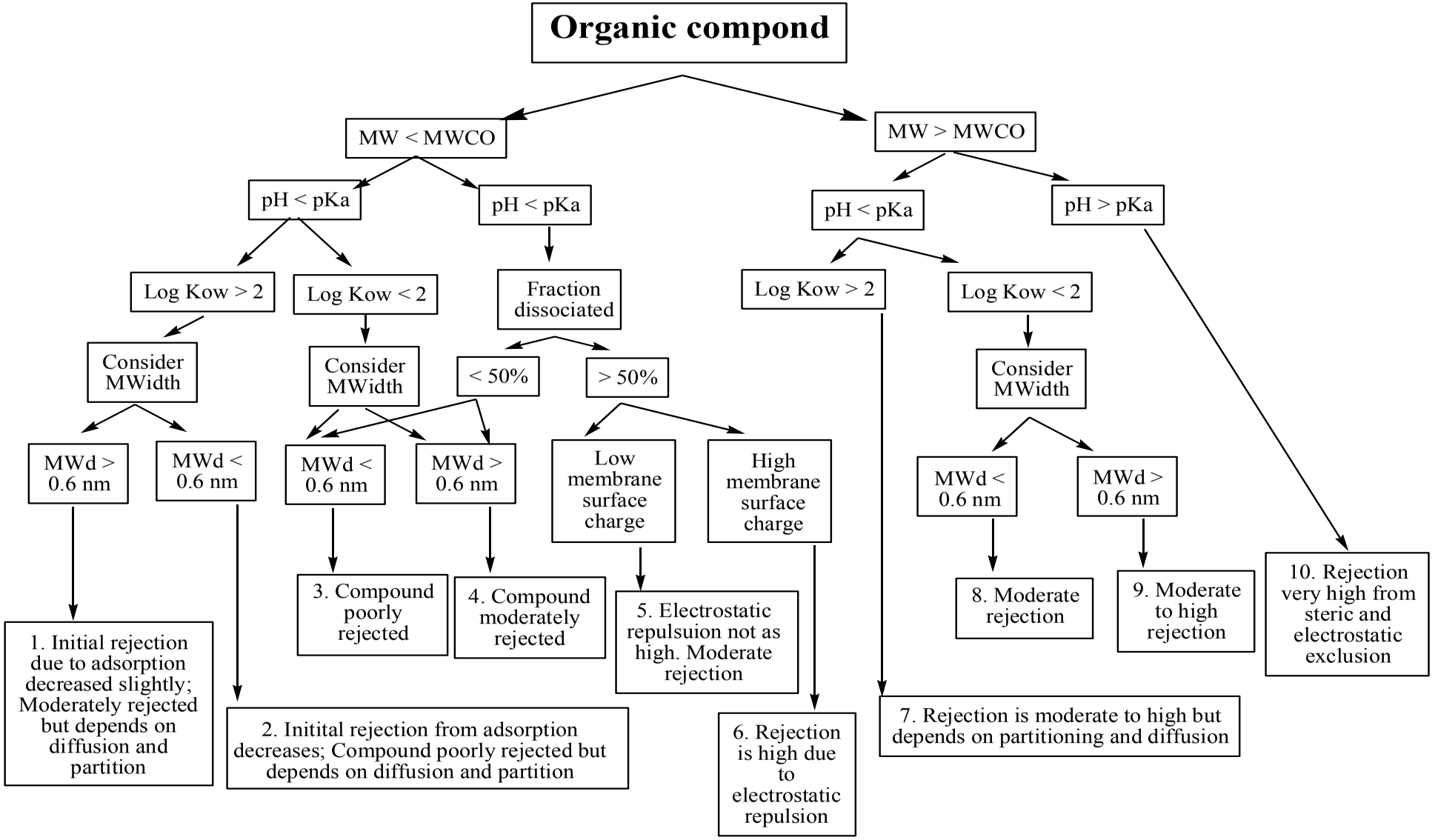


Figure 12-4. Rejection diagram for organic micropollutants during membrane treatment based on solute and membrane properties (Drewes *et al.*, 2006).

Most published data for membrane treatment processes (particularly pilot-scale and bench-scale studies) report chemical removals for single-pass systems. However, some full-scale systems employ multiple passes through subsequent membrane modules. Total removals for a multiple-pass system can be estimated by multiplying the $\log_{10}$ of the percentage removal by the number of membrane passes.

However, estimating removals for multiple-pass systems can be complicated by operating procedures that involve some degree of 'bypass' for subsequent stages. Such procedures are commonly adopted to attain full compliance with required effluent total dissolved salt (TDS) concentrations with optimum energy-efficiency. As an example, a schematic diagram is provided from the standard operating procedure manual for triple-stage RO system located at the Wollongong Sewage Treatment Plant (Figure 12-5).

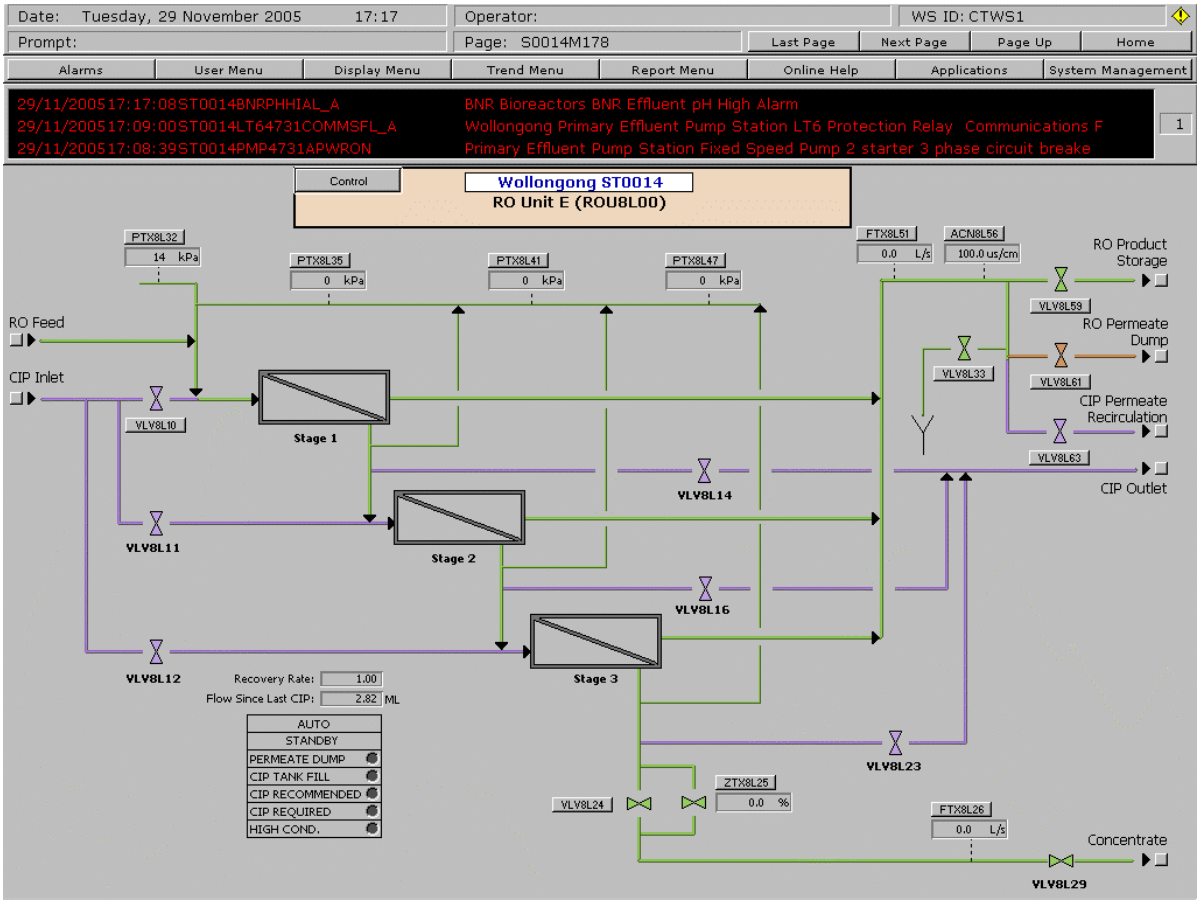


Figure 12-5. Reverse osmosis schematic for Wollongong Sewage Treatment Plant (Walter-Veolia Joint Venture, 2005)

As a 'best available' guide for removal estimation, organic chemicals were individually classified according to the criteria developed Drewes *et al.* (2006) (Figure 12-4).

Using this system, the identified organic chemical hazards have been classified in terms of likely reverse osmosis rejection behaviour. An estimated removal range is provided in Table 12-3, based on limited data provided by Drewes *et al.* (2006), Xu *et al.*(2005) and Agenson *et al.* (2003). This estimated range applies to a single-pass reverse osmosis system. Chemical removal descriptions of "good rejection" and "poor rejection" were assigned quantitative ranges based on upper and lower observed removals for organic chemicals leading to relevant "results categories" (from Figure 12-4). These rejection percentages correspond to variation observed between chemicals within

groups leading to the results categories and also in variation of removal performance for specific chemicals between different RO membranes and operating conditions.

Table 12-3. Rejection descriptions and estimated removal ranges for organic compounds by reverse osmosis

Result category	Good rejection (%)	Poor rejection (%)	Rejection description
1	90	20	Initial rejection due to adsorption decreases slightly; Moderately rejected but depend on diffusion and partition
2	10	0	Initial rejection from adsorption decreases; Compound poorly rejected but depends on diffusion and partition
3	10	0	Compound poorly rejected
4	90	20	Compound moderately rejected
5	90	20	Electrostatic repulsion not as high: Moderate rejection
6	99.9	99	Rejection is high due to electrostatic repulsion
7	99	90	Rejection moderate to high but depends on partitioning and diffusion
8	90	20	Moderate rejection
9	99	90	Moderate to high rejection
10	>99.9	99.9	Rejection very high from steric and electrostatic exclusion

The following assumptions were used in the classification of chemicals identified by hazard identification in the current study:

1. The molecular weight cut off (MWCO) of the reverse osmosis membranes to be employed is 100 Daltons; and
2. The pH of the water is 7 (although the results for these specific chemical would not change for pH 6-8).

The predicted reverse osmosis removal behaviour and estimated removal range are provided in Table 12-4. It is understood that the final design of the proposed treatment system will be a single-pass or double-pass system. The specific details regarding multiple-pass bypass are as yet unknown. Accordingly, data is presented below (and used in subsequent calculations) is for a single-pass system as a worst-case scenario.

Table 12-4. Predicted membrane rejection behaviour for organic chemicals (percentage rejection assignments based on a single-pass RO system).

Organic chemical	[1]Result category	Chemical rejection (%)		Effluent conc. (µg.L^{-1})		Rejection behaviour description
		Good	Poor	Good rejection	Poor rejection	
Acrylonitrile	3	10	0	5.E+00	5.E+00	Compound poorly rejected
Aldrin	7	99	90	1.E-04	1.E-03	Rejection moderate to high but depends on partitioning and diffusion
Atrazine	7	99	90	5.E-03	5.E-02	Rejection moderate to high but depends on partitioning and diffusion
Benz(a)anthracene	7	99	90	1.E-03	1.E-02	Rejection moderate to high but depends on partitioning and diffusion
Benzene	2	10	0	9.E-01	1.E+00	Initial rejection from adsorption decreases; Compound poorly rejected but depends on diffusion and partition
Benzene Hexachloride (Alpha)	7	99	90	1.E-04	1.E-03	Rejection moderate to high but depends on partitioning and diffusion
Benzo(a)pyrene	7	99	90	1.E-03	1.E-02	Rejection moderate to high but depends on partitioning and diffusion
Benzo(b)fluoranthene	7	99	90	1.E-03	1.E-02	Rejection moderate to high but depends on partitioning and diffusion
Carbon Tetrachloride	7	99	90	1.E-02	1.E-01	Rejection moderate to high but depends on partitioning and diffusion
Chloroform	8	90	20	7.E-01	6.E+00	Moderate rejection
Dibenz(ah)anthracene	7	99	90	1.E-03	1.E-02	Rejection moderate to high but depends on partitioning and diffusion
Dibromochloromethane	7	99	90	9.E-02	9.E-01	Rejection moderate to high but depends on partitioning and diffusion
Dichlorobenzene (1,4)	7	99	90	5.E-03	5.E-02	Rejection moderate to high but depends on partitioning and diffusion
Dichlorobenzidine	7	99	90	5.E-02	5.E-01	Rejection moderate to high but depends on partitioning and diffusion
Dichloroethane (1,2)	3	10	0	9.E-01	1.E+00	Compound poorly rejected
Dichloromethane	3	10	0	5.E+00	5.E+00	Compound poorly rejected
Dieldrin	7	99	90	1.E-04	1.E-03	Rejection moderate to high but depends on partitioning and diffusion
Diphenylhydrazine	7	99	90	5.E-02	5.E-01	Rejection moderate to high but depends on partitioning and diffusion
Heptachlor-epoxide	7	99	90	1.E-04	1.E-03	Rejection moderate to high but depends on partitioning and diffusion
Indeno(1,2,3-cd)pyrene	7	99	90	1.E-03	1.E-02	Rejection moderate to high but depends on partitioning and diffusion
Polychlorinated Biphenyls	7	99	90	1.E-03	1.E-02	Rejection moderate to high but depends on partitioning and diffusion
Tetrachloroethene	7	99	90	1.E-02	1.E-01	Rejection moderate to high but depends on partitioning and diffusion
Total Chloramines (as monochloramine)	3	10	0	3.E+02	3.E+02	Compound poorly rejected
Trichloroethene	7	99	90	1.E-02	1.E-01	Rejection moderate to high but depends on partitioning and diffusion

[1]Result Category refers to the categories defined in Table 12-3.

12.2.2.2 Inorganic chemicals

No similar procedure was identified for classification of inorganic chemicals as was used above for organic chemicals. Membrane manufacturers typically classify RO membranes in terms of a molecular weight cut off (MWCO), however this figure is unlikely to be meaningful for inorganic species since it predominantly interpreted as a '*de facto* molecular size' parameter. This relationship assumes a significant proportion of the mass is contributed by carbon atoms (as well as H, and possibly N and O). In order to obtain reasonable figures for subsequent modelling calculations, removal efficiencies shown in Table 12-5 were assumed.

Table 12-5. Assumed removal efficiencies for inorganic chemicals

Inorganic chemical	Assumed removal	Justification/Reference
Arsenic	70%	(Bartels *et al.* 2005)
Nickel	99-99.9%	Predominantly by RO, but including removal by RO pretreatment (Ipek, 2005)
Hydrogen Sulphide (un-ionised)	0-10%	Estimate based on molecular properties as a very small unionised molecule (physically very similar to H_2O). H_2S is not well removed by RO and (where it is a problem) pre-treatment or post-treatment processes are relied upon. Typical approaches include either oxidation to sulphate or degassing as H_2S (Miller & Pontek, 1992; Al Suleimani & Nair, 2000; Smith *et al.*, 2001).

12.2.3 Dilution

Following advanced treatment, recycled water will be mixed with water in the Hawkesbury-Nepean River. Depending on environmental flow conditions, this will provide a variable degree of dilution. The degree of dilution increases as the river proceeds downstream due to additional in-flows from smaller creeks and other waterways.

This assessment is made with the assumption that all water entering the river from other sources provides a diluting effect to chemicals that may be present in the water from the proposed scheme. However, it is possible that these other sources of water may also carry some background load of some chemicals and thus the full dilution effects would not be realised. No account has been made for such potential background exposures in the current analysis.

River flow conditions were determined on the basis of modelling data provided by Sydney Water. Three flow rate conditions were considered (Table 12-6). Further details have been previously presented in Table 5-9.

Table 12-6. Modelled riverine flow scenarios

Description	Flow percentile	Min dilution factor (Penrith Weir)	Description of implications	Comments
Low flow conditions	80th percentile	3.7	low dilution, but long residence time	Actual Hawkesbury-Nepean River data supplied by Sydney Water
Median flow conditions	50th percentile	5.6	Median dilution, and median residence time	
High flow conditions	20th percentile	76.9	High dilution, but short residence time	

Under these flow conditions concentrations of chemical hazards can be calculated assuming both 'good' and 'poor' removal by reverse osmosis. Such calculated concentrations are provided in Table 12-7 at 20th, 50th and 80th percentile flow conditions.

Table 12-7. Calculated chemical hazard concentrations (µg.L^{-1}) at the point of river supplementation accounting for RO removal and river dilution (assuming no background contribution from other sources).

Membrane performance:	GOOD			POOR		
Flow Percentile:	**20th**	**50th**	**80th**	**20th**	**50th**	**80th**
Acrylonitrile	6.E-02	8.E-01	1.E+00	6.E-02	9.E-01	1.E+00
Aldrin	1.E-06	2.E-05	3.E-05	1.E-05	2.E-04	3.E-04
Arsenic	4.E-03	6.E-02	8.E-02	4.E-03	6.E-02	8.E-02
Atrazine	6.E-05	9.E-04	1.E-03	6.E-04	9.E-03	1.E-02
Benz(a)anthracene	1.E-05	2.E-04	3.E-04	1.E-04	2.E-03	3.E-03
Benzene	1.E-02	2.E-01	3.E-01	1.E-02	2.E-01	3.E-01
Benzene Hexachloride (Alpha)	1.E-06	2.E-05	3.E-05	1.E-05	2.E-04	3.E-04
Benzo(a)pyrene	1.E-05	2.E-04	3.E-04	1.E-04	2.E-03	3.E-03
Benzo(b)fluoranthene	1.E-05	2.E-04	3.E-04	1.E-04	2.E-03	3.E-03
Carbon Tetrachloride	1.E-04	2.E-03	3.E-03	1.E-03	2.E-02	3.E-02
Chloroform	9.E-03	1.E-01	2.E-01	7.E-02	1.E+00	2.E+00
Dibenz(ah)anthracene	1.E-05	2.E-04	3.E-04	1.E-04	2.E-03	3.E-03
Dibromochloromethane	1.E-03	2.E-02	3.E-02	1.E-02	2.E-01	3.E-01
Dichlorobenzene (1,4)	6.E-05	9.E-04	1.E-03	6.E-04	9.E-03	1.E-02
Dichlorobenzidine	6.E-04	9.E-03	1.E-02	6.E-03	9.E-02	1.E-01
Dichloroethane (1,2)	1.E-02	2.E-01	3.E-01	1.E-02	2.E-01	3.E-01
Dichloromethane	6.E-02	8.E-01	1.E+00	6.E-02	9.E-01	1.E+00
Dieldrin	1.E-06	2.E-05	3.E-05	1.E-05	2.E-04	3.E-04
Diphenylhydrazine	6.E-04	9.E-03	1.E-02	6.E-03	9.E-02	1.E-01
Heptachlor-epoxide	1.E-06	2.E-05	3.E-05	1.E-05	2.E-04	3.E-04
Hydrogen Sulphide (un-ionised)	2.E-01	3.E+00	5.E+00	3.E-01	4.E+00	6.E+00
Indeno(1,2,3-cd)pyrene	1.E-05	2.E-04	3.E-04	1.E-04	2.E-03	3.E-03
Nickel	4.E-04	6.E-03	9.E-03	4.E-03	6.E-02	9.E-02
Polychlorinated Biphenyls	1.E-05	2.E-04	3.E-04	1.E-04	2.E-03	3.E-03
Tetrachloroethene	1.E-04	2.E-03	3.E-03	1.E-03	2.E-02	3.E-02
Total Chloramines (as monochloramine)	4.E+00	5.E+01	8.E+01	4.E+00	6.E+01	9.E+01
Trichloroethene	1.E-04	2.E-03	3.E-03	1.E-03	2.E-02	3.E-02

12.2.4 Environmental partitioning and degradation

The chemicals in the environmental release waters will enter the river as dissolved components. Once in the environment, there is potential for these chemicals to partition between other environmental phases including air, suspended sediment and bottom sediment. In addition to this partitioning, chemical removal from the system will occur by a number of mechanisms including advective flow and biodegradation. Suitable methods considering and balancing these factors are available in the form of 'fugacity' modelling calculations.

An effective approach for estimating environmental concentrations organic chemical hazards is provided by environmental fugacity calculations (Mackay & Paterson 1981; Mackay & Paterson 1991; Mackay *et al.* 1997). Various 'levels' of fugacity models have been described, ranging in complexity from Level 1 to Level 4. These models (Levels 1-4) vary according to the manner in which they deal with assumptions of equilibrium, flux and steady-state conditions (Mackay & Paterson, 1981).

It is considered that a Level 3 model is most suitable for the current application. The Level 3 model provides predictions of steady-state, non-equilibrium concentrations and distributions of environmental contaminants.

In order to describe chemical partitioning between environmental phases (air, water and sediment), various physical and chemical properties for each chemical are required. The key properties are molecular mass, octanol-water partitioning coefficient (K_{ow}), water solubility, vapour pressure, and acid dissociation constant (pKa) of any relevant acidic dissociation. The data used were sourced from the US EPA's EPI Suite database software, or when not available, from the quantitative structure activity modelling results from the same software (US EPA 2000). The modelled chemical parameters are presented in Table 12-8.

Table 12-8. Chemical-specific parameters used for fugacity modelling of organic chemicals (US EPA 2000)

NAME	MW	Aqueous solubility ($mg.L^{-1}$)	MP	$LogK_{ow}$	pKa	Vapour pressure (mmHg)	[1]AOPWIN
Acrylonitrile	53	5.E+04	-84	0.25	-	1.E+02	3.E+01
Aldrin	365	1.E-02	240	6.5	-	2.E-06	1.E+00
Atrazine	216	2.E+02	173	2.82	2.35	3.E-05	5.E+00
Benz(a)anthracene	228	3.E-02	84	5.76	-	3.E-07	3.E+00
Benzene	78	2.E+03	-78	2.13	-	9.E+01	7.E+01
Benzene Hexachloride (Alpha)	291	4.E+00	113	4.14	-	4.E-05	2.E+02
Benzo(a)pyrene	252	1.E-02	177	6.13	-	2.E-08	3.E+00
Benzo(b)fluoranthene	252	2.E-02	168	5.78	-	2.E-08	7.E+00
Carbon Tetrachloride	154	3.E+02	-23	2.83	-	1.E+02	1.E+04
Chloroform	119	2.E+03	-64	1.97	-	2.E+02	1.E+03
Dibenz(ah)anthracene	278	3.E-03	270	6.54	-	1.E-11	3.E+00
Dibromochloromethane	208	6.E+02	-20	2.16	-	2.E+01	2.E+03
Dichlorobenzene (1,4)	147	9.E+01	53	3.44	-	7.E-01	3.E+02
Dichlorobenzidine	253	2.E+01	133	3.51	2.7	4.E-06	3.E+00
Dichloroethane (1,2)	99	6.E+03	-36	1.48	-	8.E+01	5.E+02
Dichloromethane	85	1.E+04	-95	1.25	-	4.E+02	1.E+03
Dieldrin	381	1.E-01	228	5.2	-	3.E-06	1.E+01
Diphenylhydrazine	184	2.E+02	131	2.94	3.02	1.E-04	2.E+00
Heptachlor-epoxide	389	2.E-01	160	4.98	-	9.E-06	2.E+01
Indeno(1,2,3-cd)pyrene	276	2.E-03	164	6.7	-	1.E-10	2.E+00
Polychlorinated Biphenyls (As Aroclor 1254)	326	1.E-02	135	6.79	-	5.E-06	4.E+02
Tetrachloroethene	166	8.E+01	-22	3.4	-	2.E+01	6.E+02
Total Chloramines (as monochloramine)	51	1.E+06	190	-1.19	-1	1.E-09	1.E+04
Trichloroethene	131	8.E+02	-85	2.42	-	7.E+01	2.E+02

[1]AOPWIN is a quantitative structure activity relationship model supplied as a component of the US EPA EPI Suite for estimation of chemical degradation in atmospheric phases (US EPA, 2000).

Environmental biodegradation rates typically represent the greatest obstacle to reliable modelling. This is due to a general lack of information regarding degradation of specific compounds in various environmental media, as well as the extreme variation that can result from seemingly subtle environmental variations. Consequently, there are no highly reliable methods of predicting environmental biodegradation. As a conservative approach, biodegradation of all chemicals was disregarded in the current modelling process (effectively achieved by setting biodegradation half lives to 10^6 hours for all chemicals)

Photolysis half-lives in air were estimated by quantitative structure-activity relationship data (AOPWIN (US EPA, 2000)). Data derived by this processes should be considered only as reasonable estimates of the order-of-magnitudes.

Level 3 fugacity calculations were undertaken as previously described Mackay *et al.* (1997) and calculated using Microsoft Excel spreadsheets.

12.2.4.1 River fate and transport

The fugacity modelling process focused on organic chemical concentrations in the Hawkesbury-Nepean River expected to be derived from the proposed water recycling scheme. A stretch of approximately 17.5 km was modelled as the identified region of greatest potential impact to public health. This stretch begins from the point of proposed recycled water input (just below Penrith Weir) and finishes at the Yarramundi Bridge, which is just up-stream of the intake if the North Richmond Drinking Water Treatment Plant.

In order to adequately undertake the modelling process, it was necessary to divide the river into five theoretical segments. These are described in Table 12-9 and shown diagrammatically in Figure 12-6. This diagram is not intended to depict the actual 2-dimensional shape of the river (one axis is in meters, while the other is in kilometres), but represents the relative surface areas and volumes as extrapolated from Sydney Water data and used in the fate-modelling process.

Table 12-9. Description of theoretical river "segments"

	Length (m)	Surface area (m^2)	Volume (m^3)	Approximate location
Segment A	1300	143400	240488	Penrith
Segment B	3700	541250	1653682	Emu Plains
Segment C	5000	710000	1986001	Yellow Rock / Cranebrook
Segment D	6000	840000	2329181	Castlereagh / Hawkesbury Heights
Segment E	1500	168750	134618	Yarramundi

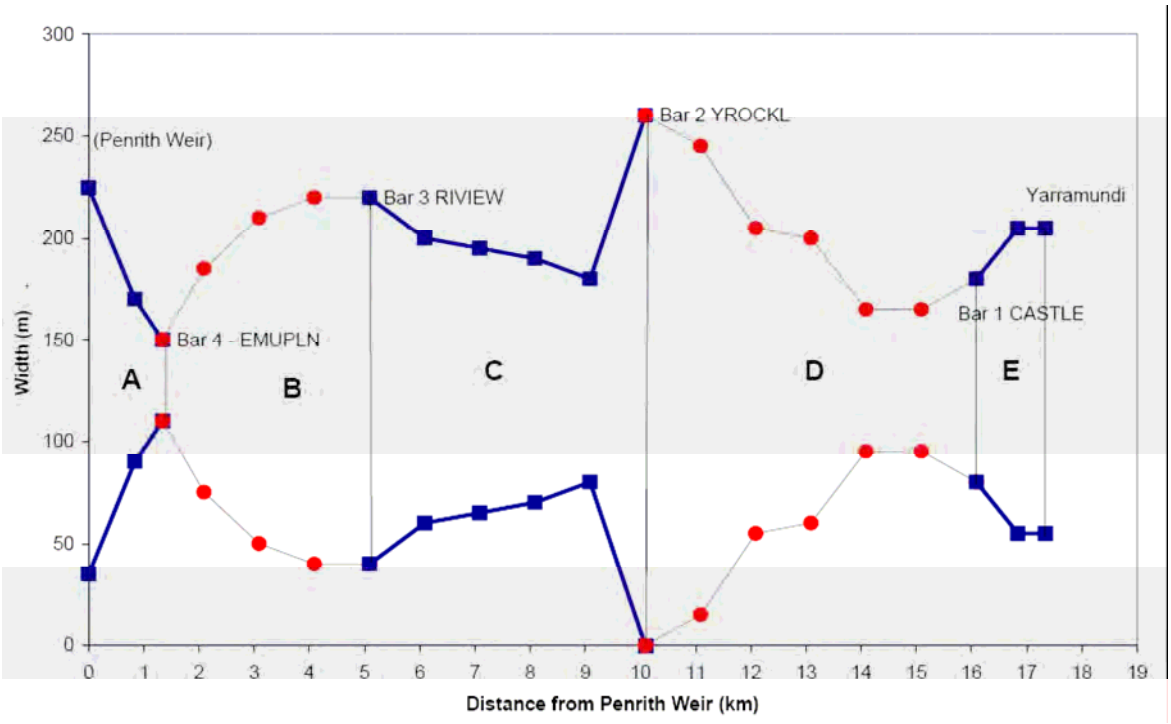


Figure 12-6. River segments used by the chemical partitioning model.

Each river segment was modelled separately with the output concentrations then used as input concentrations for the subsequent segment. The water compartment was assumed to be composed of water, suspended sediment (2% organic carbon) and aquatic biota (5% lipid). The atmospheric depth was modelled as 2 m (to ensure maximum exposure under conditions of minimal vertical air mixing) and was composed of air and aerosols. The sediment on the floor of the waterway comprised water and solids (4% organic carbon) and was assumed to be mixed to a depth of 5cm. The organic fractions and densities of all components were selected as recommended by Mackay *et al*. (1997). Advective removal by the waterway was based on low, median and high flow regimes as supplied by Sydney Water. Burial by sediment was also treated as an advective loss and was modelled at 0.002 $m^3.h^{-1}$ (Mackay *et al.* 1997).

Organic chemicals will partition between the various compartments to differing relative degrees based on their physical and chemical properties. Three examples are provided for Segment A in Figure 12-7 for illustrative purposes. These are acrylonitrile, chloroform and aldrin. Acrylonitrile is a relatively hydrophilic compound and thus remains largely partitioned in the water phase with some degree of volatilisation. Chloroform is considerably more volatile and is expected to largely evaporate from the water. Aldrin is a relatively hydrophobic compound and is predicted to partition almost exclusively to the organic carbon-rich sediment on the riverbed.

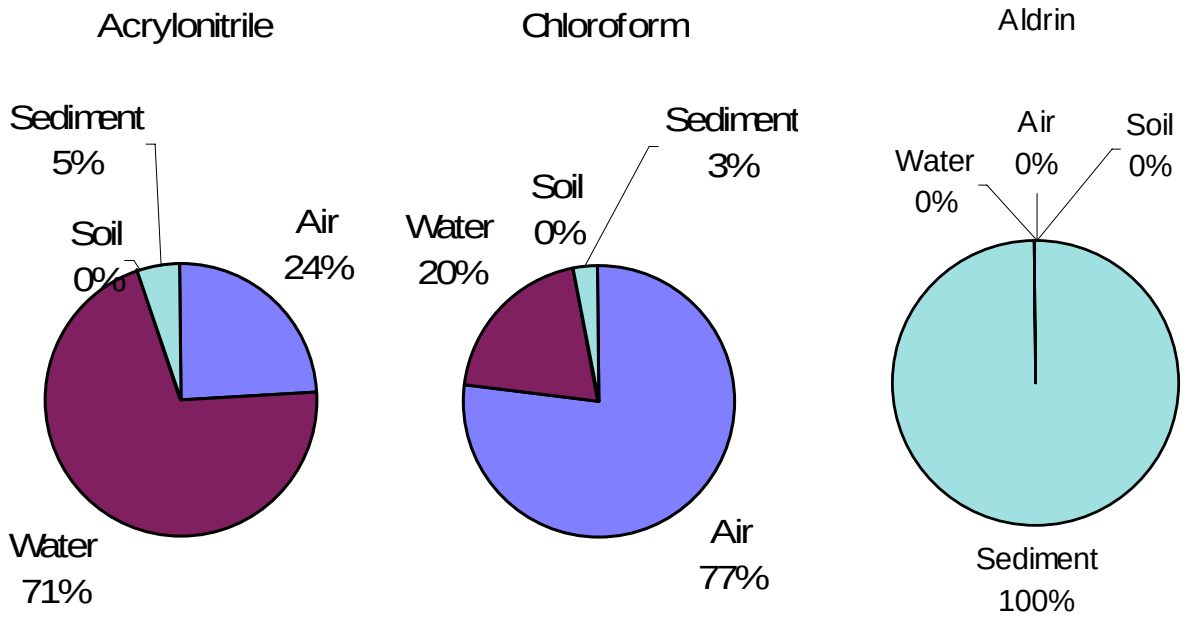


Figure 12-7. Various relative partitioning behaviour of three selected chemicals (Segment A)

The varying chemical partitioning behaviours, along with similar variability in predicted biodegradation rates, results in significant variability of predicted outcomes by the time the chemicals reach Segment E of the river.

Each river segment was modelled under conditions (determined previously) of good and poor RO treatment performance. Each of these scenarios were assessed under low flow (80^{th} percentile), median flow (50^{th} percentile) and high river flow (20^{th} percentile) conditions.

Modelled organic hazard concentrations in Segments A-E of the water phase of the river are provided for good RO removal (Table 12-10) and poor RO removal (Table 12-11).

Table 12-10. Calculated chemical concentrations (µg.L^{-1}) in river segments A-E assuming GOOD removal by RO.

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	3.E-03	2.E-04	8.E-06	4.E-07	2.E-08	4.E-02	1.E-03	5.E-05	2.E-06	9.E-08	5.E-02	2.E-03	7.E-05	3.E-06	1.E-07
Aldrin	5.E-07	2.E-07	6.E-08	2.E-08	7.E-09	6.E-06	2.E-06	5.E-07	1.E-07	5.E-08	8.E-06	2.E-06	8.E-07	2.E-07	7.E-08
Atrazine	1.E-05	3.E-06	6.E-07	1.E-07	3.E-08	2.E-04	4.E-05	7.E-06	1.E-06	3.E-07	3.E-04	6.E-05	1.E-05	2.E-06	5.E-07
Benz(a)anthracene	3.E-06	7.E-07	2.E-07	3.E-08	7.E-09	4.E-05	8.E-06	2.E-06	3.E-07	6.E-08	6.E-05	1.E-05	3.E-06	5.E-07	1.E-07
Benzene	8.E-04	6.E-05	3.E-06	2.E-07	1.E-08	7.E-03	2.E-04	5.E-06	2.E-07	1.E-08	8.E-03	2.E-04	7.E-06	2.E-07	7.E-09
Benzene Hexachloride (Alpha)	4.E-07	1.E-07	3.E-08	9.E-09	2.E-09	5.E-06	1.E-06	3.E-07	8.E-08	2.E-08	8.E-06	2.E-06	6.E-07	2.E-07	4.E-08
Benzo(a)pyrene	3.E-06	8.E-07	2.E-07	5.E-08	1.E-08	4.E-05	1.E-05	2.E-06	4.E-07	1.E-07	6.E-05	1.E-05	3.E-06	7.E-07	2.E-07
Benzo(b)fluoranthene	3.E-06	8.E-07	2.E-07	5.E-08	1.E-08	5.E-05	1.E-05	2.E-06	4.E-07	1.E-07	7.E-05	2.E-05	4.E-06	8.E-07	2.E-07
Carbon Tetrachloride	2.E-05	3.E-06	2.E-07	3.E-08	3.E-09	1.E-04	8.E-06	4.E-07	2.E-08	2.E-09	2.E-04	7.E-06	4.E-07	2.E-08	1.E-09
Chloroform	1.E-03	1.E-04	7.E-06	7.E-07	7.E-08	8.E-03	4.E-04	1.E-05	7.E-07	5.E-08	9.E-03	3.E-04	1.E-05	6.E-07	3.E-08
Dibenz(ah)anthracene	3.E-06	1.E-06	3.E-07	7.E-08	2.E-08	5.E-05	1.E-05	2.E-06	5.E-07	1.E-07	7.E-05	2.E-05	4.E-06	9.E-07	2.E-07
Dibromochloromethane	2.E-04	4.E-05	5.E-06	8.E-07	1.E-07	2.E-03	1.E-04	9.E-06	9.E-07	1.E-07	2.E-03	1.E-04	1.E-05	8.E-07	8.E-08
Dichlorobenzene (1,4)	9.E-06	1.E-06	1.E-07	2.E-08	2.E-09	8.E-05	6.E-06	3.E-07	3.E-08	3.E-09	9.E-05	5.E-06	4.E-07	3.E-08	2.E-09
Dichlorobenzidine	2.E-04	4.E-05	1.E-05	2.E-06	6.E-07	2.E-03	5.E-04	1.E-04	2.E-05	6.E-06	4.E-03	9.E-04	2.E-04	5.E-05	1.E-05
Dichloroethane (1,2)	1.E-03	1.E-04	7.E-06	5.E-07	5.E-08	1.E-02	4.E-04	2.E-05	9.E-07	6.E-08	1.E-02	4.E-04	2.E-05	9.E-07	5.E-08
Dichloromethane	4.E-03	4.E-04	2.E-05	1.E-06	9.E-08	4.E-02	1.E-03	4.E-05	1.E-06	8.E-08	4.E-02	1.E-03	4.E-05	1.E-06	5.E-08
Dieldrin	5.E-07	2.E-07	7.E-08	2.E-08	9.E-09	7.E-06	2.E-06	7.E-07	2.E-07	8.E-08	1.E-05	4.E-06	1.E-06	4.E-07	2.E-07
Diphenylhydrazine	1.E-04	2.E-05	4.E-06	7.E-07	1.E-07	2.E-03	3.E-04	4.E-05	7.E-06	1.E-06	3.E-03	5.E-04	8.E-05	1.E-05	2.E-06
Heptachlor-epoxide	5.E-07	2.E-07	7.E-08	3.E-08	1.E-08	7.E-06	2.E-06	7.E-07	2.E-07	9.E-08	1.E-05	3.E-06	1.E-06	4.E-07	2.E-07
Indeno(1,2,3-cd)pyrene	3.E-06	1.E-06	3.E-07	7.E-08	2.E-08	5.E-05	1.E-05	2.E-06	5.E-07	1.E-07	7.E-05	2.E-05	4.E-06	9.E-07	2.E-07
Polychlorinated Biphenyls (As Aroclor 1254)	4.E-06	1.E-06	4.E-07	1.E-07	4.E-08	5.E-05	1.E-05	3.E-06	9.E-07	3.E-07	7.E-05	2.E-05	5.E-06	1.E-06	4.E-07
Tetrachloroethene	2.E-05	3.E-06	3.E-07	3.E-08	5.E-09	2.E-04	1.E-05	4.E-07	3.E-08	3.E-09	2.E-04	8.E-06	5.E-07	3.E-08	2.E-09
Total Chloramines (as monochloramine)	2.E-01	1.E-02	5.E-04	2.E-05	1.E-06	3.E+00	1.E-01	6.E-03	2.E-04	1.E-05	4.E+00	2.E-01	1.E-02	4.E-04	2.E-05
Trichloroethene	2.E-05	2.E-06	1.E-07	1.E-08	2.E-09	1.E-04	6.E-06	2.E-07	1.E-08	1.E-09	1.E-04	5.E-06	3.E-07	1.E-08	8.E-10

Table 12-11. Calculated chemical concentrations (µg.L^{-1}) in river segments A-E assuming POOR removal by RO.

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	3.E-03	2.E-04	8.E-06	4.E-07	2.E-08	4.E-02	2.E-03	6.E-05	2.E-06	1.E-07	5.E-02	2.E-03	8.E-05	3.E-06	1.E-07
Aldrin	5.E-06	2.E-06	6.E-07	2.E-07	7.E-08	6.E-05	2.E-05	5.E-06	1.E-06	5.E-07	8.E-05	2.E-05	8.E-06	2.E-06	7.E-07
Atrazine	1.E-04	3.E-05	6.E-06	1.E-06	3.E-07	2.E-03	4.E-04	7.E-05	1.E-05	3.E-06	3.E-03	6.E-04	1.E-04	2.E-05	5.E-06
Benz(a)anthracene	3.E-05	7.E-06	2.E-06	3.E-07	7.E-08	4.E-04	8.E-05	2.E-05	3.E-06	6.E-07	6.E-04	1.E-04	3.E-05	5.E-06	1.E-06
Benzene	9.E-04	7.E-05	3.E-06	2.E-07	1.E-08	8.E-03	2.E-04	6.E-06	2.E-07	1.E-08	9.E-03	2.E-04	7.E-06	2.E-07	8.E-09
Benzene Hexachloride (Alpha)	4.E-06	1.E-06	3.E-07	9.E-08	2.E-08	5.E-05	1.E-05	3.E-06	8.E-07	2.E-07	8.E-05	2.E-05	6.E-06	2.E-06	4.E-07
Benzo(a)pyrene	3.E-05	8.E-06	2.E-06	5.E-07	1.E-07	4.E-04	1.E-04	2.E-05	4.E-06	1.E-06	6.E-04	1.E-04	3.E-05	7.E-06	2.E-06
Benzo(b)fluoranthene	3.E-05	8.E-06	2.E-06	5.E-07	1.E-07	5.E-04	1.E-04	2.E-05	4.E-06	1.E-06	7.E-04	2.E-04	4.E-05	8.E-06	2.E-06
Carbon Tetrachloride	2.E-04	3.E-05	2.E-06	3.E-07	3.E-08	1.E-03	8.E-05	4.E-06	2.E-07	2.E-08	2.E-03	7.E-05	4.E-06	2.E-07	1.E-08
Chloroform	8.E-03	9.E-04	6.E-05	5.E-06	5.E-07	7.E-02	3.E-03	1.E-04	6.E-06	4.E-07	7.E-02	3.E-03	1.E-04	5.E-06	3.E-07
Dibenz(ah)anthracene	3.E-05	1.E-05	3.E-06	7.E-07	2.E-07	5.E-04	1.E-04	2.E-05	5.E-06	1.E-06	7.E-04	2.E-04	4.E-05	9.E-06	2.E-06
Dibromochloromethane	2.E-03	4.E-04	5.E-05	8.E-06	1.E-06	2.E-02	1.E-03	9.E-05	9.E-06	1.E-06	2.E-02	1.E-03	1.E-04	8.E-06	8.E-07
Dichlorobenzene (1,4)	9.E-05	1.E-05	1.E-06	2.E-07	2.E-08	8.E-04	6.E-05	3.E-06	3.E-07	3.E-08	9.E-04	5.E-05	4.E-06	3.E-07	2.E-08
Dichlorobenzidine	2.E-03	4.E-04	1.E-04	2.E-05	6.E-06	2.E-02	5.E-03	1.E-03	2.E-04	6.E-05	4.E-02	9.E-03	2.E-03	5.E-04	1.E-04
Dichloroethane (1,2)	1.E-03	1.E-04	7.E-06	6.E-07	5.E-08	1.E-02	5.E-04	2.E-05	1.E-06	7.E-08	1.E-02	5.E-04	2.E-05	1.E-06	5.E-08
Dichloromethane	5.E-03	4.E-04	2.E-05	1.E-06	1.E-07	4.E-02	1.E-03	4.E-05	2.E-06	9.E-08	5.E-02	1.E-03	5.E-05	2.E-06	6.E-08
Dieldrin	5.E-06	2.E-06	7.E-07	2.E-07	9.E-08	7.E-05	2.E-05	7.E-06	2.E-06	8.E-07	1.E-04	4.E-05	1.E-05	4.E-06	2.E-06
Diphenylhydrazine	1.E-03	2.E-04	4.E-05	7.E-06	1.E-06	2.E-02	3.E-03	4.E-04	7.E-05	1.E-05	3.E-02	5.E-03	8.E-04	1.E-04	2.E-05
Heptachlor-epoxide	5.E-06	2.E-06	7.E-07	3.E-07	1.E-07	7.E-05	2.E-05	7.E-06	2.E-06	9.E-07	1.E-04	3.E-05	1.E-05	4.E-06	2.E-06
Indeno(1,2,3-cd)pyrene	3.E-05	1.E-05	3.E-06	7.E-07	2.E-07	5.E-04	1.E-04	2.E-05	5.E-06	1.E-06	7.E-04	2.E-04	4.E-05	9.E-06	2.E-06
Polychlorinated Biphenyls (As Aroclor 1254)	4.E-05	1.E-05	4.E-06	1.E-06	4.E-07	5.E-04	1.E-04	3.E-05	9.E-06	3.E-06	7.E-04	2.E-04	5.E-05	1.E-05	4.E-06
Tetrachloroethene	2.E-04	3.E-05	3.E-06	3.E-07	5.E-08	2.E-03	1.E-04	4.E-06	3.E-07	3.E-08	2.E-03	8.E-05	5.E-06	3.E-07	2.E-08
Total Chloramines (as monochloramine)	2.E-01	1.E-02	6.E-04	3.E-05	1.E-06	3.E+00	1.E-01	6.E-03	3.E-04	1.E-05	5.E+00	2.E-01	1.E-02	5.E-04	3.E-05
Trichloroethene	2.E-04	2.E-05	1.E-06	1.E-07	2.E-08	1.E-03	6.E-05	2.E-06	1.E-07	1.E-08	1.E-03	5.E-05	3.E-06	1.E-07	8.E-09

Notes:

1. Modelled organic hazard concentrations in sediment beneath Segments A-E of the river are provided for good RO removal (Table 12-12) and poor RO removal (Table 12-13).

Table 12-12. Calculated chemical concentrations (mg.kg^{-1}) in sediment beneath river segments A-E assuming GOOD removal by RO

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	2.E-06	1.E-07	5.E-09	2.E-10	1.E-11	2.E-05	9.E-07	3.E-08	1.E-09	6.E-11	3.E-05	1.E-06	5.E-08	2.E-09	8.E-11
Aldrin	2.E-05	8.E-06	3.E-06	9.E-07	3.E-07	3.E-04	8.E-05	2.E-05	7.E-06	2.E-06	4.E-04	1.E-04	4.E-05	1.E-05	3.E-06
Atrazine	8.E-08	2.E-08	4.E-09	8.E-10	2.E-10	1.E-06	2.E-07	4.E-08	8.E-09	2.E-09	2.E-06	4.E-07	8.E-08	2.E-08	3.E-09
Benz(a)anthracene	5.E-05	1.E-05	3.E-06	6.E-07	1.E-07	7.E-04	2.E-04	3.E-05	5.E-06	1.E-06	1.E-03	2.E-04	5.E-05	1.E-05	2.E-06
Benzene	1.E-06	1.E-07	4.E-09	3.E-10	2.E-11	1.E-05	3.E-07	8.E-09	3.E-10	2.E-11	1.E-05	3.E-07	1.E-08	3.E-10	1.E-11
Benzene Hexachloride (Alpha)	1.E-07	4.E-08	1.E-08	3.E-09	9.E-10	2.E-06	5.E-07	1.E-07	3.E-08	9.E-09	3.E-06	8.E-07	2.E-07	6.E-08	2.E-08
Benzo(a)pyrene	1.E-04	3.E-05	7.E-06	2.E-06	4.E-07	1.E-03	3.E-04	6.E-05	1.E-05	3.E-06	2.E-03	5.E-04	1.E-04	2.E-05	5.E-06
Benzo(b)fluoranthene	6.E-05	2.E-05	4.E-06	9.E-07	2.E-07	9.E-04	2.E-04	4.E-05	8.E-06	2.E-06	1.E-03	3.E-04	7.E-05	2.E-05	3.E-06
Carbon Tetrachloride	1.E-07	2.E-08	1.E-09	2.E-10	2.E-11	1.E-06	5.E-08	2.E-09	2.E-10	1.E-11	1.E-06	5.E-08	3.E-09	1.E-10	9.E-12
Chloroform	1.E-06	1.E-07	9.E-09	8.E-10	9.E-11	1.E-05	5.E-07	2.E-08	9.E-10	6.E-11	1.E-05	4.E-07	2.E-08	8.E-10	4.E-11
Dibenz(ah)anthracene	2.E-04	5.E-05	1.E-05	3.E-06	9.E-07	2.E-03	5.E-04	1.E-04	3.E-05	7.E-06	3.E-03	8.E-04	2.E-04	4.E-05	1.E-05
Dibromochloromethane	4.E-07	7.E-08	8.E-09	1.E-09	2.E-10	3.E-06	2.E-07	2.E-08	1.E-09	2.E-10	3.E-06	2.E-07	2.E-08	1.E-09	1.E-10
Dichlorobenzene (1,4)	3.E-07	5.E-08	5.E-09	6.E-10	8.E-11	3.E-06	2.E-07	1.E-08	1.E-09	1.E-10	4.E-06	2.E-07	2.E-08	1.E-09	8.E-11
Dichlorobenzidine	8.E-06	2.E-06	5.E-07	1.E-07	3.E-08	1.E-04	3.E-05	6.E-06	1.E-06	3.E-07	2.E-04	4.E-05	1.E-05	2.E-06	6.E-07
Dichloroethane (1,2)	9.E-07	8.E-08	5.E-09	5.E-10	4.E-11	8.E-06	4.E-07	1.E-08	8.E-10	5.E-11	9.E-06	3.E-07	2.E-08	8.E-10	4.E-11
Dichloromethane	3.E-06	3.E-07	1.E-08	9.E-10	7.E-11	3.E-05	1.E-06	3.E-08	1.E-09	6.E-11	3.E-05	9.E-07	3.E-08	1.E-09	4.E-11
Dieldrin	3.E-06	1.E-06	4.E-07	2.E-07	6.E-08	4.E-05	1.E-05	5.E-06	1.E-06	5.E-07	6.E-05	2.E-05	8.E-06	3.E-06	9.E-07
Diphenylhydrazine	1.E-06	2.E-07	3.E-08	6.E-09	1.E-09	1.E-05	2.E-06	4.E-07	6.E-08	1.E-08	2.E-05	4.E-06	7.E-07	1.E-07	2.E-08
Heptachlor-epoxide	2.E-06	8.E-07	3.E-07	1.E-07	4.E-08	3.E-05	9.E-06	3.E-06	9.E-07	3.E-07	4.E-05	1.E-05	5.E-06	2.E-06	5.E-07
Indeno(1,2,3-cd)pyrene	2.E-04	5.E-05	1.E-05	4.E-06	9.E-07	2.E-03	6.E-04	1.E-04	3.E-05	7.E-06	3.E-03	8.E-04	2.E-04	5.E-05	1.E-05
Polychlorinated Biphenyls (As Aroclor 1254)	2.E-04	8.E-05	2.E-05	7.E-06	2.E-06	3.E-03	8.E-04	2.E-04	5.E-05	1.E-05	4.E-03	1.E-03	3.E-04	8.E-05	2.E-05
Tetrachloroethene	6.E-07	1.E-07	9.E-09	1.E-09	2.E-10	5.E-06	3.E-07	2.E-08	1.E-09	1.E-10	6.E-06	3.E-07	2.E-08	1.E-09	7.E-11
Total Chloramines (as monochloramine)	1.E-04	6.E-06	3.E-07	2.E-08	8.E-10	2.E-03	8.E-05	3.E-06	1.E-07	8.E-09	3.E-03	1.E-04	6.E-06	3.E-07	1.E-08
Trichloroethene	4.E-08	5.E-09	3.E-10	4.E-11	4.E-12	3.E-07	2.E-08	6.E-10	4.E-11	3.E-12	4.E-07	1.E-08	7.E-10	3.E-11	2.E-12

Table 12-13. Calculated chemical concentrations (mg.kg^{-1}) in sediment beneath river segments A-E assuming POOR removal by RO

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	2.E-06	1.E-07	5.E-09	3.E-10	1.E-11	3.E-05	1.E-06	4.E-08	1.E-09	6.E-11	3.E-05	1.E-06	5.E-08	2.E-09	8.E-11
Aldrin	2.E-04	8.E-05	3.E-05	9.E-06	3.E-06	3.E-03	8.E-04	2.E-04	7.E-05	2.E-05	4.E-03	1.E-03	4.E-04	1.E-04	3.E-05
Atrazine	8.E-07	2.E-07	4.E-08	8.E-09	2.E-09	1.E-05	2.E-06	4.E-07	8.E-08	2.E-08	2.E-05	4.E-06	8.E-07	2.E-07	3.E-08
Benz(a)anthracene	5.E-04	1.E-04	3.E-05	6.E-06	1.E-06	7.E-03	2.E-03	3.E-04	5.E-05	1.E-05	1.E-02	2.E-03	5.E-04	1.E-04	2.E-05
Benzene	1.E-06	1.E-07	5.E-09	3.E-10	2.E-11	1.E-05	4.E-07	9.E-09	4.E-10	2.E-11	1.E-05	3.E-07	1.E-08	3.E-10	1.E-11
Benzene Hexachloride (Alpha)	1.E-06	4.E-07	1.E-07	3.E-08	9.E-09	2.E-05	5.E-06	1.E-06	3.E-07	9.E-08	3.E-05	8.E-06	2.E-06	6.E-07	2.E-07
Benzo(a)pyrene	1.E-03	3.E-04	7.E-05	2.E-05	4.E-06	1.E-02	3.E-03	6.E-04	1.E-04	3.E-05	2.E-02	5.E-03	1.E-03	2.E-04	5.E-05
Benzo(b)fluoranthene	6.E-04	2.E-04	4.E-05	9.E-06	2.E-06	9.E-03	2.E-03	4.E-04	8.E-05	2.E-05	1.E-02	3.E-03	7.E-04	2.E-04	3.E-05
Carbon Tetrachloride	1.E-06	2.E-07	1.E-08	2.E-09	2.E-10	1.E-05	5.E-07	2.E-08	2.E-09	1.E-10	1.E-05	5.E-07	3.E-08	1.E-09	9.E-11
Chloroform	1.E-05	1.E-06	7.E-08	7.E-09	7.E-10	8.E-05	4.E-06	1.E-07	7.E-09	5.E-10	9.E-05	3.E-06	1.E-07	6.E-09	3.E-10
Dibenz(ah)anthracene	2.E-03	5.E-04	1.E-04	3.E-05	9.E-06	2.E-02	5.E-03	1.E-03	3.E-04	7.E-05	3.E-02	8.E-03	2.E-03	4.E-04	1.E-04
Dibromochloromethane	4.E-06	7.E-07	8.E-08	1.E-08	2.E-09	3.E-05	2.E-06	2.E-07	1.E-08	2.E-09	3.E-05	2.E-06	2.E-07	1.E-08	1.E-09
Dichlorobenzene (1,4)	3.E-06	5.E-07	5.E-08	6.E-09	8.E-10	3.E-05	2.E-06	1.E-07	1.E-08	1.E-09	4.E-05	2.E-06	2.E-07	1.E-08	8.E-10
Dichlorobenzidine	8.E-05	2.E-05	5.E-06	1.E-06	3.E-07	1.E-03	3.E-04	6.E-05	1.E-05	3.E-06	2.E-03	4.E-04	1.E-04	2.E-05	6.E-06
Dichloroethane (1,2)	1.E-06	9.E-08	6.E-09	5.E-10	4.E-11	9.E-06	4.E-07	2.E-08	8.E-10	6.E-11	1.E-05	4.E-07	2.E-08	8.E-10	4.E-11
Dichloromethane	4.E-06	3.E-07	1.E-08	1.E-09	7.E-11	3.E-05	1.E-06	3.E-08	1.E-09	7.E-11	4.E-05	1.E-06	3.E-08	1.E-09	5.E-11
Dieldrin	3.E-05	1.E-05	4.E-06	2.E-06	6.E-07	4.E-04	1.E-04	5.E-05	1.E-05	5.E-06	6.E-04	2.E-04	8.E-05	3.E-05	9.E-06
Diphenylhydrazine	1.E-05	2.E-06	3.E-07	6.E-08	1.E-08	1.E-04	2.E-05	4.E-06	6.E-07	1.E-07	2.E-04	4.E-05	7.E-06	1.E-06	2.E-07
Heptachlor-epoxide	2.E-05	8.E-06	3.E-06	1.E-06	4.E-07	3.E-04	9.E-05	3.E-05	9.E-06	3.E-06	4.E-04	1.E-04	5.E-05	2.E-05	5.E-06
Indeno(1,2,3-cd)pyrene	2.E-03	5.E-04	1.E-04	4.E-05	9.E-06	2.E-02	6.E-03	1.E-03	3.E-04	7.E-05	3.E-02	8.E-03	2.E-03	5.E-04	1.E-04
Polychlorinated Biphenyls (As Aroclor 1254)	2.E-03	8.E-04	2.E-04	7.E-05	2.E-05	3.E-02	8.E-03	2.E-03	5.E-04	1.E-04	4.E-02	1.E-02	3.E-03	8.E-04	2.E-04
Tetrachloroethene	6.E-06	1.E-06	9.E-08	1.E-08	2.E-09	5.E-05	3.E-06	2.E-07	1.E-08	1.E-09	6.E-05	3.E-06	2.E-07	1.E-08	7.E-10
Total Chloramines (as monochloramine)	1.E-04	7.E-06	4.E-07	2.E-08	9.E-10	2.E-03	9.E-05	4.E-06	2.E-07	8.E-09	3.E-03	1.E-04	7.E-06	3.E-07	2.E-08
Trichloroethene	4.E-07	5.E-08	3.E-09	4.E-10	4.E-11	3.E-06	2.E-07	6.E-09	4.E-10	3.E-11	4.E-06	1.E-07	7.E-09	3.E-10	2.E-11

Notes:

1. Modelled organic hazard concentrations in air above Segments A-E of the river are provided for good RO removal (Table 12-14) and poor RO removal (Table 12-15).

Table 12-14. Calculated chemical concentrations (µg.m^{-3}) in air (2 m) above river segments A-E assuming GOOD removal by RO

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	6.E-03	6.E-04	3.E-05	2.E-06	4.E-08	7.E-02	5.E-03	2.E-04	9.E-06	2.E-07	9.E-02	7.E-03	3.E-04	1.E-05	2.E-07
Aldrin	1.E-07	8.E-08	3.E-08	1.E-08	2.E-09	2.E-06	8.E-07	2.E-07	7.E-08	1.E-08	2.E-06	1.E-06	4.E-07	1.E-07	2.E-08
Atrazine	7.E-10	3.E-10	6.E-11	1.E-11	2.E-12	1.E-08	3.E-09	6.E-10	1.E-10	1.E-11	2.E-08	5.E-09	1.E-09	2.E-10	3.E-11
Benz(a)anthracene	3.E-08	1.E-08	3.E-09	6.E-10	8.E-11	4.E-07	1.E-07	3.E-08	5.E-09	7.E-10	6.E-07	2.E-07	5.E-08	1.E-08	1.E-09
Benzene	5.E-03	1.E-03	8.E-05	6.E-06	9.E-08	5.E-02	5.E-03	2.E-04	7.E-06	8.E-08	5.E-02	4.E-03	2.E-04	6.E-06	5.E-08
Benzene Hexachloride (Alpha)	2.E-08	1.E-08	3.E-09	8.E-10	1.E-10	3.E-07	1.E-07	3.E-08	8.E-09	1.E-09	4.E-07	2.E-07	5.E-08	1.E-08	2.E-09
Benzo(a)pyrene	4.E-09	2.E-09	5.E-10	1.E-10	2.E-11	6.E-08	2.E-08	5.E-09	1.E-09	1.E-10	8.E-08	3.E-08	8.E-09	2.E-09	2.E-10
Benzo(b)fluoranthene	3.E-09	2.E-09	4.E-10	1.E-10	1.E-11	5.E-08	2.E-08	4.E-09	9.E-10	1.E-10	7.E-08	3.E-08	7.E-09	2.E-09	2.E-10
Carbon Tetrachloride	1.E-04	7.E-05	7.E-06	1.E-06	3.E-08	1.E-03	2.E-04	1.E-05	1.E-06	2.E-08	1.E-03	2.E-04	1.E-05	9.E-07	1.E-08
Chloroform	7.E-03	3.E-03	2.E-04	3.E-05	6.E-07	6.E-02	9.E-03	4.E-04	3.E-05	4.E-07	6.E-02	8.E-03	5.E-04	2.E-05	3.E-07
Dibenz(ah)anthracene	4.E-12	2.E-12	5.E-13	1.E-13	2.E-14	5.E-11	2.E-11	5.E-12	1.E-12	2.E-13	7.E-11	3.E-11	8.E-12	2.E-12	3.E-13
Dibromochloromethane	1.E-03	1.E-03	2.E-04	3.E-05	1.E-06	1.E-02	4.E-03	3.E-04	3.E-05	1.E-06	1.E-02	3.E-03	3.E-04	3.E-05	6.E-07
Dichlorobenzene (1,4)	5.E-05	2.E-05	2.E-06	3.E-07	1.E-08	4.E-04	9.E-05	6.E-06	6.E-07	2.E-08	5.E-04	8.E-05	8.E-06	6.E-07	1.E-08
Dichlorobenzidine	2.E-08	9.E-09	2.E-09	6.E-10	8.E-11	3.E-07	1.E-07	3.E-08	5.E-09	8.E-10	4.E-07	2.E-07	4.E-08	1.E-08	2.E-09
Dichloroethane (1,2)	6.E-03	2.E-03	1.E-04	1.E-05	3.E-07	5.E-02	7.E-03	3.E-04	2.E-05	4.E-07	6.E-02	7.E-03	4.E-04	2.E-05	3.E-07
Dichloromethane	3.E-02	8.E-03	5.E-04	4.E-05	7.E-07	3.E-01	3.E-02	1.E-03	5.E-05	6.E-07	3.E-01	3.E-02	1.E-03	4.E-05	4.E-07
Dieldrin	6.E-08	4.E-08	2.E-08	6.E-09	1.E-09	9.E-07	5.E-07	2.E-07	6.E-08	1.E-08	1.E-06	8.E-07	3.E-07	1.E-07	2.E-08
Diphenylhydrazine	8.E-08	3.E-08	5.E-09	9.E-10	9.E-11	1.E-06	3.E-07	5.E-08	8.E-09	9.E-10	2.E-06	5.E-07	1.E-07	2.E-08	2.E-09
Heptachlor-epoxide	2.E-07	1.E-07	5.E-08	2.E-08	4.E-09	2.E-06	1.E-06	5.E-07	2.E-07	3.E-08	3.E-06	2.E-06	8.E-07	3.E-07	6.E-08
Indeno(1,2,3-cd)pyrene	4.E-11	2.E-11	6.E-12	1.E-12	2.E-13	5.E-10	2.E-10	5.E-11	1.E-11	2.E-12	7.E-10	3.E-10	8.E-11	2.E-11	3.E-12
Polychlorinated Biphenyls (As Aroclor 1254)	1.E-06	9.E-07	3.E-07	9.E-08	1.E-08	2.E-05	9.E-06	2.E-06	6.E-07	9.E-08	2.E-05	1.E-05	4.E-06	1.E-06	1.E-07
Tetrachloroethene	1.E-04	8.E-05	9.E-06	1.E-06	4.E-08	1.E-03	3.E-04	2.E-05	1.E-06	3.E-08	1.E-03	2.E-04	2.E-05	1.E-06	2.E-08
Total Chloramines (as monochloramine)	8.E-22	7.E-23	4.E-24	2.E-25	6.E-27	1.E-20	9.E-22	4.E-23	2.E-24	6.E-26	2.E-20	2.E-21	8.E-23	4.E-24	1.E-25
Trichloroethene	1.E-04	5.E-05	5.E-06	5.E-07	1.E-08	9.E-04	2.E-04	8.E-06	5.E-07	1.E-08	1.E-03	1.E-04	9.E-06	5.E-07	6.E-09

Table 12-15. Calculated chemical concentrations (µg.m^{-3}) in air (2 m) above river segments A-E assuming POOR removal by RO

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	6.E-03	7.E-04	4.E-05	2.E-06	4.E-08	8.E-02	6.E-03	2.E-04	1.E-05	2.E-07	1.E-01	7.E-03	3.E-04	1.E-05	3.E-07
Aldrin	1.E-06	8.E-07	3.E-07	1.E-07	2.E-08	2.E-05	8.E-06	2.E-06	7.E-07	1.E-07	2.E-05	1.E-05	4.E-06	1.E-06	2.E-07
Atrazine	7.E-09	3.E-09	6.E-10	1.E-10	2.E-11	1.E-07	3.E-08	6.E-09	1.E-09	1.E-10	2.E-07	5.E-08	1.E-08	2.E-09	3.E-10
Benz(a)anthracene	3.E-07	1.E-07	3.E-08	6.E-09	8.E-10	4.E-06	1.E-06	3.E-07	5.E-08	7.E-09	6.E-06	2.E-06	5.E-07	1.E-07	1.E-08
Benzene	6.E-03	2.E-03	9.E-05	6.E-06	1.E-07	5.E-02	5.E-03	2.E-04	8.E-06	9.E-08	6.E-02	5.E-03	2.E-04	7.E-06	6.E-08
Benzene Hexachloride (Alpha)	2.E-07	1.E-07	3.E-08	8.E-09	1.E-09	3.E-06	1.E-06	3.E-07	8.E-08	1.E-08	4.E-06	2.E-06	5.E-07	1.E-07	2.E-08
Benzo(a)pyrene	4.E-08	2.E-08	5.E-09	1.E-09	2.E-10	6.E-07	2.E-07	5.E-08	1.E-08	1.E-09	8.E-07	3.E-07	8.E-08	2.E-08	2.E-09
Benzo(b)fluoranthene	3.E-08	2.E-08	4.E-09	1.E-09	1.E-10	5.E-07	2.E-07	4.E-08	9.E-09	1.E-09	7.E-07	3.E-07	7.E-08	2.E-08	2.E-09
Carbon Tetrachloride	1.E-03	7.E-04	7.E-05	1.E-05	3.E-07	1.E-02	2.E-03	1.E-04	1.E-05	2.E-07	1.E-02	2.E-03	1.E-04	9.E-06	1.E-07
Chloroform	5.E-02	2.E-02	2.E-03	2.E-04	4.E-06	5.E-01	7.E-02	3.E-03	2.E-04	3.E-06	5.E-01	6.E-02	4.E-03	2.E-04	2.E-06
Dibenz(ah)anthracene	4.E-11	2.E-11	5.E-12	1.E-12	2.E-13	5.E-10	2.E-10	5.E-11	1.E-11	2.E-12	7.E-10	3.E-10	8.E-11	2.E-11	3.E-12
Dibromochloromethane	1.E-02	1.E-02	2.E-03	3.E-04	1.E-05	1.E-01	4.E-02	3.E-03	3.E-04	1.E-05	1.E-01	3.E-02	3.E-03	3.E-04	6.E-06
Dichlorobenzene (1,4)	5.E-04	2.E-04	2.E-05	3.E-06	1.E-07	4.E-03	9.E-04	6.E-05	6.E-06	2.E-07	5.E-03	8.E-04	8.E-05	6.E-06	1.E-07
Dichlorobenzidine	2.E-07	9.E-08	2.E-08	6.E-09	8.E-10	3.E-06	1.E-06	3.E-07	5.E-08	8.E-09	4.E-06	2.E-06	4.E-07	1.E-07	2.E-08
Dichloroethane (1,2)	7.E-03	2.E-03	2.E-04	1.E-05	3.E-07	6.E-02	8.E-03	4.E-04	2.E-05	4.E-07	7.E-02	8.E-03	5.E-04	2.E-05	3.E-07
Dichloromethane	3.E-02	9.E-03	6.E-04	4.E-05	8.E-07	3.E-01	3.E-02	1.E-03	5.E-05	7.E-07	3.E-01	3.E-02	1.E-03	5.E-05	5.E-07
Dieldrin	6.E-07	4.E-07	2.E-07	6.E-08	1.E-08	9.E-06	5.E-06	2.E-06	6.E-07	1.E-07	1.E-05	8.E-06	3.E-06	1.E-06	2.E-07
Diphenylhydrazine	8.E-07	3.E-07	5.E-08	9.E-09	9.E-10	1.E-05	3.E-06	5.E-07	8.E-08	9.E-09	2.E-05	5.E-06	1.E-06	2.E-07	2.E-08
Heptachlor-epoxide	2.E-06	1.E-06	5.E-07	2.E-07	4.E-08	2.E-05	1.E-05	5.E-06	2.E-06	3.E-07	3.E-05	2.E-05	8.E-06	3.E-06	6.E-07
Indeno(1,2,3-cd)pyrene	4.E-10	2.E-10	6.E-11	1.E-11	2.E-12	5.E-09	2.E-09	5.E-10	1.E-10	2.E-11	7.E-09	3.E-09	8.E-10	2.E-10	3.E-11
Polychlorinated Biphenyls (As Aroclor 1254)	1.E-05	9.E-06	3.E-06	9.E-07	1.E-07	2.E-04	9.E-05	2.E-05	6.E-06	9.E-07	2.E-04	1.E-04	4.E-05	1.E-05	1.E-06
Tetrachloroethene	1.E-03	8.E-04	9.E-05	1.E-05	4.E-07	1.E-02	3.E-03	2.E-04	1.E-05	3.E-07	1.E-02	2.E-03	2.E-04	1.E-05	2.E-07
Total Chloramines (as monochloramine)	9.E-22	8.E-23	4.E-24	2.E-25	7.E-27	1.E-20	1.E-21	5.E-23	2.E-24	6.E-26	2.E-20	2.E-21	9.E-23	4.E-24	1.E-25
Trichloroethene	1.E-03	5.E-04	5.E-05	5.E-06	1.E-07	9.E-03	2.E-03	8.E-05	5.E-06	1.E-07	1.E-02	1.E-03	9.E-05	5.E-06	6.E-08

12.2.4.2 Irrigation on soil

An evaluative irrigated property was modelled to provide approximate 'worst-case' steady-state concentrations of chemicals that may accumulate in an irrigated soil. The evaluative irrigated property consisted of a rectangular field of dimensions 450 m x 400 m. A 25 m wide waterway runs along one of the two 400 m boundaries, thus the overall area of the property including the irrigated soil and the waterway was 180 000 m^2. The average depth of the waterway was 1m. The water compartment was composed of water, suspended sediment (2% organic carbon) and aquatic biota (5% lipid). The atmospheric depth was modelled as 2 m (to assume maximum potential exposure under conditions of poor mixing) and was composed of air and aerosols. The soil compartment was composed of air, water and solids comprising 2% organic carbon. Soil was presumed to be well mixed to a depth of 10cm. The sediment on the floor of the waterway comprised water and solids (4% organic carbon) and was mixed to a depth of 5cm. The organic fractions and densities of all components were selected as recommended by Mackay *et al.* (1997). Advective removal by the waterway was 200 $m^3.h^{-1}$. Burial by sediment was also treated as an advective loss and was modelled at 0.002 $m^3.h^{-1}$. Further details of the environmental parameters are provided in Table 12-16.

Table 12-16. Compartment dimensions and properties for irrigation

Compartment		**Depth (m)**	**Area (m^2)**	**Volume (m^3)**	**Organic fraction**	**Density ($kg.m^{-3}$)**	**Advective flow ($m^3.h^{-1}$)**
Air	Total compartment	2	1.9×10^5	3.8×10^5	-	1.2	10^6
	Air			3.8×10^5	-	1.2	10^6
	Aerosol			2×10^{-11}	-	2000	10^6
Water	Total compartment	1	10^4	10^4	-	1000	200
	Water			10^4	-	1000	200
	Suspended sediment			1	0.02	1500	200
	Aquatic biota			0.02	0.05 lipid	1000	200
Soil	Total compartment	0.1	1.8×10^5	1.8×10^4	-	1500	-
	Air			3.6×10^3	-	1.2	-
	Water			5.4×10^3	-	1000	-
	Solid			9×10^3	0.02	2400	-
Sediment	Total compartment	0.05	10^4	500	-	1280	0.002
	Water			400	-	1000	0.002
	Solid			100	0.04	2400	0.002

The irrigation water was assumed to have been sourced from Segment B of the river (Emu Plains), which was considered to be the earliest relevant extraction point. The field was assumed to be irrigated at an average of 700 mm per year over the entire surface area. This was based on the difference between average annual rainfall and average annual evaporation (Bureau of Meteorology, 2004).

The calculated concentrations of organic chemical hazards in irrigated soil and partitioned into air (2 m) above the soil are provided in Table 12-17.

Table 12-17. Calculated organic chemical concentrations (mg.kg^{-1}) in irrigated soil and air above soil (µg.m^{-3})

	Concentration in soil (mg.kg^{-1})						Concentration in air above soil (µg.m^{-3})					
RO Performance:	**GOOD RO Removal**			**POOR RO Removal**			**GOOD RO Removal**			**POOR RO Removal**		
River flow percentile:	**20th**	**50th**	**80th**	**20th**	**50th**	**80th**	**20th**	**50th**	**80th**	**20th**	**50th**	**80th**
Acrylonitrile	9.E-07	8.E-06	9.E-06	1.E-06	8.E-06	1.E-05	2.E-03	1.E-02	2.E-02	2.E-03	2.E-02	2.E-02
Aldrin	4.E-05	4.E-04	5.E-04	4.E-04	4.E-03	5.E-03	6.E-08	6.E-07	8.E-07	6.E-07	6.E-06	8.E-06
Atrazine	6.E-06	7.E-05	1.E-04	6.E-05	7.E-04	1.E-03	3.E-07	3.E-06	6.E-06	3.E-06	3.E-05	6.E-05
Benz(a)anthracene	9.E-05	1.E-03	2.E-03	9.E-04	1.E-02	2.E-02	6.E-08	7.E-07	1.E-06	6.E-07	7.E-06	1.E-05
Benzene	1.E-07	4.E-07	4.E-07	1.E-07	5.E-07	4.E-07	9.E-04	3.E-03	3.E-03	1.E-03	3.E-03	3.E-03
Benzene Hexachloride (Alpha)	4.E-06	4.E-05	7.E-05	4.E-05	4.E-04	7.E-04	3.E-07	4.E-06	6.E-06	3.E-06	4.E-05	6.E-05
Benzo(a)pyrene	1.E-04	1.E-03	2.E-03	1.E-03	1.E-02	2.E-02	2.E-08	2.E-07	3.E-07	2.E-07	2.E-06	3.E-06
Benzo(b)fluoranthene	1.E-04	1.E-03	2.E-03	1.E-03	1.E-02	2.E-02	4.E-08	5.E-07	7.E-07	4.E-07	5.E-06	7.E-06
Carbon Tetrachloride	3.E-09	9.E-09	8.E-09	3.E-08	9.E-08	8.E-08	4.E-05	1.E-04	1.E-04	4.E-04	1.E-03	1.E-03
Chloroform	8.E-08	3.E-07	2.E-07	7.E-07	2.E-06	2.E-06	2.E-03	5.E-03	5.E-03	1.E-02	4.E-02	4.E-02
Dibenz(ah)anthracene	2.E-04	2.E-03	3.E-03	2.E-03	2.E-02	3.E-02	2.E-10	2.E-09	3.E-09	2.E-09	2.E-08	3.E-08
Dibromochloromethane	1.E-07	5.E-07	4.E-07	1.E-06	5.E-06	4.E-06	6.E-04	2.E-03	2.E-03	6.E-03	2.E-02	2.E-02
Dichlorobenzene (1,4)	2.E-07	1.E-06	1.E-06	2.E-06	1.E-05	1.E-05	2.E-05	8.E-05	7.E-05	2.E-04	8.E-04	7.E-04
Dichlorobenzidine	4.E-04	5.E-03	9.E-03	4.E-03	5.E-02	9.E-02	7.E-06	9.E-05	1.E-04	7.E-05	9.E-04	1.E-03
Dichloroethane (1,2)	3.E-07	1.E-06	1.E-06	3.E-07	1.E-06	1.E-06	1.E-03	6.E-03	6.E-03	2.E-03	7.E-03	6.E-03
Dichloromethane	2.E-07	9.E-07	8.E-07	3.E-07	1.E-06	8.E-07	5.E-03	2.E-02	2.E-02	6.E-03	2.E-02	2.E-02
Dieldrin	3.E-05	4.E-04	6.E-04	3.E-04	4.E-03	6.E-03	3.E-07	3.E-06	5.E-06	3.E-06	3.E-05	5.E-05
Diphenylhydrazine	5.E-05	7.E-04	1.E-03	5.E-04	7.E-03	1.E-02	1.E-05	1.E-04	2.E-04	1.E-04	1.E-03	2.E-03
Heptachlor-epoxide	2.E-05	3.E-04	4.E-04	2.E-04	3.E-03	4.E-03	7.E-07	8.E-06	1.E-05	7.E-06	8.E-05	1.E-04
Indeno(1,2,3-cd)pyrene	2.E-04	2.E-03	3.E-03	2.E-03	2.E-02	3.E-02	1.E-09	1.E-08	2.E-08	1.E-08	1.E-07	2.E-07
Polychlorinated Biphenyls (As Aroclor 1254)	3.E-04	3.E-03	4.E-03	3.E-03	3.E-02	4.E-02	5.E-07	5.E-06	7.E-06	5.E-06	5.E-05	7.E-05
Tetrachloroethene	2.E-08	6.E-08	5.E-08	2.E-07	6.E-07	5.E-07	4.E-05	1.E-04	1.E-04	4.E-04	1.E-03	1.E-03
Total Chloramines (as monochloramine)	2.E-04	2.E-03	3.E-03	2.E-04	2.E-03	4.E-03	2.E-19	2.E-18	3.E-18	2.E-19	2.E-18	3.E-18
Trichloroethene	3.E-09	1.E-08	9.E-09	3.E-08	1.E-07	9.E-08	3.E-05	9.E-05	8.E-05	3.E-04	9.E-04	8.E-04

12.2.5 Drinking water treatment

For drinking water sourced by the North Richmond Water Treatment plant, the drinking water treatment processes provide an additional barrier for chemical hazards. The most universal of the process operations for trace dissolved chemicals is granular activated carbon (GAC).

GAC is effective for the removal of a diverse range of lipophilic organic compounds as well as some relatively lipophilic inorganic compounds such as nitrogen, sulphides and heavy metals. More polar compounds are relatively poorly removed by carbon adsorption (Metcalf & Eddy. Inc. 2003).

The key to effective chemical removal by GAC is effective adsorption to the carbon surface. The US EPA has developed adsorption isotherms for a variety of toxic compounds (at specific pH conditions) (Dobbs & Cohen 1980). The Freundlich capacity factor for the various compounds is extremely wide (*e.g.* 1.4×10^{4} for polychlorinated biphenyls and 6.8×10^{-5} for NDMA). Because of the wide variation, the Freundlich capacity factor must be determined for each specific compound (Metcalf & Eddy. Inc. 2003). As a further complication, specific mixtures of compounds in a raw water source will affect the adsorptive capacity for each compound. Precise operating conditions are also important.

Since adsorption kinetics are so chemical-specific and often system-specific, it was not possible to identify general removal efficiency values which could be applied to the diverse range of dissolved chemicals whose risk potential was assessed. Accordingly, reasonable quantitative concentration reductions could only be provided subsequent to further detailed investigation of the specific system including overall raw water quality.

Scenarios were already being modelled that assumed that some (small) populations may use water directly from the Hawkesbury-Nepean River (without treatment at the North Richmond Drinking Water Treatment Plant). So this was used as a conservative surrogate for exposure from North Richmond WTP water and additional chemical removal during drinking water treatment was not quantitatively assessed in the current risk assessment.

13 Risk Characterisation

The risk characterisation for chemical hazards has two parts. The first is the quantitative determination of residual risks associated with individual chemical contaminants identified from Schedule 10 monitoring data (after initial hazard identification screening). This is followed by a qualitative interpretation of the overall risks based on hazard matrix analysis.

13.1 Calculation of residual risks associated with individual chemicals

Once water consumption exposure concentrations have been established, calculated risks associated with individual carcinogenic and non-carcinogenic chemicals can be determined by standard chemical risk calculations adapted for the specific exposure scenarios. The equations presented here are based on those described in documentation published by the US EPA for the assessment of risk associated with contaminated sites (US Environmental Protection Agency 1989; US Environmental Protection Agency 1991; US Environmental Protection Agency 2004a). Risks and hazard quotients determined by these equations were calculated separately for various identified exposure routes (oral, dermal, inhalation) in order to retain the integrity of the modelled chemical mass balance incorporating detailed consideration of partitioning for individual chemicals.

13.1.1 Exposure due to oral consumption of water as a household supply

Risks associated with ingestion exposure to carcinogenic contaminants in water were calculated according to Equation 13-1. Assumptions include the ingestion of 2 litres of water by adults, 350 days per year over a period of 30 years. This equation considers oral exposure only and does not account for potential inhalation or dermal exposure of chemicals in drinking water.

$$\text{Risk (R)} = \frac{C_w \times EF \times CSF_o \times IR_w \times ED}{BW \times AT_c \text{ x } 365 \text{ days/year} \times 1000 \mu\text{g/mg}}$$

Equation 13-1. Calculated risk from ingestion exposure to carcinogenic contaminants in water

Symbol	Definition (units)	Default	References
C_w	Contaminant exposure concentration in water ($\mu g.L^{-1}$)	-	
CSF_o	Cancer slope factor oral ($mg^{-1}.kg.day$)	-	(US Environmental Protection Agency, 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency, 2006b; US Environmental Protection Agency, 2006c; US Environmental Protection Agency, 2006d)
AT_c	Averaging time – carcinogens (years)	70	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)
EF	Exposure frequency ($day.year^{-1}$)	350	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)
IR_w	Daily water ingestion rate ($L.day^{-1}$)	2	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)
ED	Exposure duration (years)	30	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)
BW	Adult body weight (kg)	70	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)

Hazard quotients associated with ingestion exposure to noncarcinogenic contaminants in water were calculated according to Equation 13-2. Assumptions include the ingestion of 2 litres of water by adults, 350 days per year over a period of 30 years. This equation considers oral exposure only and does not account for potential inhalation or dermal exposure of chemicals in drinking water.

$$\text{Hazard Quotient (HQ)} = \frac{C_w \times EF \times ED \times IR_w}{RfD_o \times BW \times AT_n \times 365\ \text{days/year} \times 1000\ \mu\text{g/mg}}$$

Equation 13-2. Calculated hazard quotients from ingestion exposure to noncarcinogenic contaminants in water

Symbol	Definition (units)	Default	References
C_w	Contaminant exposure concentration in water ($\mu g.L^{-1}$)	-	
RfD_o	Reference dose oral ($mg.kg^{-1}.day^{-1}$)	-	(US Environmental Protection Agency, 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency, 2006b; US Environmental Protection Agency, 2006c; US Environmental Protection Agency, 2006d)
BW	Adult body weight (kg)	70	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)
AT_n	Averaging time – noncarcinogens (years)	ED (30)	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)
IR_w	Drinking water ingestion – adult ($L.day^{-1}$)	2	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)
EF	Exposure frequency ($day.year^{-1}$)	350	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)
ED	Exposure duration (years)	30	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)

Calculated cancer exposure risks from oral consumption of organic chemical hazards are presented assuming good reverse osmosis removal (Table 13-1) and poor reverse osmosis removal (Table 13-2). The quantitative risk data presented here does not include additional chemical removal at the North Richmond Water Treatment Plant.

Table 13-1. Calculated risks from organic[1] cancer hazards assuming GOOD RO removal – oral consumption of water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	9.E-09	5.E-10	2.E-11	1.E-12	6.E-14	1.E-07	4.E-09	2.E-10	6.E-12	3.E-13	2.E-07	6.E-09	2.E-10	9.E-12	4.E-13
Aldrin	5.E-11	2.E-11	6.E-12	2.E-12	7.E-13	6.E-10	2.E-10	5.E-11	1.E-11	5.E-12	8.E-10	2.E-10	8.E-11	2.E-11	7.E-12
Atrazine	2.E-11	4.E-12	8.E-13	2.E-13	4.E-14	3.E-10	5.E-11	9.E-12	2.E-12	4.E-13	4.E-10	8.E-11	2.E-11	3.E-12	7.E-13
Benz(a)anthracene	1.E-11	3.E-12	6.E-13	1.E-13	3.E-14	2.E-10	3.E-11	7.E-12	1.E-12	3.E-13	3.E-10	5.E-11	1.E-11	2.E-12	5.E-13
Benzene	3.E-10	2.E-11	9.E-13	6.E-14	4.E-15	2.E-09	7.E-11	2.E-12	7.E-14	3.E-15	3.E-09	6.E-11	2.E-12	6.E-14	2.E-15
Benzene Hexachloride (Alpha)	1.E-11	4.E-12	1.E-12	3.E-13	9.E-14	2.E-10	5.E-11	1.E-11	3.E-12	9.E-13	3.E-10	8.E-11	2.E-11	6.E-12	2.E-12
Benzo(a)pyrene	1.E-10	4.E-11	9.E-12	2.E-12	5.E-13	2.E-09	4.E-10	8.E-11	2.E-11	4.E-12	3.E-09	6.E-10	1.E-10	3.E-11	7.E-12
Benzo(b)fluoranthene	1.E-11	4.E-12	9.E-13	2.E-13	5.E-14	2.E-10	4.E-11	9.E-12	2.E-12	4.E-13	3.E-10	7.E-11	2.E-11	3.E-12	8.E-13
Carbon Tetrachloride	1.E-11	2.E-12	2.E-13	2.E-14	3.E-15	1.E-10	6.E-12	3.E-13	2.E-14	2.E-15	1.E-10	5.E-12	3.E-13	2.E-14	1.E-15
Chloroform	6.E-11	6.E-12	4.E-13	4.E-14	4.E-15	5.E-10	2.E-11	7.E-13	4.E-14	3.E-15	5.E-10	2.E-11	9.E-13	4.E-14	2.E-15
Dibenz(ah)anthracene	1.E-10	4.E-11	1.E-11	3.E-12	8.E-13	2.E-09	5.E-10	1.E-10	2.E-11	6.E-12	3.E-09	7.E-10	2.E-10	4.E-11	1.E-11
Dibromochloromethane	1.E-10	2.E-11	3.E-12	4.E-13	7.E-14	9.E-10	7.E-11	5.E-12	5.E-13	6.E-14	1.E-09	6.E-11	5.E-12	4.E-13	4.E-14
Dichlorobenzene (1,4)	1.E-12	2.E-13	2.E-14	2.E-15	3.E-16	1.E-11	8.E-13	4.E-14	4.E-15	4.E-16	1.E-11	7.E-13	6.E-14	4.E-15	3.E-16
Dichlorobenzidine	4.E-10	1.E-10	3.E-11	7.E-12	2.E-12	6.E-09	1.E-09	3.E-10	6.E-11	2.E-11	9.E-09	2.E-09	5.E-10	1.E-10	3.E-11
Dichloroethane (1,2)	6.E-10	5.E-11	4.E-12	3.E-13	3.E-14	5.E-09	2.E-10	9.E-12	5.E-13	3.E-14	6.E-09	2.E-10	1.E-11	5.E-13	3.E-14
Dichloromethane	2.E-10	2.E-11	8.E-13	5.E-14	4.E-15	2.E-09	6.E-11	2.E-12	7.E-14	4.E-15	2.E-09	5.E-11	2.E-12	6.E-14	2.E-15
Dieldrin	4.E-11	2.E-11	7.E-12	2.E-12	9.E-13	7.E-10	2.E-10	7.E-11	2.E-11	8.E-12	1.E-09	3.E-10	1.E-10	4.E-11	1.E-11
Diphenylhydrazine	5.E-10	1.E-10	2.E-11	3.E-12	6.E-13	8.E-09	1.E-09	2.E-10	3.E-11	6.E-12	1.E-08	2.E-09	4.E-10	6.E-11	1.E-11
Heptachlor-epoxide	3.E-11	1.E-11	4.E-12	1.E-12	5.E-13	4.E-10	1.E-10	4.E-11	1.E-11	5.E-12	5.E-10	2.E-10	7.E-11	2.E-11	8.E-12
Indeno(1,2,3-cd)pyrene	1.E-11	4.E-12	1.E-12	3.E-13	8.E-14	2.E-10	5.E-11	1.E-11	2.E-12	6.E-13	3.E-10	7.E-11	2.E-11	4.E-12	9.E-13
Polychlorinated Biphenyls (As Aroclor 1254)	1.E-11	3.E-12	1.E-12	3.E-13	9.E-14	1.E-10	3.E-11	8.E-12	2.E-12	6.E-13	2.E-10	4.E-11	1.E-11	3.E-12	9.E-13
Tetrachloroethene	6.E-11	9.E-12	9.E-13	1.E-13	2.E-14	5.E-10	3.E-11	1.E-12	1.E-13	1.E-14	6.E-10	3.E-11	2.E-12	9.E-14	7.E-15
Trichloroethene	4.E-11	4.E-12	3.E-13	3.E-14	4.E-15	3.E-10	1.E-11	5.E-13	3.E-14	3.E-15	3.E-10	1.E-11	7.E-13	3.E-14	2.E-15

Note:

1. Though chloramines are strictly inorganic compounds their physical and chemical properties are more typical of organic chemicals and thus they have been grouped and assessed in the 'organic' category.

Table 13-2. Calculated risks from organic cancer hazards assuming POOR RO removal – oral consumption of water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	1.E-08	6.E-10	3.E-11	1.E-12	7.E-14	1.E-07	5.E-09	2.E-10	7.E-12	3.E-13	2.E-07	6.E-09	3.E-10	1.E-11	4.E-13
Aldrin	5.E-10	2.E-10	6.E-11	2.E-11	7.E-12	6.E-09	2.E-09	5.E-10	1.E-10	5.E-11	8.E-09	2.E-09	8.E-10	2.E-10	7.E-11
Atrazine	2.E-10	4.E-11	8.E-12	2.E-12	4.E-13	3.E-09	5.E-10	9.E-11	2.E-11	4.E-12	4.E-09	8.E-10	2.E-10	3.E-11	7.E-12
Benz(a)anthracene	1.E-10	3.E-11	6.E-12	1.E-12	3.E-13	2.E-09	3.E-10	7.E-11	1.E-11	3.E-12	3.E-09	5.E-10	1.E-10	2.E-11	5.E-12
Benzene	3.E-10	2.E-11	1.E-12	6.E-14	4.E-15	3.E-09	8.E-11	2.E-12	8.E-14	4.E-15	3.E-09	7.E-11	2.E-12	7.E-14	3.E-15
Benzene Hexachloride (Alpha)	1.E-10	4.E-11	1.E-11	3.E-12	9.E-13	2.E-09	5.E-10	1.E-10	3.E-11	9.E-12	3.E-09	8.E-10	2.E-10	6.E-11	2.E-11
Benzo(a)pyrene	1.E-09	4.E-10	9.E-11	2.E-11	5.E-12	2.E-08	4.E-09	8.E-10	2.E-10	4.E-11	3.E-08	6.E-09	1.E-09	3.E-10	7.E-11
Benzo(b)fluoranthene	1.E-10	4.E-11	9.E-12	2.E-12	5.E-13	2.E-09	4.E-10	9.E-11	2.E-11	4.E-12	3.E-09	7.E-10	2.E-10	3.E-11	8.E-12
Carbon Tetrachloride	1.E-10	2.E-11	2.E-12	2.E-13	3.E-14	1.E-09	6.E-11	3.E-12	2.E-13	2.E-14	1.E-09	5.E-11	3.E-12	2.E-13	1.E-14
Chloroform	5.E-10	5.E-11	3.E-12	3.E-13	3.E-14	4.E-09	2.E-10	6.E-12	3.E-13	2.E-14	4.E-09	1.E-10	7.E-12	3.E-13	2.E-14
Dibenz(ah)anthracene	1.E-09	4.E-10	1.E-10	3.E-11	8.E-12	2.E-08	5.E-09	1.E-09	2.E-10	6.E-11	3.E-08	7.E-09	2.E-09	4.E-10	1.E-10
Dibromochloromethane	1.E-09	2.E-10	3.E-11	4.E-12	7.E-13	9.E-09	7.E-10	5.E-11	5.E-12	6.E-13	1.E-08	6.E-10	5.E-11	4.E-12	4.E-13
Dichlorobenzene (1,4)	1.E-11	2.E-12	2.E-13	2.E-14	3.E-15	1.E-10	8.E-12	4.E-13	4.E-14	4.E-15	1.E-10	7.E-12	6.E-13	4.E-14	3.E-15
Dichlorobenzidine	4.E-09	1.E-09	3.E-10	7.E-11	2.E-11	6.E-08	1.E-08	3.E-09	6.E-10	2.E-10	9.E-08	2.E-08	5.E-09	1.E-09	3.E-10
Dichloroethane (1,2)	6.E-10	6.E-11	4.E-12	3.E-13	3.E-14	6.E-09	3.E-10	1.E-11	5.E-13	4.E-14	7.E-09	2.E-10	1.E-11	6.E-13	3.E-14
Dichloromethane	2.E-10	2.E-11	9.E-13	6.E-14	4.E-15	2.E-09	6.E-11	2.E-12	7.E-14	4.E-15	2.E-09	6.E-11	2.E-12	7.E-14	3.E-15
Dieldrin	4.E-10	2.E-10	7.E-11	2.E-11	9.E-12	7.E-09	2.E-09	7.E-10	2.E-10	8.E-11	1.E-08	3.E-09	1.E-09	4.E-10	1.E-10
Diphenylhydrazine	5.E-09	1.E-09	2.E-10	3.E-11	6.E-12	8.E-08	1.E-08	2.E-09	3.E-10	6.E-11	1.E-07	2.E-08	4.E-09	6.E-10	1.E-10
Heptachlor-epoxide	3.E-10	1.E-10	4.E-11	1.E-11	5.E-12	4.E-09	1.E-09	4.E-10	1.E-10	5.E-11	5.E-09	2.E-09	7.E-10	2.E-10	8.E-11
Indeno(1,2,3-cd)pyrene	1.E-10	4.E-11	1.E-11	3.E-12	8.E-13	2.E-09	5.E-10	1.E-10	2.E-11	6.E-12	3.E-09	7.E-10	2.E-10	4.E-11	9.E-12
Polychlorinated Biphenyls (As Aroclor 1254)	1.E-10	3.E-11	1.E-11	3.E-12	9.E-13	1.E-09	3.E-10	8.E-11	2.E-11	6.E-12	2.E-09	4.E-10	1.E-10	3.E-11	9.E-12
Tetrachloroethene	6.E-10	9.E-11	9.E-12	1.E-12	2.E-13	5.E-09	3.E-10	1.E-11	1.E-12	1.E-13	6.E-09	3.E-10	2.E-11	9.E-13	7.E-14
Trichloroethene	4.E-10	4.E-11	3.E-12	3.E-13	4.E-14	3.E-09	1.E-10	5.E-12	3.E-13	3.E-14	3.E-09	1.E-10	7.E-12	3.E-13	2.E-14

Calculated non-cancer hazard quotients are provided for organic chemical hazards under conditions of good RO removal (Table 13-3) and poor RO removal (Table 13-4). Chloramines (calculated for monochloramine) are the only identified hazards for which significant doses are determined by non-cancer risks.

Table 13-3. Calculated hazard quotients for organic non-cancer hazards assuming GOOD RO removal – oral consumption of water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Total Chloramines (as monochloramine)	5.E-05	3.E-06	1.E-07	7.E-09	3.E-10	8.E-04	3.E-05	2.E-06	6.E-08	3.E-09	1.E-03	6.E-05	3.E-06	1.E-07	6.E-09

Table 13-4. Calculated hazard quotients for organic non-cancer hazards assuming POOR RO removal – oral consumption of water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Total Chloramines (as monochloramine)	6.E-05	3.E-06	2.E-07	7.E-09	4.E-10	9.E-04	4.E-05	2.E-06	7.E-08	4.E-09	1.E-03	6.E-05	3.E-06	1.E-07	7.E-09

Since inorganic chemicals are not suitable for fugacity modelling, risks for these chemicals are presented separately with environmental concentration reductions (from Segment A-E) determined using only dilution in the river.

Calculated cancer exposure risks from inorganic chemical hazards are presented assuming good reverse osmosis removal (Table 13-5) and poor reverse osmosis removal (Table 13-6).

Table 13-5. Calculated risks from inorganic cancer hazards assuming GOOD RO removal – oral consumption of water

Flow percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Arsenic	3.E-08	4.E-08	3.E-08	3.E-08	3.E-08	5.E-07	4.E-07	4.E-07	3.E-07	3.E-07	7.E-07	7.E-07	7.E-07	6.E-07	6.E-07

Table 13-6. Calculated risks from inorganic cancer hazards assuming POOR RO removal – oral consumption of water

Flow percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Arsenic	3.E-08	4.E-08	3.E-08	3.E-08	3.E-08	5.E-07	4.E-07	4.E-07	3.E-07	3.E-07	7.E-07	7.E-07	7.E-07	6.E-07	6.E-07

Calculated non-cancer hazard quotients for inorganic chemical contaminants are provided assuming good RO removal (Table 13-7) and poor RO removal (Table 13-8).

Table 13-7. Calculated hazard quotients for inorganic non-cancer hazards assuming GOOD RO removal – oral consumption of water

Flow percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River segment:	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**
Hydrogen Sulphide (un-ionised)	2.E-03	2.E-03	2.E-03	2.E-03	2.E-03	3.E-02	3.E-02	2.E-02	2.E-02	2.E-02	5.E-02	4.E-02	4.E-02	4.E-02	4.E-02
Nickel	5.E-07	6.E-07	6.E-07	5.E-07	5.E-07	8.E-06	7.E-06	6.E-06	5.E-06	5.E-06	1.E-05	1.E-05	1.E-05	1.E-05	1.E-05

Table 13-8. Calculated hazard quotients for inorganic non-cancer hazards assuming POOR RO removal – oral consumption of water

Flow percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River segment:	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**
Hydrogen Sulphide (un-ionised)	2.E-03	2.E-03	2.E-03	2.E-03	2.E-03	3.E-02	3.E-02	3.E-02	2.E-02	2.E-02	5.E-02	5.E-02	5.E-02	4.E-02	4.E-02
Nickel	5.E-06	6.E-06	6.E-06	5.E-06	5.E-06	8.E-05	7.E-05	6.E-05	5.E-05	5.E-05	1.E-04	1.E-04	1.E-04	1.E-04	1.E-04

13.1.2 Exposure due to recreational activities in the Hawkesbury-Nepean River

Risks and hazard quotients associated with exposure to carcinogenic and noncarcinogenic contaminants during recreational activities in the Hawkesbury-Nepean River were calculated assuming four distinct exposure pathways:

1. Direct ingestion of water from the river;
2. Dermal absorption of contaminants from water while swimming;
3. Dermal absorption of contaminants from sediment (mud) during exposure to mud; and
4. Inhalation of volatile contaminants while boating (or skiing, *etc*.).

All of these pathways were modelled with the assumption of 26 visits per year (1 day per week during the six summer months) over a period of 30 years.

Risks from ingestion exposure to carcinogenic contaminants in water were calculated using Equation 13-3. The calculation assumes the accidental ingestion of 50 mL of water per visit.

$$\text{Risk (R)} = \frac{C_w \times EF \times CSF_o \times IR_w \times ED}{BW \times AT_c \text{ x } 365 \text{ days/year} \times 1000 \mu\text{g/mg}}$$

Equation 13-3. Calculated risk from ingestion exposure to carcinogenic contaminants in water

Symbol	Definition (units)	Default	References
C_w	Contaminant exposure concentration in water ($\mu g.L^{-1}$)	-	
CSF_o	Cancer slope factor oral ($mg^{-1}.kg.day$)	-	(US Environmental Protection Agency, 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency, 2006b; US Environmental Protection Agency, 2006c; US Environmental Protection Agency, 2006d)
AT_c	Averaging time – carcinogens (years)	70	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)
EF	Exposure frequency ($day.year^{-1}$)	26	
IR_w	Daily water ingestion rate ($L.day^{-1}$)	0.05	
ED	Exposure duration (years)	30	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)
BW	Adult body weight (kg)	70	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)

Hazard quotients from ingestion exposure to noncarcinogenic contaminants in water were calculated using Equation 13-4. The calculation assumes the accidental ingestion of 50 mL of water per visit.

$$\text{Hazard Quotient (HQ)} = \frac{C_w \times EF \times ED \times IR_w}{RfD_o \times BW \times AT_n \times 365 \text{ days/year} \times 1000 \mu\text{g/mg}}$$

Equation 13-4. Calculated hazard quotients from ingestion exposure to noncarcinogenic contaminants in water

Symbol	Definition (units)	Default	References
C_w	Contaminant exposure concentration in water ($\mu g.L^{-1}$)	-	
RfD_o	Reference dose oral ($mg.kg^{-1}.day^{-1}$)	-	(US Environmental Protection Agency 2004b; US Environmental Protection Agency 2006a; US Environmental Protection Agency 2006b; US Environmental Protection Agency 2006c; US

			Environmental Protection Agency 2006d)
BW	Adult body weight (kg)	70	(US Environmental Protection Agency 1989; US Environmental Protection Agency, 1991)
AT_n	Averaging time – noncarcinogens (years)	ED (30)	(US Environmental Protection Agency 1989; US Environmental Protection Agency 1991)
IR_w	Drinking water ingestion – adult ($L.day^{-1}$)	0.05	
EF	Exposure frequency ($day.year^{-1}$)	26	
ED	Exposure duration (years)	30	(US Environmental Protection Agency 1989; US Environmental Protection Agency 1991)

Risks from dermal exposure to carcinogenic contaminants in water were calculated using Equation 13-5. The calculation assumes bodily immersion in water for a period of 1 hour per visit.

$$\text{Risk (R)} = \frac{C_w \times (DA_{event} \times 10^{-6} / C_w) \times EV \times ED \times EF \times SA \times CSF_o}{BW \times ABS_{GI} \times AT_c \times 365 \text{days/year}}$$

Equation 13-5. Calculated risk from dermal exposures to carcinogenic contaminants in river water

Symbol	Definition (units)	Default	References
C_w	Contaminant exposure concentration in water ($\mu g.L^{-1}$)	-	
CSF_o	Cancer slope factor oral ($mg^{-1}.kg.day$)	-	(US Environmental Protection Agency 2004b; US Environmental Protection Agency 2006a; US Environmental Protection Agency 2006b; US Environmental Protection Agency 2006c; US Environmental Protection Agency 2006d)
DA_{event}	Adsorbed dose per event (mg/cm^2-event)	Chem.-specific	(US Environmental Protection Agency 2004a)
EV	Event frequency (events per day)	1	-
ED	Exposure duration (years)	30	-
EF	Exposure frequency (days/year)	26	
SA	Skin surface area available for contact – adult (cm^2)	18000	(US Environmental Protection Agency 2004a)
BW	Body weight – adult (kg)	70	(US Environmental Protection Agency 2004a)
ABS_{GI}	Fraction absorbed in gastro-intestinal tract (dimensionless)	Chem.-specific	(US Environmental Protection Agency 2004a)
AT_c	Averaging time-cancer (years)	70	(US Environmental Protection Agency 2004a)

Hazard quotients from dermal exposure to noncarcinogenic contaminants in water were calculated using Equation 13-6. The calculation assumes bodily immersion in water for a period of 1 hour per visit.

$$HQ = \frac{C_w \times (DA_{event} \times 10^{-6} / C_w) \times EV \times ED \times EF \times SA}{BW \times RfD_o \times ABS_{GI} \times AT_n \times 365 \text{days/year}}$$

Equation 13-6. Calculated hazard quotient from dermal exposures to noncarcinogenic contaminants in river water

Symbol	Definition (units)	Default	References
C_w	Contaminant exposure concentration in water	-	

	($\mu g.L^{-1}$)		
RfD_o	Reference dose oral ($mg.kg^{-1}.day^{-1}$)	-	(US Environmental Protection Agency 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency 2006b; US Environmental Protection Agency 2006c; US Environmental Protection Agency 2006d)
DA_{event}	Adsorbed dose per event (mg/cm^2-event)	Chem.-specific	(US Environmental Protection Agency, 2004a)
EV	Event frequency (events per day)	1	-
ED	Exposure duration (years)	30	-
EF	Exposure frequency (days/year)	26	
SA	Skin surface area available for contact – adult (cm^2)	18000	(US Environmental Protection Agency 2004a)
BW	Body weight – adult (kg)	70	(US Environmental Protection Agency 2004a)
ABS_{GI}	Fraction absorbed in gastro-intestinal tract (dimensionless)	Chem.-specific	(US Environmental Protection Agency 2004a)
AT_n	Averaging time-noncancer (years)	30	(US Environmental Protection Agency 2004a)

Risks from dermal exposure to carcinogenic contaminants in river mud (sediment) were calculated using Equation 13-7. The calculation assumes bodily coverage in mud (with a very high adherence factor) during each visit.

$$\text{Risk (R)} = \frac{C_s \times 10^{-6}\,\text{kg/mg} \times AF \times ABS_d \times EV \times ED \times EF \times SA \times CSF_o}{BW \times ABS_{GI} \times AT_c \times 365\,\text{days/year}}$$

Equation 13-7. Calculated risk from dermal exposures to carcinogenic contaminants in river mud (sediment)

Symbol	Definition (units)	Default	References
C_s	Contaminant exposure concentration in sediment ($mg.kg^{-1}$)	-	
CSF_o	Cancer slope factor oral ($mg^{-1}.kg.day$)	-	(US Environmental Protection Agency 2004b; US Environmental Protection Agency 2006a; US Environmental Protection Agency 2006b; US Environmental Protection Agency 2006c; US Environmental Protection Agency 2006d)
AF	Adherence factor of sediment to skin (mg/cm^2-event)	21	(US Environmental Protection Agency, 2004a)
ABS_d	Dermal adsorption fraction	Chem.-specific	(US Environmental Protection Agency 2004a)
EV	Event frequency (events per day)	1	-
ED	Exposure duration (years)	30	-
EF	Exposure frequency (days/year)	26	-
SA	Skin surface area available for contact – adult (cm^2)	18000	(US Environmental Protection Agency 2004a)
BW	Body weight – adult (kg)	70	(US Environmental Protection Agency 2004a)
ABS_{GI}	Fraction absorbed in gastro-intestinal tract (dimensionless)	Chem.-specific	(US Environmental Protection Agency 2004a)
AT_c	Averaging time-cancer (years)	70	(US Environmental Protection Agency 2004a)

Hazard quotients from dermal exposure to noncarcinogenic contaminants in river mud (sediment) were calculated using Equation 13-8. The calculation assumes bodily coverage in mud (with a very high adherence factor) during each visit.

$$HQ = \frac{C_s \times 10^{-6}\,kg/mg \times AF \times ABS_d \times EV \times ED \times EF \times SA}{BW \times RfD_o \times ABS_{GI} \times AT_n \times 365 days/year}$$

Equation 13-8. Calculated hazard quotient from dermal exposures to noncarcinogenic contaminants in river mud (sediment)

Symbol	Definition (units)	Default	References
C_s	Contaminant exposure concentration in sediment ($mg.kg^{-1}$)	-	
RfD_o	Reference dose oral ($mg.kg^{-1}.day^{-1}$)	-	(US Environmental Protection Agency 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency 2006b; US Environmental Protection Agency 2006c; US Environmental Protection Agency 2006d)
AF	Adherence factor of soil to skin (mg/cm^2-event)	21	(US Environmental Protection Agency 2004a)
ABS_d	Dermal adsorption fraction	Chem.-specific	(US Environmental Protection Agency 2004a)
EV	Event frequency (events per day)	1	-
ED	Exposure duration (years)	30	-
EF	Exposure frequency (days/year)	26	
SA	Skin surface area available for contact – adult (cm^2)	18000	(US Environmental Protection Agency 2004a)
BW	Body weight – adult (kg)	70	(US Environmental Protection Agency 2004a)
ABS_{GI}	Fraction absorbed in gastro-intestinal tract (dimensionless)	Chem.-specific	(US Environmental Protection Agency 2004a)
AT_n	Averaging time-noncancer (years)	30	(US Environmental Protection Agency 2004a)

Risks from inhalation exposure to carcinogenic contaminants volatilised into the air phase (up to 2 m) above the river were calculated using Equation 13-9. The calculation assumes breathing air very close to the river for 26 full days per year.

$$Risk(R) = \frac{C_a\ (\mu g/m^3) \times EF_{rec} \times ED_{rec} \times IRA_a \times CSF_i}{BW_a \times AT_c \times 365\ days/year \times 1000\,\mu g/mg}$$

Equation 13-9. Calculated risk from inhalation exposure to carcinogenic contaminants in air over river

Symbol	Definition (units)	Default	References
C_a	Contaminant exposure concentration in air ($\mu g.m^3$)	-	
CSF_i	Cancer slope factor inhaled ($mg^{-1}.kg.day$)	-	(US Environmental Protection Agency 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency 2006b; US Environmental Protection Agency 2006c; US Environmental Protection Agency 2006d)
BW_a	Body weight, adult (kg)	70	(US Environmental Protection Agency 1989)
AT_c	Averaging time–noncarcinogens (years)	70	(US Environmental Protection Agency 1989)
IRA_a	Inhalation rate – adult ($m^3.day^{-1}$)	20	(US Environmental Protection Agency 2004c)
EF_{rec}	Exposure frequency –	26	

	recreational (day.year^{-1})		
ED_{rec}	Exposure duration – rec recreational (years)	30	(US Environmental Protection Agency 1989)

Hazard quotients from inhalation exposure to noncarcinogenic contaminants volatilised into the air phase (up to 2 m) above the river were calculated using Equation 13-10. The calculation assumes breathing air very close to the river for 26 full days per year.

$$HQ = \frac{C_a\ (\mu g/m^3) \times EF_{rec} \times ED_{rec} \times IRA_a}{RfD_i \times BW_a \times AT_n \times 365\ days/year \times 1000\,\mu g/mg}$$

Equation 13-10. Calculated hazard quotients from inhalation exposure to noncarcinogenic contaminants in air over river

Symbol	Definition (units)	Default	References
C_a	Contaminant exposure concentration in air (µg.m^3)	-	
RfD_i	Reference dose inhaled (mg.kg^{-1}.day^{-1})	-	(US Environmental Protection Agency 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency 2006b; US Environmental Protection Agency 2006c; US Environmental Protection Agency 2006d)
BW_a	Body weight, adult (kg)	70	(US Environmental Protection Agency 1989)
AT_n	Averaging time–noncarcinogens (years)	ED (30)	(US Environmental Protection Agency 1989)
IRA_a	Inhalation rate – adult (m^3.day^{-1})	20	(US Environmental Protection Agency 2004c)
EF_{rec}	Exposure frequency – recreational (day.year^{-1})	26	
ED_{rec}	Exposure duration – rec recreational (years)	30	(US Environmental Protection Agency 1989)

Calculated cancer exposure risks and noncancer hazard quotients due to recreational exposure to contaminants in the Hawkesbury-Nepean River are provided in the following tables.

Table 13-9. Calculated risks from organic cancer hazards assuming GOOD RO removal – oral ingestion of river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	3.E-11	2.E-12	9.E-14	4.E-15	2.E-16	4.E-10	2.E-11	6.E-13	2.E-14	1.E-15	6.E-10	2.E-11	9.E-13	3.E-14	1.E-15
Aldrin	2.E-13	6.E-14	2.E-14	7.E-15	3.E-15	2.E-12	7.E-13	2.E-13	5.E-14	2.E-14	3.E-12	9.E-13	3.E-13	8.E-14	3.E-14
Atrazine	7.E-14	1.E-14	3.E-15	6.E-16	1.E-16	1.E-12	2.E-13	3.E-14	6.E-15	1.E-15	1.E-12	3.E-13	6.E-14	1.E-14	2.E-15
Benz(a)anthracene	5.E-14	1.E-14	2.E-15	5.E-16	1.E-16	7.E-13	1.E-13	2.E-14	5.E-15	1.E-15	1.E-12	2.E-13	4.E-14	8.E-15	2.E-15
Benzene	1.E-12	7.E-14	3.E-15	2.E-16	1.E-17	9.E-12	3.E-13	6.E-15	3.E-16	1.E-17	1.E-11	2.E-13	8.E-15	2.E-16	9.E-18
Benzene Hexachloride (Alpha)	5.E-14	2.E-14	4.E-15	1.E-15	3.E-16	7.E-13	2.E-13	5.E-14	1.E-14	3.E-15	1.E-12	3.E-13	8.E-14	2.E-14	6.E-15
Benzo(a)pyrene	5.E-13	1.E-13	3.E-14	7.E-15	2.E-15	7.E-12	2.E-12	3.E-13	6.E-14	2.E-14	1.E-11	2.E-12	5.E-13	1.E-13	3.E-14
Benzo(b)fluoranthene	5.E-14	1.E-14	3.E-15	8.E-16	2.E-16	7.E-13	2.E-13	3.E-14	7.E-15	2.E-15	1.E-12	2.E-13	6.E-14	1.E-14	3.E-15
Carbon Tetrachloride	5.E-14	7.E-15	6.E-16	7.E-17	9.E-18	4.E-13	2.E-14	1.E-15	7.E-17	7.E-18	5.E-13	2.E-14	1.E-15	6.E-17	4.E-18
Chloroform	2.E-13	2.E-14	2.E-15	1.E-16	1.E-17	2.E-12	8.E-14	3.E-15	2.E-16	1.E-17	2.E-12	7.E-14	3.E-15	1.E-16	7.E-18
Dibenz(ah)anthracene	6.E-13	2.E-13	4.E-14	1.E-14	3.E-15	8.E-12	2.E-12	4.E-13	9.E-14	2.E-14	1.E-11	3.E-12	6.E-13	1.E-13	4.E-14
Dibromochloromethane	4.E-13	8.E-14	9.E-15	2.E-15	3.E-16	3.E-12	3.E-13	2.E-14	2.E-15	2.E-16	4.E-12	2.E-13	2.E-14	2.E-15	1.E-16
Dichlorobenzene (1,4)	5.E-15	7.E-16	6.E-17	8.E-18	1.E-18	4.E-14	3.E-15	2.E-16	1.E-17	1.E-18	5.E-14	3.E-15	2.E-16	1.E-17	1.E-18
Dichlorobenzidine	2.E-12	4.E-13	1.E-13	2.E-14	6.E-15	2.E-11	5.E-12	1.E-12	2.E-13	6.E-14	4.E-11	8.E-12	2.E-12	4.E-13	1.E-13
Dichloroethane (1,2)	2.E-12	2.E-13	1.E-14	1.E-15	9.E-17	2.E-11	9.E-13	3.E-14	2.E-15	1.E-16	2.E-11	8.E-13	4.E-14	2.E-15	9.E-17
Dichloromethane	7.E-13	6.E-14	3.E-15	2.E-16	1.E-17	6.E-12	2.E-13	6.E-15	2.E-16	1.E-17	7.E-12	2.E-13	7.E-15	2.E-16	9.E-18
Dieldrin	2.E-13	7.E-14	2.E-14	9.E-15	3.E-15	2.E-12	8.E-13	3.E-13	8.E-14	3.E-14	4.E-12	1.E-12	4.E-13	1.E-13	5.E-14
Diphenylhydrazine	2.E-12	4.E-13	7.E-14	1.E-14	2.E-15	3.E-11	5.E-12	8.E-13	1.E-13	2.E-14	5.E-11	8.E-12	1.E-12	2.E-13	4.E-14
Heptachlor-epoxide	1.E-13	4.E-14	1.E-14	5.E-15	2.E-15	1.E-12	5.E-13	1.E-13	5.E-14	2.E-14	2.E-12	7.E-13	2.E-13	8.E-14	3.E-14
Indeno(1,2,3-cd)pyrene	5.E-14	2.E-14	4.E-15	1.E-15	3.E-16	7.E-13	2.E-13	4.E-14	8.E-15	2.E-15	1.E-12	2.E-13	6.E-14	1.E-14	3.E-15
Polychlorinated Biphenyls (As Aroclor 1254)	4.E-14	1.E-14	4.E-15	1.E-15	3.E-16	5.E-13	1.E-13	3.E-14	8.E-15	2.E-15	6.E-13	2.E-13	5.E-14	1.E-14	3.E-15
Tetrachloroethene	2.E-13	4.E-14	3.E-15	4.E-16	6.E-17	2.E-12	1.E-13	5.E-15	4.E-16	4.E-17	2.E-12	1.E-13	6.E-15	3.E-16	3.E-17
Trichloroethene	1.E-13	2.E-14	1.E-15	1.E-16	1.E-17	1.E-12	5.E-14	2.E-15	1.E-16	1.E-17	1.E-12	5.E-14	2.E-15	1.E-16	7.E-18

Table 13-10. Calculated risks from organic cancer hazards assuming POOR RO removal – oral ingestion of river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	4.E-11	2.E-12	1.E-13	5.E-15	2.E-16	5.E-10	2.E-11	7.E-13	3.E-14	1.E-15	6.E-10	2.E-11	1.E-12	4.E-14	2.E-15
Aldrin	2.E-12	6.E-13	2.E-13	7.E-14	3.E-14	2.E-11	7.E-12	2.E-12	5.E-13	2.E-13	3.E-11	9.E-12	3.E-12	8.E-13	3.E-13
Atrazine	7.E-13	1.E-13	3.E-14	6.E-15	1.E-15	1.E-11	2.E-12	3.E-13	6.E-14	1.E-14	1.E-11	3.E-12	6.E-13	1.E-13	2.E-14
Benz(a)anthracene	5.E-13	1.E-13	2.E-14	5.E-15	1.E-15	7.E-12	1.E-12	2.E-13	5.E-14	1.E-14	1.E-11	2.E-12	4.E-13	8.E-14	2.E-14
Benzene	1.E-12	8.E-14	4.E-15	2.E-16	2.E-17	9.E-12	3.E-13	7.E-15	3.E-16	1.E-17	1.E-11	3.E-13	9.E-15	3.E-16	9.E-18
Benzene Hexachloride (Alpha)	5.E-13	2.E-13	4.E-14	1.E-14	3.E-15	7.E-12	2.E-12	5.E-13	1.E-13	3.E-14	1.E-11	3.E-12	8.E-13	2.E-13	6.E-14
Benzo(a)pyrene	5.E-12	1.E-12	3.E-13	7.E-14	2.E-14	7.E-11	2.E-11	3.E-12	6.E-13	2.E-13	1.E-10	2.E-11	5.E-12	1.E-12	3.E-13
Benzo(b)fluoranthene	5.E-13	1.E-13	3.E-14	8.E-15	2.E-15	7.E-12	2.E-12	3.E-13	7.E-14	2.E-14	1.E-11	2.E-12	6.E-13	1.E-13	3.E-14
Carbon Tetrachloride	5.E-13	7.E-14	6.E-15	7.E-16	9.E-17	4.E-12	2.E-13	1.E-14	7.E-16	7.E-17	5.E-12	2.E-13	1.E-14	6.E-16	4.E-17
Chloroform	2.E-12	2.E-13	1.E-14	1.E-15	1.E-16	1.E-11	6.E-13	2.E-14	1.E-15	9.E-17	2.E-11	5.E-13	3.E-14	1.E-15	6.E-17
Dibenz(ah)anthracene	6.E-12	2.E-12	4.E-13	1.E-13	3.E-14	8.E-11	2.E-11	4.E-12	9.E-13	2.E-13	1.E-10	3.E-11	6.E-12	1.E-12	4.E-13
Dibromochloromethane	4.E-12	8.E-13	9.E-14	2.E-14	3.E-15	3.E-11	3.E-12	2.E-13	2.E-14	2.E-15	4.E-11	2.E-12	2.E-13	2.E-14	1.E-15
Dichlorobenzene (1,4)	5.E-14	7.E-15	6.E-16	8.E-17	1.E-17	4.E-13	3.E-14	2.E-15	1.E-16	1.E-17	5.E-13	3.E-14	2.E-15	1.E-16	1.E-17
Dichlorobenzidine	2.E-11	4.E-12	1.E-12	2.E-13	6.E-14	2.E-10	5.E-11	1.E-11	2.E-12	6.E-13	4.E-10	8.E-11	2.E-11	4.E-12	1.E-12
Dichloroethane (1,2)	2.E-12	2.E-13	1.E-14	1.E-15	1.E-16	2.E-11	1.E-12	4.E-14	2.E-15	1.E-16	2.E-11	9.E-13	5.E-14	2.E-15	1.E-16
Dichloromethane	8.E-13	7.E-14	3.E-15	2.E-16	2.E-17	7.E-12	2.E-13	6.E-15	3.E-16	1.E-17	8.E-12	2.E-13	8.E-15	2.E-16	1.E-17
Dieldrin	2.E-12	7.E-13	2.E-13	9.E-14	3.E-14	2.E-11	8.E-12	3.E-12	8.E-13	3.E-13	4.E-11	1.E-11	4.E-12	1.E-12	5.E-13
Diphenylhydrazine	2.E-11	4.E-12	7.E-13	1.E-13	2.E-14	3.E-10	5.E-11	8.E-12	1.E-12	2.E-13	5.E-10	8.E-11	1.E-11	2.E-12	4.E-13
Heptachlor-epoxide	1.E-12	4.E-13	1.E-13	5.E-14	2.E-14	1.E-11	5.E-12	1.E-12	5.E-13	2.E-13	2.E-11	7.E-12	2.E-12	8.E-13	3.E-13
Indeno(1,2,3-cd)pyrene	5.E-13	2.E-13	4.E-14	1.E-14	3.E-15	7.E-12	2.E-12	4.E-13	8.E-14	2.E-14	1.E-11	2.E-12	6.E-13	1.E-13	3.E-14
Polychlorinated Biphenyls (As Aroclor 1254)	4.E-13	1.E-13	4.E-14	1.E-14	3.E-15	5.E-12	1.E-12	3.E-13	8.E-14	2.E-14	6.E-12	2.E-12	5.E-13	1.E-13	3.E-14
Tetrachloroethene	2.E-12	4.E-13	3.E-14	4.E-15	6.E-16	2.E-11	1.E-12	5.E-14	4.E-15	4.E-16	2.E-11	1.E-12	6.E-14	3.E-15	3.E-16
Trichloroethene	1.E-12	2.E-13	1.E-14	1.E-15	1.E-16	1.E-11	5.E-13	2.E-14	1.E-15	1.E-16	1.E-11	5.E-13	2.E-14	1.E-15	7.E-17

Table 13-11. Calculated risks from organic cancer hazards assuming GOOD RO removal – dermal contact to river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	2.E-11	1.E-12	5.E-14	3.E-15	1.E-16	2.E-10	1.E-11	3.E-13	1.E-14	6.E-16	3.E-10	1.E-11	5.E-13	2.E-14	8.E-16
Aldrin	1.E-10	4.E-11	1.E-11	4.E-12	2.E-12	1.E-09	4.E-10	1.E-10	3.E-11	1.E-11	2.E-09	5.E-10	2.E-10	5.E-11	2.E-11
Atrazine	4.E-13	1.E-13	2.E-14	4.E-15	9.E-16	7.E-12	1.E-12	2.E-13	4.E-14	9.E-15	1.E-11	2.E-12	4.E-13	8.E-14	2.E-14
Benz(a)anthracene	3.E-11	8.E-12	2.E-12	4.E-13	8.E-14	5.E-10	9.E-11	2.E-11	3.E-12	7.E-13	7.E-10	1.E-10	3.E-11	6.E-12	1.E-12
Benzene	8.E-12	6.E-13	3.E-14	2.E-15	1.E-16	7.E-11	2.E-12	5.E-14	2.E-15	1.E-16	8.E-11	2.E-12	7.E-14	2.E-15	7.E-17
Benzene Hexachloride (Alpha)	1.E-12	4.E-13	1.E-13	3.E-14	8.E-15	2.E-11	4.E-12	1.E-12	3.E-13	7.E-14	3.E-11	7.E-12	2.E-12	5.E-13	1.E-13
Benzo(a)pyrene	5.E-10	1.E-10	3.E-11	7.E-12	2.E-12	7.E-09	1.E-09	3.E-10	6.E-11	1.E-11	1.E-08	2.E-09	5.E-10	1.E-10	2.E-11
Benzo(b)fluoranthene	3.E-11	8.E-12	2.E-12	5.E-13	1.E-13	4.E-10	1.E-10	2.E-11	4.E-12	1.E-12	7.E-10	1.E-10	3.E-11	8.E-12	2.E-12
Carbon Tetrachloride	7.E-13	1.E-13	9.E-15	1.E-15	1.E-16	6.E-12	3.E-13	1.E-14	1.E-15	9.E-17	7.E-12	3.E-13	2.E-14	9.E-16	6.E-17
Chloroform	1.E-12	1.E-13	7.E-15	7.E-16	7.E-17	8.E-12	4.E-13	1.E-14	7.E-16	5.E-17	1.E-11	3.E-13	2.E-14	6.E-16	3.E-17
Dibenz(ah)anthracene	7.E-10	2.E-10	5.E-11	1.E-11	4.E-12	1.E-08	2.E-09	5.E-10	1.E-10	3.E-11	1.E-08	3.E-09	8.E-10	2.E-10	5.E-11
Dibromochloromethane	1.E-12	3.E-13	3.E-14	5.E-15	1.E-15	1.E-11	1.E-12	6.E-14	6.E-15	8.E-16	1.E-11	8.E-13	7.E-14	5.E-15	5.E-16
Dichlorobenzene (1,4)	2.E-13	2.E-14	2.E-15	3.E-16	4.E-17	2.E-12	1.E-13	6.E-15	5.E-16	5.E-17	2.E-12	1.E-13	8.E-15	5.E-16	4.E-17
Dichlorobenzidine	3.E-11	9.E-12	2.E-12	5.E-13	1.E-13	5.E-10	1.E-10	2.E-11	5.E-12	1.E-12	7.E-10	2.E-10	4.E-11	9.E-12	2.E-12
Dichloroethane (1,2)	6.E-12	5.E-13	3.E-14	3.E-15	3.E-16	5.E-11	2.E-12	9.E-14	5.E-15	3.E-16	6.E-11	2.E-12	1.E-13	5.E-15	2.E-16
Dichloromethane	2.E-12	1.E-13	6.E-15	4.E-16	3.E-17	1.E-11	4.E-13	1.E-14	5.E-16	3.E-17	1.E-11	4.E-13	1.E-14	5.E-16	2.E-17
Dieldrin	2.E-11	9.E-12	3.E-12	1.E-12	4.E-13	3.E-10	1.E-10	3.E-11	1.E-11	4.E-12	5.E-10	2.E-10	6.E-11	2.E-11	7.E-12
Diphenylhydrazine	3.E-11	5.E-12	1.E-12	2.E-13	3.E-14	4.E-10	7.E-11	1.E-11	2.E-12	3.E-13	6.E-10	1.E-10	2.E-11	3.E-12	6.E-13
Heptachlor-epoxide	6.E-12	3.E-12	1.E-12	4.E-13	1.E-13	9.E-11	3.E-11	1.E-11	3.E-12	1.E-12	1.E-10	5.E-11	2.E-11	5.E-12	2.E-12
Indeno(1,2,3-cd)pyrene	8.E-11	2.E-11	6.E-12	2.E-12	4.E-13	1.E-09	2.E-10	5.E-11	1.E-11	3.E-12	2.E-09	4.E-10	9.E-11	2.E-11	5.E-12
Polychlorinated Biphenyls (As Aroclor 1254)	4.E-11	1.E-11	4.E-12	1.E-12	3.E-13	5.E-10	1.E-10	3.E-11	7.E-12	2.E-12	6.E-10	2.E-10	5.E-11	1.E-11	3.E-12
Tetrachloroethene	7.E-12	1.E-12	1.E-13	1.E-14	2.E-15	6.E-11	4.E-12	2.E-13	1.E-14	1.E-15	7.E-11	3.E-12	2.E-13	1.E-14	8.E-16
Trichloroethene	1.E-12	1.E-13	1.E-14	1.E-15	1.E-16	1.E-11	5.E-13	2.E-14	1.E-15	9.E-17	1.E-11	4.E-13	2.E-14	1.E-15	6.E-17

Table 13-12. Calculated risks from organic cancer hazards assuming POOR RO removal – dermal contact to river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	2.E-11	1.E-12	6.E-14	3.E-15	1.E-16	3.E-10	1.E-11	4.E-13	2.E-14	7.E-16	4.E-10	1.E-11	6.E-13	2.E-14	9.E-16
Aldrin	1.E-09	4.E-10	1.E-10	4.E-11	2.E-11	1.E-08	4.E-09	1.E-09	3.E-10	1.E-10	2.E-08	5.E-09	2.E-09	5.E-10	2.E-10
Atrazine	4.E-12	1.E-12	2.E-13	4.E-14	9.E-15	7.E-11	1.E-11	2.E-12	4.E-13	9.E-14	1.E-10	2.E-11	4.E-12	8.E-13	2.E-13
Benz(a)anthracene	3.E-10	8.E-11	2.E-11	4.E-12	8.E-13	5.E-09	9.E-10	2.E-10	3.E-11	7.E-12	7.E-09	1.E-09	3.E-10	6.E-11	1.E-11
Benzene	9.E-12	7.E-13	3.E-14	2.E-15	1.E-16	8.E-11	2.E-12	6.E-14	2.E-15	1.E-16	9.E-11	2.E-12	7.E-14	2.E-15	8.E-17
Benzene Hexachloride (Alpha)	1.E-11	4.E-12	1.E-12	3.E-13	8.E-14	2.E-10	4.E-11	1.E-11	3.E-12	7.E-13	3.E-10	7.E-11	2.E-11	5.E-12	1.E-12
Benzo(a)pyrene	5.E-09	1.E-09	3.E-10	7.E-11	2.E-11	7.E-08	1.E-08	3.E-09	6.E-10	1.E-10	1.E-07	2.E-08	5.E-09	1.E-09	2.E-10
Benzo(b)fluoranthene	3.E-10	8.E-11	2.E-11	5.E-12	1.E-12	4.E-09	1.E-09	2.E-10	4.E-11	1.E-11	7.E-09	1.E-09	3.E-10	8.E-11	2.E-11
Carbon Tetrachloride	7.E-12	1.E-12	9.E-14	1.E-14	1.E-15	6.E-11	3.E-12	1.E-13	1.E-14	9.E-16	7.E-11	3.E-12	2.E-13	9.E-15	6.E-16
Chloroform	8.E-12	9.E-13	6.E-14	6.E-15	6.E-16	7.E-11	3.E-12	1.E-13	6.E-15	4.E-16	8.E-11	3.E-12	1.E-13	5.E-15	3.E-16
Dibenz(ah)anthracene	7.E-09	2.E-09	5.E-10	1.E-10	4.E-11	1.E-07	2.E-08	5.E-09	1.E-09	3.E-10	1.E-07	3.E-08	8.E-09	2.E-09	5.E-10
Dibromochloromethane	1.E-11	3.E-12	3.E-13	5.E-14	1.E-14	1.E-10	1.E-11	6.E-13	6.E-14	8.E-15	1.E-10	8.E-12	7.E-13	5.E-14	5.E-15
Dichlorobenzene (1,4)	2.E-12	2.E-13	2.E-14	3.E-15	4.E-16	2.E-11	1.E-12	6.E-14	5.E-15	5.E-16	2.E-11	1.E-12	8.E-14	5.E-15	4.E-16
Dichlorobenzidine	3.E-10	9.E-11	2.E-11	5.E-12	1.E-12	5.E-09	1.E-09	2.E-10	5.E-11	1.E-11	7.E-09	2.E-09	4.E-10	9.E-11	2.E-11
Dichloroethane (1,2)	6.E-12	6.E-13	4.E-14	3.E-15	3.E-16	6.E-11	3.E-12	1.E-13	5.E-15	4.E-16	7.E-11	2.E-12	1.E-13	5.E-15	3.E-16
Dichloromethane	2.E-12	1.E-13	7.E-15	5.E-16	3.E-17	1.E-11	5.E-13	1.E-14	6.E-16	3.E-17	2.E-11	4.E-13	2.E-14	5.E-16	2.E-17
Dieldrin	2.E-10	9.E-11	3.E-11	1.E-11	4.E-12	3.E-09	1.E-09	3.E-10	1.E-10	4.E-11	5.E-09	2.E-09	6.E-10	2.E-10	7.E-11
Diphenylhydrazine	3.E-10	5.E-11	1.E-11	2.E-12	3.E-13	4.E-09	7.E-10	1.E-10	2.E-11	3.E-12	6.E-09	1.E-09	2.E-10	3.E-11	6.E-12
Heptachlor-epoxide	6.E-11	3.E-11	1.E-11	4.E-12	1.E-12	9.E-10	3.E-10	1.E-10	3.E-11	1.E-11	1.E-09	5.E-10	2.E-10	5.E-11	2.E-11
Indeno(1,2,3-cd)pyrene	8.E-10	2.E-10	6.E-11	2.E-11	4.E-12	1.E-08	2.E-09	5.E-10	1.E-10	3.E-11	2.E-08	4.E-09	9.E-10	2.E-10	5.E-11
Polychlorinated Biphenyls (As Aroclor 1254)	4.E-10	1.E-10	4.E-11	1.E-11	3.E-12	5.E-09	1.E-09	3.E-10	7.E-11	2.E-11	6.E-09	2.E-09	5.E-10	1.E-10	3.E-11
Tetrachloroethene	7.E-11	1.E-11	1.E-12	1.E-13	2.E-14	6.E-10	4.E-11	2.E-12	1.E-13	1.E-14	7.E-10	3.E-11	2.E-12	1.E-13	8.E-15
Trichloroethene	1.E-11	1.E-12	1.E-13	1.E-14	1.E-15	1.E-10	5.E-12	2.E-13	1.E-14	9.E-16	1.E-10	4.E-12	2.E-13	1.E-14	6.E-16

Table 13-13. Calculated risks from organic cancer hazards assuming GOOD RO removal – dermal contact to river mud (sediment)

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	2.E-11	9.E-13	4.E-14	2.E-15	1.E-16	2.E-10	8.E-12	3.E-13	1.E-14	5.E-16	3.E-10	1.E-11	4.E-13	2.E-14	7.E-16
Aldrin	6.E-09	2.E-09	8.E-10	3.E-10	9.E-11	8.E-08	2.E-08	6.E-09	2.E-09	6.E-10	1.E-07	3.E-08	1.E-08	3.E-09	9.E-10
Atrazine	3.E-13	7.E-14	1.E-14	3.E-15	6.E-16	5.E-12	9.E-13	2.E-13	3.E-14	6.E-15	7.E-12	1.E-12	3.E-13	6.E-14	1.E-14
Benz(a)anthracene	8.E-10	2.E-10	4.E-11	1.E-11	2.E-12	1.E-08	2.E-09	5.E-10	8.E-11	2.E-11	2.E-08	4.E-09	8.E-10	2.E-10	3.E-11
Benzene	1.E-12	9.E-14	4.E-15	2.E-16	2.E-17	1.E-11	3.E-13	8.E-15	3.E-16	1.E-17	1.E-11	3.E-13	9.E-15	3.E-16	1.E-17
Benzene Hexachloride (Alpha)	1.E-11	4.E-12	1.E-12	3.E-13	1.E-13	2.E-10	5.E-11	1.E-11	3.E-12	9.E-13	3.E-10	9.E-11	2.E-11	6.E-12	2.E-12
Benzo(a)pyrene	2.E-08	4.E-09	1.E-09	2.E-10	6.E-11	2.E-07	5.E-08	1.E-08	2.E-09	5.E-10	3.E-07	7.E-08	2.E-08	4.E-09	8.E-10
Benzo(b)fluoranthene	9.E-10	3.E-10	6.E-11	1.E-11	4.E-12	1.E-08	3.E-09	6.E-10	1.E-10	3.E-11	2.E-08	5.E-09	1.E-09	2.E-10	5.E-11
Carbon Tetrachloride	2.E-13	4.E-14	3.E-15	3.E-16	5.E-17	2.E-12	1.E-13	5.E-15	3.E-16	3.E-17	2.E-12	1.E-13	6.E-15	3.E-16	2.E-17
Chloroform	2.E-13	2.E-14	1.E-15	1.E-16	1.E-17	2.E-12	8.E-14	3.E-15	1.E-16	1.E-17	2.E-12	7.E-14	3.E-15	1.E-16	7.E-18
Dibenz(ah)anthracene	3.E-08	8.E-09	2.E-09	5.E-10	1.E-10	3.E-07	8.E-08	2.E-08	4.E-09	1.E-09	5.E-07	1.E-07	3.E-08	7.E-09	2.E-09
Dibromochloromethane	5.E-13	1.E-13	1.E-14	2.E-15	3.E-16	4.E-12	3.E-13	2.E-14	2.E-15	3.E-16	5.E-12	3.E-13	2.E-14	2.E-15	2.E-16
Dichlorobenzene (1,4)	1.E-13	2.E-14	2.E-15	2.E-16	3.E-17	1.E-12	8.E-14	5.E-15	4.E-16	4.E-17	1.E-12	8.E-14	6.E-15	4.E-16	3.E-17
Dichlorobenzidine	6.E-11	2.E-11	4.E-12	9.E-13	2.E-13	8.E-10	2.E-10	4.E-11	9.E-12	2.E-12	1.E-09	3.E-10	7.E-11	2.E-11	4.E-12
Dichloroethane (1,2)	1.E-12	1.E-13	8.E-15	7.E-16	6.E-17	1.E-11	5.E-13	2.E-14	1.E-15	8.E-17	1.E-11	5.E-13	3.E-14	1.E-15	6.E-17
Dichloromethane	4.E-13	3.E-14	2.E-15	1.E-16	8.E-18	4.E-12	1.E-13	3.E-15	1.E-16	7.E-18	4.E-12	1.E-13	4.E-15	1.E-16	5.E-18
Dieldrin	8.E-10	3.E-10	1.E-10	4.E-11	1.E-11	1.E-08	4.E-09	1.E-09	4.E-10	1.E-10	2.E-08	6.E-09	2.E-09	7.E-10	2.E-10
Diphenylhydrazine	1.E-11	3.E-12	5.E-13	8.E-14	1.E-14	2.E-10	3.E-11	5.E-12	8.E-13	1.E-13	3.E-10	5.E-11	9.E-12	1.E-12	3.E-13
Heptachlor-epoxide	3.E-10	1.E-10	4.E-11	2.E-11	6.E-12	4.E-09	1.E-09	4.E-10	1.E-10	5.E-11	5.E-09	2.E-09	7.E-10	2.E-10	8.E-11
Indeno(1,2,3-cd)pyrene	3.E-09	8.E-10	2.E-10	6.E-11	1.E-11	4.E-08	9.E-09	2.E-09	4.E-10	1.E-10	5.E-08	1.E-08	3.E-09	7.E-10	2.E-10
Polychlorinated Biphenyls (As Aroclor 1254)	2.E-09	7.E-10	2.E-10	7.E-11	2.E-11	3.E-08	7.E-09	2.E-09	4.E-10	1.E-10	4.E-08	1.E-08	3.E-09	7.E-10	2.E-10
Tetrachloroethene	6.E-12	9.E-13	8.E-14	1.E-14	1.E-15	5.E-11	3.E-12	1.E-13	1.E-14	1.E-15	5.E-11	3.E-12	2.E-13	9.E-15	7.E-16
Trichloroethene	3.E-13	3.E-14	2.E-15	2.E-16	3.E-17	2.E-12	1.E-13	4.E-15	2.E-16	2.E-17	2.E-12	9.E-14	5.E-15	2.E-16	1.E-17

Table 13-14. Calculated risks from organic cancer hazards assuming POOR RO removal – dermal contact to river mud (sediment)

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**
Acrylonitrile	2.E-11	1.E-12	5.E-14	2.E-15	1.E-16	2.E-10	9.E-12	3.E-13	1.E-14	6.E-16	3.E-10	1.E-11	5.E-13	2.E-14	7.E-16
Aldrin	6.E-08	2.E-08	8.E-09	3.E-09	9.E-10	8.E-07	2.E-07	6.E-08	2.E-08	6.E-09	**1.E-06**	3.E-07	1.E-07	3.E-08	9.E-09
Atrazine	3.E-12	7.E-13	1.E-13	3.E-14	6.E-15	5.E-11	9.E-12	2.E-12	3.E-13	6.E-14	7.E-11	1.E-11	3.E-12	6.E-13	1.E-13
Benz(a)anthracene	8.E-09	2.E-09	4.E-10	1.E-10	2.E-11	1.E-07	2.E-08	5.E-09	8.E-10	2.E-10	2.E-07	4.E-08	8.E-09	2.E-09	3.E-10
Benzene	1.E-12	1.E-13	4.E-15	3.E-16	2.E-17	1.E-11	3.E-13	8.E-15	3.E-16	2.E-17	1.E-11	3.E-13	1.E-14	3.E-16	1.E-17
Benzene Hexachloride (Alpha)	1.E-10	4.E-11	1.E-11	3.E-12	1.E-12	2.E-09	5.E-10	1.E-10	3.E-11	9.E-12	3.E-09	9.E-10	2.E-10	6.E-11	2.E-11
Benzo(a)pyrene	2.E-07	4.E-08	1.E-08	2.E-09	6.E-10	**2.E-06**	5.E-07	1.E-07	2.E-08	5.E-09	**3.E-06**	7.E-07	2.E-07	4.E-08	8.E-09
Benzo(b)fluoranthene	9.E-09	3.E-09	6.E-10	1.E-10	4.E-11	1.E-07	3.E-08	6.E-09	1.E-09	3.E-10	2.E-07	5.E-08	1.E-08	2.E-09	5.E-10
Carbon Tetrachloride	2.E-12	4.E-13	3.E-14	3.E-15	5.E-16	2.E-11	1.E-12	5.E-14	3.E-15	3.E-16	2.E-11	1.E-12	6.E-14	3.E-15	2.E-16
Chloroform	2.E-12	2.E-13	1.E-14	1.E-15	1.E-16	1.E-11	6.E-13	2.E-14	1.E-15	9.E-17	2.E-11	5.E-13	2.E-14	1.E-15	6.E-17
Dibenz(ah)anthracene	3.E-07	8.E-08	2.E-08	5.E-09	1.E-09	**3.E-06**	8.E-07	2.E-07	4.E-08	1.E-08	**5.E-06**	**1.E-06**	3.E-07	7.E-08	2.E-08
Dibromochloromethane	5.E-12	1.E-12	1.E-13	2.E-14	3.E-15	4.E-11	3.E-12	2.E-13	2.E-14	3.E-15	5.E-11	3.E-12	2.E-13	2.E-14	2.E-15
Dichlorobenzene (1,4)	1.E-12	2.E-13	2.E-14	2.E-15	3.E-16	1.E-11	8.E-13	5.E-14	4.E-15	4.E-16	1.E-11	8.E-13	6.E-14	4.E-15	3.E-16
Dichlorobenzidine	6.E-10	2.E-10	4.E-11	9.E-12	2.E-12	8.E-09	2.E-09	4.E-10	9.E-11	2.E-11	1.E-08	3.E-09	7.E-10	2.E-10	4.E-11
Dichloroethane (1,2)	1.E-12	1.E-13	9.E-15	8.E-16	7.E-17	1.E-11	6.E-13	2.E-14	1.E-15	8.E-17	2.E-11	6.E-13	3.E-14	1.E-15	6.E-17
Dichloromethane	5.E-13	4.E-14	2.E-15	1.E-16	9.E-18	4.E-12	1.E-13	4.E-15	2.E-16	8.E-18	4.E-12	1.E-13	4.E-15	1.E-16	6.E-18
Dieldrin	8.E-09	3.E-09	1.E-09	4.E-10	1.E-10	1.E-07	4.E-08	1.E-08	4.E-09	1.E-09	2.E-07	6.E-08	2.E-08	7.E-09	2.E-09
Diphenylhydrazine	1.E-10	3.E-11	5.E-12	8.E-13	1.E-13	2.E-09	3.E-10	5.E-11	8.E-12	1.E-12	3.E-09	5.E-10	9.E-11	1.E-11	3.E-12
Heptachlor-epoxide	3.E-09	1.E-09	4.E-10	2.E-10	6.E-11	4.E-08	1.E-08	4.E-09	1.E-09	5.E-10	5.E-08	2.E-08	7.E-09	2.E-09	8.E-10
Indeno(1,2,3-cd)pyrene	3.E-08	8.E-09	2.E-09	6.E-10	1.E-10	4.E-07	9.E-08	2.E-08	4.E-09	1.E-09	5.E-07	1.E-07	3.E-08	7.E-09	2.E-09
Polychlorinated Biphenyls (As Aroclor 1254)	2.E-08	7.E-09	2.E-09	7.E-10	2.E-10	3.E-07	7.E-08	2.E-08	4.E-09	1.E-09	4.E-07	1.E-07	3.E-08	7.E-09	2.E-09
Tetrachloroethene	6.E-11	9.E-12	8.E-13	1.E-13	1.E-14	5.E-10	3.E-11	1.E-12	1.E-13	1.E-14	5.E-10	3.E-11	2.E-12	9.E-14	7.E-15
Trichloroethene	3.E-12	3.E-13	2.E-14	2.E-15	3.E-16	2.E-11	1.E-12	4.E-14	2.E-15	2.E-16	2.E-11	9.E-13	5.E-14	2.E-15	1.E-16

Note: Bolded values equal or exceed the 10^{-6} benchmark.

Table 13-15. Calculated risks from organic cancer hazards assuming GOOD RO removal – inhalation of air above river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	4.E-10	4.E-11	2.E-12	1.E-13	3.E-15	5.E-09	4.E-10	1.E-11	6.E-13	1.E-14	6.E-09	5.E-10	2.E-11	9.E-13	2.E-14
Aldrin	6.E-13	4.E-13	1.E-13	5.E-14	1.E-14	8.E-12	4.E-12	1.E-12	4.E-13	7.E-14	1.E-11	6.E-12	2.E-12	6.E-13	1.E-13
Atrazine	4.E-17	2.E-17	4.E-18	8.E-19	1.E-19	7.E-16	2.E-16	4.E-17	7.E-18	9.E-19	1.E-15	3.E-16	7.E-17	1.E-17	2.E-18
Benz(a)anthracene	6.E-15	3.E-15	6.E-16	1.E-16	2.E-17	9.E-14	3.E-14	6.E-15	1.E-15	1.E-16	1.E-13	5.E-14	1.E-14	2.E-15	3.E-16
Benzene	4.E-11	1.E-11	6.E-13	4.E-14	7.E-16	4.E-10	4.E-11	1.E-12	5.E-14	6.E-16	4.E-10	3.E-11	1.E-12	5.E-14	4.E-16
Benzene Hexachloride (Alpha)	3.E-14	2.E-14	5.E-15	1.E-15	2.E-16	5.E-13	2.E-13	6.E-14	1.E-14	2.E-15	7.E-13	3.E-13	1.E-13	3.E-14	4.E-15
Benzo(a)pyrene	9.E-15	4.E-15	1.E-15	3.E-16	4.E-17	1.E-13	5.E-14	1.E-14	2.E-15	3.E-16	2.E-13	7.E-14	2.E-14	4.E-15	5.E-16
Benzo(b)fluoranthene	7.E-16	3.E-16	9.E-17	2.E-17	3.E-18	1.E-14	4.E-15	9.E-16	2.E-16	3.E-17	2.E-14	6.E-15	2.E-15	3.E-16	5.E-17
Carbon Tetrachloride	2.E-12	1.E-12	1.E-13	2.E-14	4.E-16	2.E-11	3.E-12	2.E-13	2.E-14	3.E-16	2.E-11	3.E-12	2.E-13	1.E-14	2.E-16
Chloroform	2.E-10	7.E-11	6.E-12	6.E-13	1.E-14	1.E-09	2.E-10	1.E-11	6.E-13	1.E-14	2.E-09	2.E-10	1.E-11	6.E-13	6.E-15
Dibenz(ah)anthracene	8.E-18	4.E-18	1.E-18	3.E-19	5.E-20	1.E-16	4.E-17	1.E-17	2.E-18	3.E-19	2.E-16	6.E-17	2.E-17	4.E-18	6.E-19
Dibromochloromethane	4.E-11	3.E-11	4.E-12	7.E-13	3.E-14	3.E-10	9.E-11	7.E-12	8.E-13	2.E-14	3.E-10	8.E-11	8.E-12	7.E-13	2.E-14
Dichlorobenzene (1,4)	3.E-13	1.E-13	2.E-14	2.E-15	8.E-17	3.E-12	6.E-13	4.E-14	4.E-15	1.E-16	3.E-12	5.E-13	5.E-14	4.E-15	8.E-17
Dichlorobenzidine	3.E-15	1.E-15	3.E-16	7.E-17	1.E-17	4.E-14	1.E-14	3.E-15	7.E-16	1.E-16	6.E-14	2.E-14	6.E-15	1.E-15	2.E-16
Dichloroethane (1,2)	2.E-10	5.E-11	4.E-12	3.E-13	8.E-15	1.E-09	2.E-10	9.E-12	6.E-13	1.E-14	2.E-09	2.E-10	1.E-11	6.E-13	8.E-15
Dichloromethane	1.E-11	4.E-12	2.E-13	2.E-14	3.E-16	1.E-10	1.E-11	5.E-13	2.E-14	3.E-16	1.E-10	1.E-11	6.E-13	2.E-14	2.E-16
Dieldrin	3.E-13	2.E-13	8.E-14	3.E-14	6.E-15	4.E-12	3.E-12	8.E-13	3.E-13	6.E-14	6.E-12	4.E-12	1.E-12	5.E-13	1.E-13
Diphenylhydrazine	2.E-14	6.E-15	1.E-15	2.E-16	2.E-17	3.E-13	7.E-14	1.E-14	2.E-15	2.E-16	4.E-13	1.E-13	2.E-14	4.E-15	4.E-16
Heptachlor-epoxide	4.E-13	3.E-13	1.E-13	5.E-14	1.E-14	6.E-12	4.E-12	1.E-12	4.E-13	8.E-14	9.E-12	6.E-12	2.E-12	7.E-13	1.E-13
Indeno(1,2,3-cd)pyrene	8.E-18	4.E-18	1.E-18	3.E-19	5.E-20	1.E-16	5.E-17	1.E-17	2.E-18	3.E-19	2.E-16	7.E-17	2.E-17	4.E-18	6.E-19
Polychlorinated Biphenyls (As Aroclor 1254)	1.E-13	9.E-14	3.E-14	9.E-15	1.E-15	2.E-12	9.E-13	2.E-13	7.E-14	9.E-15	2.E-12	1.E-12	4.E-13	1.E-13	1.E-14
Tetrachloroethene	8.E-13	5.E-13	6.E-14	9.E-15	2.E-16	7.E-12	2.E-12	9.E-14	8.E-15	2.E-16	8.E-12	1.E-12	1.E-13	7.E-15	1.E-16
Trichloroethene	1.E-11	6.E-12	5.E-13	6.E-14	1.E-15	1.E-10	2.E-11	9.E-13	6.E-14	1.E-15	1.E-10	2.E-11	1.E-12	6.E-14	7.E-16

Table 13-16. Calculated risks from organic cancer hazards assuming POOR RO removal – inhalation of air above river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**
Acrylonitrile	4.E-10	5.E-11	2.E-12	1.E-13	3.E-15	5.E-09	4.E-10	2.E-11	7.E-13	1.E-14	7.E-09	5.E-10	2.E-11	1.E-12	2.E-14
Aldrin	6.E-12	4.E-12	1.E-12	5.E-13	1.E-13	8.E-11	4.E-11	1.E-11	4.E-12	7.E-13	1.E-10	6.E-11	2.E-11	6.E-12	1.E-12
Atrazine	4.E-16	2.E-16	4.E-17	8.E-18	1.E-18	7.E-15	2.E-15	4.E-16	7.E-17	9.E-18	1.E-14	3.E-15	7.E-16	1.E-16	2.E-17
Benz(a)anthracene	6.E-14	3.E-14	6.E-15	1.E-15	2.E-16	9.E-13	3.E-13	6.E-14	1.E-14	1.E-15	1.E-12	5.E-13	1.E-13	2.E-14	3.E-15
Benzene	5.E-11	1.E-11	7.E-13	5.E-14	8.E-16	4.E-10	4.E-11	1.E-12	6.E-14	7.E-16	5.E-10	4.E-11	2.E-12	5.E-14	5.E-16
Benzene Hexachloride (Alpha)	3.E-13	2.E-13	5.E-14	1.E-14	2.E-15	5.E-12	2.E-12	6.E-13	1.E-13	2.E-14	7.E-12	3.E-12	1.E-12	3.E-13	4.E-14
Benzo(a)pyrene	9.E-14	4.E-14	1.E-14	3.E-15	4.E-16	1.E-12	5.E-13	1.E-13	2.E-14	3.E-15	2.E-12	7.E-13	2.E-13	4.E-14	5.E-15
Benzo(b)fluoranthene	7.E-15	3.E-15	9.E-16	2.E-16	3.E-17	1.E-13	4.E-14	9.E-15	2.E-15	3.E-16	2.E-13	6.E-14	2.E-14	3.E-15	5.E-16
Carbon Tetrachloride	2.E-11	1.E-11	1.E-12	2.E-13	4.E-15	2.E-10	3.E-11	2.E-12	2.E-13	3.E-15	2.E-10	3.E-11	2.E-12	1.E-13	2.E-15
Chloroform	1.E-09	5.E-10	4.E-11	5.E-12	1.E-13	1.E-08	2.E-09	8.E-11	5.E-12	8.E-14	1.E-08	2.E-09	9.E-11	4.E-12	5.E-14
Dibenz(ah)anthracene	8.E-17	4.E-17	1.E-17	3.E-18	5.E-19	1.E-15	4.E-16	1.E-16	2.E-17	3.E-18	2.E-15	6.E-16	2.E-16	4.E-17	6.E-18
Dibromochloromethane	4.E-10	3.E-10	4.E-11	7.E-12	3.E-13	3.E-09	9.E-10	7.E-11	8.E-12	2.E-13	3.E-09	8.E-10	8.E-11	7.E-12	2.E-13
Dichlorobenzene (1,4)	3.E-12	1.E-12	2.E-13	2.E-14	8.E-16	3.E-11	6.E-12	4.E-13	4.E-14	1.E-15	3.E-11	5.E-12	5.E-13	4.E-14	8.E-16
Dichlorobenzidine	3.E-14	1.E-14	3.E-15	7.E-16	1.E-16	4.E-13	1.E-13	3.E-14	7.E-15	1.E-15	6.E-13	2.E-13	6.E-14	1.E-14	2.E-15
Dichloroethane (1,2)	2.E-10	5.E-11	4.E-12	4.E-13	9.E-15	2.E-09	2.E-10	1.E-11	6.E-13	1.E-14	2.E-09	2.E-10	1.E-11	6.E-13	9.E-15
Dichloromethane	2.E-11	4.E-12	3.E-13	2.E-14	4.E-16	1.E-10	2.E-11	5.E-13	3.E-14	3.E-16	2.E-10	1.E-11	6.E-13	2.E-14	2.E-16
Dieldrin	3.E-12	2.E-12	8.E-13	3.E-13	6.E-14	4.E-11	3.E-11	8.E-12	3.E-12	6.E-13	6.E-11	4.E-11	1.E-11	5.E-12	1.E-12
Diphenylhydrazine	2.E-13	6.E-14	1.E-14	2.E-15	2.E-16	3.E-12	7.E-13	1.E-13	2.E-14	2.E-15	4.E-12	1.E-12	2.E-13	4.E-14	4.E-15
Heptachlor-epoxide	4.E-12	3.E-12	1.E-12	5.E-13	1.E-13	6.E-11	4.E-11	1.E-11	4.E-12	8.E-13	9.E-11	6.E-11	2.E-11	7.E-12	1.E-12
Indeno(1,2,3-cd)pyrene	8.E-17	4.E-17	1.E-17	3.E-18	5.E-19	1.E-15	5.E-16	1.E-16	2.E-17	3.E-18	2.E-15	7.E-16	2.E-16	4.E-17	6.E-18
Polychlorinated Biphenyls (As Aroclor 1254)	1.E-12	9.E-13	3.E-13	9.E-14	1.E-14	2.E-11	9.E-12	2.E-12	7.E-13	9.E-14	2.E-11	1.E-11	4.E-12	1.E-12	1.E-13
Tetrachloroethene	8.E-12	5.E-12	6.E-13	9.E-14	2.E-15	7.E-11	2.E-11	9.E-13	8.E-14	2.E-15	8.E-11	1.E-11	1.E-12	7.E-14	1.E-15
Trichloroethene	1.E-10	6.E-11	5.E-12	6.E-13	1.E-14	1.E-09	2.E-10	9.E-12	6.E-13	1.E-14	1.E-09	2.E-10	1.E-11	6.E-13	7.E-15

Table 13-17. Calculated risks from organic cancer hazards assuming GOOD RO removal – sum of all recreational exposures

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	5.E-10	5.E-11	2.E-12	1.E-13	3.E-15	6.E-09	4.E-10	2.E-11	7.E-13	2.E-14	7.E-09	5.E-10	2.E-11	1.E-12	2.E-14
Aldrin	6.E-09	2.E-09	8.E-10	3.E-10	9.E-11	8.E-08	2.E-08	7.E-09	2.E-09	6.E-10	1.E-07	3.E-08	1.E-08	3.E-09	9.E-10
Atrazine	8.E-13	2.E-13	4.E-14	8.E-15	2.E-15	1.E-11	2.E-12	4.E-13	8.E-14	2.E-14	2.E-11	4.E-12	8.E-13	1.E-13	3.E-14
Benz(a)anthracene	8.E-10	2.E-10	5.E-11	1.E-11	2.E-12	1.E-08	3.E-09	5.E-10	9.E-11	2.E-11	2.E-08	4.E-09	8.E-10	2.E-10	3.E-11
Benzene	5.E-11	1.E-11	7.E-13	5.E-14	9.E-16	5.E-10	4.E-11	1.E-12	6.E-14	8.E-16	5.E-10	4.E-11	2.E-12	5.E-14	5.E-16
Benzene Hexachloride (Alpha)	2.E-11	5.E-12	1.E-12	4.E-13	1.E-13	2.E-10	6.E-11	1.E-11	4.E-12	1.E-12	3.E-10	9.E-11	3.E-11	7.E-12	2.E-12
Benzo(a)pyrene	2.E-08	4.E-09	1.E-09	2.E-10	6.E-11	2.E-07	5.E-08	1.E-08	2.E-09	5.E-10	3.E-07	7.E-08	2.E-08	4.E-09	8.E-10
Benzo(b)fluoranthene	1.E-09	3.E-10	6.E-11	2.E-11	4.E-12	1.E-08	3.E-09	7.E-10	1.E-10	3.E-11	2.E-08	5.E-09	1.E-09	2.E-10	6.E-11
Carbon Tetrachloride	3.E-12	1.E-12	1.E-13	2.E-14	6.E-16	2.E-11	4.E-12	2.E-13	2.E-14	4.E-16	3.E-11	3.E-12	2.E-13	1.E-14	3.E-16
Chloroform	2.E-10	7.E-11	6.E-12	6.E-13	1.E-14	1.E-09	2.E-10	1.E-11	6.E-13	1.E-14	2.E-09	2.E-10	1.E-11	6.E-13	6.E-15
Dibenz(ah)anthracene	3.E-08	8.E-09	2.E-09	5.E-10	1.E-10	4.E-07	9.E-08	2.E-08	4.E-09	1.E-09	5.E-07	1.E-07	3.E-08	7.E-09	2.E-09
Dibromochloromethane	4.E-11	3.E-11	4.E-12	7.E-13	3.E-14	3.E-10	9.E-11	7.E-12	8.E-13	2.E-14	4.E-10	8.E-11	8.E-12	7.E-13	2.E-14
Dichlorobenzene (1,4)	6.E-13	2.E-13	2.E-14	3.E-15	1.E-16	6.E-12	8.E-13	5.E-14	5.E-15	2.E-16	7.E-12	7.E-13	6.E-14	5.E-15	2.E-16
Dichlorobenzidine	9.E-11	2.E-11	6.E-12	1.E-12	4.E-13	1.E-09	3.E-10	7.E-11	1.E-11	3.E-12	2.E-09	5.E-10	1.E-10	3.E-11	7.E-12
Dichloroethane (1,2)	2.E-10	5.E-11	4.E-12	3.E-13	9.E-15	2.E-09	2.E-10	9.E-12	6.E-13	1.E-14	2.E-09	2.E-10	1.E-11	6.E-13	8.E-15
Dichloromethane	2.E-11	4.E-12	3.E-13	2.E-14	4.E-16	1.E-10	1.E-11	5.E-13	2.E-14	3.E-16	2.E-10	1.E-11	6.E-13	2.E-14	2.E-16
Dieldrin	8.E-10	3.E-10	1.E-10	4.E-11	2.E-11	1.E-08	4.E-09	1.E-09	4.E-10	1.E-10	2.E-08	6.E-09	2.E-09	7.E-10	2.E-10
Diphenylhydrazine	4.E-11	8.E-12	1.E-12	3.E-13	5.E-14	6.E-10	1.E-10	2.E-11	2.E-12	5.E-13	1.E-09	2.E-10	3.E-11	5.E-12	9.E-13
Heptachlor-epoxide	3.E-10	1.E-10	4.E-11	2.E-11	6.E-12	4.E-09	1.E-09	4.E-10	1.E-10	5.E-11	6.E-09	2.E-09	7.E-10	2.E-10	8.E-11
Indeno(1,2,3-cd)pyrene	3.E-09	9.E-10	2.E-10	6.E-11	1.E-11	4.E-08	9.E-09	2.E-09	4.E-10	1.E-10	5.E-08	1.E-08	3.E-09	7.E-10	2.E-10
Polychlorinated Biphenyls (As Aroclor 1254)	2.E-09	7.E-10	2.E-10	7.E-11	2.E-11	3.E-08	7.E-09	2.E-09	5.E-10	1.E-10	4.E-08	1.E-08	3.E-09	7.E-10	2.E-10
Tetrachloroethene	1.E-11	3.E-12	2.E-13	3.E-14	4.E-15	1.E-10	8.E-12	4.E-13	3.E-14	3.E-15	1.E-10	7.E-12	5.E-13	3.E-14	2.E-15
Trichloroethene	1.E-11	6.E-12	5.E-13	6.E-14	2.E-15	1.E-10	2.E-11	9.E-13	7.E-14	1.E-15	1.E-10	2.E-11	1.E-12	6.E-14	8.E-16

Table 13-18. Calculated risks from organic cancer hazards assuming POOR RO removal – sum of all recreational exposures

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Acrylonitrile	5.E-10	5.E-11	3.E-12	1.E-13	3.E-15	6.E-09	4.E-10	2.E-11	7.E-13	2.E-14	8.E-09	6.E-10	3.E-11	1.E-12	2.E-14
Aldrin	6.E-08	2.E-08	8.E-09	3.E-09	9.E-10	8.E-07	2.E-07	7.E-08	2.E-08	6.E-09	**1.E-06**	3.E-07	1.E-07	3.E-08	9.E-09
Atrazine	8.E-12	2.E-12	4.E-13	8.E-14	2.E-14	1.E-10	2.E-11	4.E-12	8.E-13	2.E-13	2.E-10	4.E-11	8.E-12	1.E-12	3.E-13
Benz(a)anthracene	8.E-09	2.E-09	5.E-10	1.E-10	2.E-11	1.E-07	3.E-08	5.E-09	9.E-10	2.E-10	2.E-07	4.E-08	8.E-09	2.E-09	3.E-10
Benzene	6.E-11	1.E-11	7.E-13	5.E-14	9.E-16	5.E-10	5.E-11	1.E-12	6.E-14	8.E-16	6.E-10	4.E-11	2.E-12	6.E-14	6.E-16
Benzene Hexachloride (Alpha)	2.E-10	5.E-11	1.E-11	4.E-12	1.E-12	2.E-09	6.E-10	1.E-10	4.E-11	1.E-11	3.E-09	9.E-10	3.E-10	7.E-11	2.E-11
Benzo(a)pyrene	2.E-07	4.E-08	1.E-08	2.E-09	6.E-10	**2.E-06**	5.E-07	1.E-07	2.E-08	5.E-09	**3.E-06**	7.E-07	2.E-07	4.E-08	8.E-09
Benzo(b)fluoranthene	1.E-08	3.E-09	6.E-10	2.E-10	4.E-11	1.E-07	3.E-08	7.E-09	1.E-09	3.E-10	2.E-07	5.E-08	1.E-08	2.E-09	6.E-10
Carbon Tetrachloride	3.E-11	1.E-11	1.E-12	2.E-13	6.E-15	2.E-10	4.E-11	2.E-12	2.E-13	4.E-15	3.E-10	3.E-11	2.E-12	1.E-13	3.E-15
Chloroform	1.E-09	5.E-10	4.E-11	5.E-12	1.E-13	1.E-08	2.E-09	8.E-11	5.E-12	8.E-14	1.E-08	2.E-09	9.E-11	4.E-12	5.E-14
Dibenz(ah)anthracene	3.E-07	8.E-08	2.E-08	5.E-09	1.E-09	**4.E-06**	9.E-07	2.E-07	4.E-08	1.E-08	**5.E-06**	**1.E-06**	3.E-07	7.E-08	2.E-08
Dibromochloromethane	4.E-10	3.E-10	4.E-11	7.E-12	3.E-13	3.E-09	9.E-10	7.E-11	8.E-12	2.E-13	4.E-09	8.E-10	8.E-11	7.E-12	2.E-13
Dichlorobenzene (1,4)	6.E-12	2.E-12	2.E-13	3.E-14	1.E-15	6.E-11	8.E-12	5.E-13	5.E-14	2.E-15	7.E-11	7.E-12	6.E-13	5.E-14	2.E-15
Dichlorobenzidine	9.E-10	2.E-10	6.E-11	1.E-11	4.E-12	1.E-08	3.E-09	7.E-10	1.E-10	3.E-11	2.E-08	5.E-09	1.E-09	3.E-10	7.E-11
Dichloroethane (1,2)	2.E-10	5.E-11	4.E-12	4.E-13	1.E-14	2.E-09	2.E-10	1.E-11	6.E-13	1.E-14	2.E-09	2.E-10	1.E-11	6.E-13	9.E-15
Dichloromethane	2.E-11	5.E-12	3.E-13	2.E-14	4.E-16	2.E-10	2.E-11	6.E-13	3.E-14	4.E-16	2.E-10	1.E-11	7.E-13	2.E-14	3.E-16
Dieldrin	8.E-09	3.E-09	1.E-09	4.E-10	2.E-10	1.E-07	4.E-08	1.E-08	4.E-09	1.E-09	2.E-07	6.E-08	2.E-08	7.E-09	2.E-09
Diphenylhydrazine	4.E-10	8.E-11	1.E-11	3.E-12	5.E-13	6.E-09	1.E-09	2.E-10	2.E-11	5.E-12	1.E-08	2.E-09	3.E-10	5.E-11	9.E-12
Heptachlor-epoxide	3.E-09	1.E-09	4.E-10	2.E-10	6.E-11	4.E-08	1.E-08	4.E-09	1.E-09	5.E-10	6.E-08	2.E-08	7.E-09	2.E-09	8.E-10
Indeno(1,2,3-cd)pyrene	3.E-08	9.E-09	2.E-09	6.E-10	1.E-10	4.E-07	9.E-08	2.E-08	4.E-09	1.E-09	5.E-07	1.E-07	3.E-08	7.E-09	2.E-09
Polychlorinated Biphenyls (As Aroclor 1254)	2.E-08	7.E-09	2.E-09	7.E-10	2.E-10	3.E-07	7.E-08	2.E-08	5.E-09	1.E-09	4.E-07	1.E-07	3.E-08	7.E-09	2.E-09
Tetrachloroethene	1.E-10	3.E-11	2.E-12	3.E-13	4.E-14	1.E-09	8.E-11	4.E-12	3.E-13	3.E-14	1.E-09	7.E-11	5.E-12	3.E-13	2.E-14
Trichloroethene	1.E-10	6.E-11	5.E-12	6.E-13	2.E-14	1.E-09	2.E-10	9.E-12	7.E-13	1.E-14	1.E-09	2.E-10	1.E-11	6.E-13	8.E-15

Note: Bolded values equal or exceed the 10^{-6} benchmark.

Table 13-19. Calculated hazard quotients from organic noncancer hazards assuming GOOD RO removal – oral ingestion of river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Total Chloramines (as monochloramine)	9.E-08	5.E-09	3.E-10	1.E-11	6.E-13	1.E-06	6.E-08	3.E-09	1.E-10	6.E-12	2.E-06	1.E-07	5.E-09	2.E-10	1.E-11

Table 13-20. Calculated hazard quotients from organic noncancer hazards assuming POOR RO removal – oral ingestion of river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Total Chloramines (as monochloramine)	1.E-07	6.E-09	3.E-10	1.E-11	7.E-13	2.E-06	7.E-08	3.E-09	1.E-10	7.E-12	2.E-06	1.E-07	6.E-09	3.E-10	1.E-11

Table 13-21. Calculated hazard quotients from organic noncancer hazards assuming GOOD RO removal – dermal exposure to river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Total Chloramines (as monochloramine)	6.E-09	3.E-10	2.E-11	8.E-13	4.E-14	9.E-08	4.E-09	2.E-10	8.E-12	4.E-13	1.E-07	7.E-09	3.E-10	2.E-11	8.E-13

Table 13-22. Calculated hazard quotients from organic noncancer hazards assuming POOR RO removal – dermal exposure to river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Total Chloramines (as monochloramine)	7.E-09	4.E-10	2.E-11	9.E-13	5.E-14	1.E-07	5.E-09	2.E-10	9.E-12	4.E-13	2.E-07	8.E-09	4.E-10	2.E-11	9.E-13

Table 13-23. Calculated hazard quotients from organic noncancer hazards assuming GOOD RO removal – dermal exposure to river mud (sediment)

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Total Chloramines (as monochloramine)	4.E-08	2.E-09	1.E-10	6.E-12	3.E-13	7.E-07	3.E-08	1.E-09	6.E-11	3.E-12	1.E-06	5.E-08	2.E-09	1.E-10	6.E-12

Table 13-24. Calculated hazard quotients from organic noncancer hazards assuming POOR RO removal – dermal exposure to river mud (sediment)

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Total Chloramines (as monochloramine)	5.E-08	3.E-09	1.E-10	6.E-12	3.E-13	7.E-07	3.E-08	1.E-09	6.E-11	3.E-12	1.E-06	5.E-08	3.E-09	1.E-10	6.E-12

Table 13-25. Calculated hazard quotients from organic noncancer hazards assuming GOOD RO removal – inhalation of air above river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Total Chloramines (as monochloramine)	2.E-25	2.E-26	8.E-28	4.E-29	1.E-30	2.E-24	2.E-25	9.E-27	4.E-28	1.E-29	4.E-24	3.E-25	2.E-26	7.E-28	2.E-29

Table 13-26. Calculated hazard quotients from organic noncancer hazards assuming POOR RO removal – inhalation of air above river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Total Chloramines (as monochloramine)	2.E-25	2.E-26	9.E-28	4.E-29	1.E-30	3.E-24	2.E-25	1.E-26	4.E-28	1.E-29	4.E-24	3.E-25	2.E-26	8.E-28	2.E-29

Table 13-27. Calculated hazard quotients from organic noncancer hazards assuming GOOD RO removal – sum of all recreational exposures

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Total Chloramines (as monochloramine)	1.E-07	8.E-09	4.E-10	2.E-11	1.E-12	2.E-06	1.E-07	4.E-09	2.E-10	9.E-12	3.E-06	2.E-07	8.E-09	4.E-10	2.E-11

Table 13-28. Calculated hazard quotients from organic noncancer hazards assuming POOR RO removal – sum of all recreational exposures

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Total Chloramines (as monochloramine)	2.E-07	9.E-09	4.E-10	2.E-11	1.E-12	2.E-06	1.E-07	5.E-09	2.E-10	1.E-11	4.E-06	2.E-07	9.E-09	4.E-10	2.E-11

Table 13-29. Calculated risks from inorganic cancer hazards assuming GOOD RO removal – oral ingestion of river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Arsenic	1.E-10	1.E-10	1.E-10	1.E-10	1.E-10	2.E-09	2.E-09	1.E-09	1.E-09	1.E-09	3.E-09	3.E-09	2.E-09	2.E-09	2.E-09

Table 13-30. Calculated risks from inorganic cancer hazards assuming POOR RO removal – oral ingestion of river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Arsenic	1.E-10	1.E-10	1.E-10	1.E-10	1.E-10	2.E-09	2.E-09	1.E-09	1.E-09	1.E-09	3.E-09	3.E-09	2.E-09	2.E-09	2.E-09

Table 13-31. Calculated risks from inorganic cancer hazards assuming GOOD RO removal – dermal exposure to river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Arsenic	4.E-11	5.E-11	5.E-11	4.E-11	4.E-11	7.E-10	6.E-10	5.E-10	4.E-10	4.E-10	1.E-09	9.E-10	9.E-10	8.E-10	8.E-10

Table 13-32. Calculated risks from inorganic cancer hazards assuming POOR RO removal – dermal exposure to river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Arsenic	4.E-11	5.E-11	5.E-11	4.E-11	4.E-11	7.E-10	6.E-10	5.E-10	4.E-10	4.E-10	1.E-09	9.E-10	9.E-10	8.E-10	8.E-10

Table 13-33. Calculated risks from inorganic cancer hazards assuming GOOD RO removal – sum of recreational exposures

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Arsenic	2.E-10	2.E-10	2.E-10	2.E-10	2.E-10	3.E-09	2.E-09	2.E-09	2.E-09	2.E-09	4.E-09	4.E-09	3.E-09	3.E-09	3.E-09

Table 13-34. Calculated risks from inorganic cancer hazards assuming POOR RO removal – sum of recreational exposures

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Arsenic	2.E-10	2.E-10	2.E-10	2.E-10	2.E-10	3.E-09	2.E-09	2.E-09	2.E-09	2.E-09	4.E-09	4.E-09	3.E-09	3.E-09	3.E-09

Table 13-35. Calculated hazard quotients from inorganic cancer hazards assuming GOOD RO removal – oral ingestion of river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Hydrogen Sulphide (un-ionised)	4.E-06	4.E-06	4.E-06	4.E-06	4.E-06	6.E-05	5.E-05	4.E-05	4.E-05	4.E-05	9.E-05	8.E-05	8.E-05	7.E-05	7.E-05
Nickel	1.E-09	1.E-09	1.E-09	1.E-09	1.E-09	2.E-08	1.E-08	1.E-08	9.E-09	9.E-09	2.E-08	2.E-08	2.E-08	2.E-08	2.E-08

Table 13-36. Calculated hazard quotients from inorganic cancer hazards assuming POOR RO removal – oral ingestion of river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Hydrogen Sulphide (un-ionised)	4.E-06	5.E-06	4.E-06	4.E-06	4.E-06	6.E-05	6.E-05	5.E-05	4.E-05	4.E-05	1.E-04	9.E-05	9.E-05	8.E-05	8.E-05
Nickel	1.E-08	1.E-08	1.E-08	1.E-08	1.E-08	2.E-07	1.E-07	1.E-07	9.E-08	9.E-08	2.E-07	2.E-07	2.E-07	2.E-07	2.E-07

Table 13-37. Calculated hazard quotients from inorganic cancer hazards assuming GOOD RO removal – dermal exposure to river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Hydrogen Sulphide (un-ionised)	2.E-05	2.E-05	2.E-05	1.E-05	1.E-05	2.E-04	2.E-04	2.E-04	1.E-04	1.E-04	3.E-04	3.E-04	3.E-04	3.E-04	3.E-04
Nickel	2.E-09	2.E-09	2.E-09	2.E-09	2.E-09	3.E-08	2.E-08	2.E-08	2.E-08	2.E-08	4.E-08	4.E-08	4.E-08	3.E-08	3.E-08

Table 13-38. Calculated hazard quotients from inorganic cancer hazards assuming POOR RO removal – dermal exposure to river water

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Hydrogen Sulphide (un-ionised)	2.E-05	2.E-05	2.E-05	2.E-05	2.E-05	3.E-04	2.E-04	2.E-04	2.E-04	2.E-04	4.E-04	4.E-04	3.E-04	3.E-04	3.E-04

Nickel	2.E-08	2.E-08	2.E-08	2.E-08	2.E-08	3.E-07	2.E-07	2.E-07	2.E-07	2.E-07	4.E-07	4.E-07	4.E-07	3.E-07	3.E-07

Table 13-39. Calculated hazard quotients from inorganic cancer hazards assuming GOOD RO removal – sum of recreational pathways

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Hydrogen Sulphide (un-ionised)	2.E-05	2.E-05	2.E-05	2.E-05	2.E-05	3.E-04	3.E-04	2.E-04	2.E-04	2.E-04	4.E-04	4.E-04	4.E-04	3.E-04	3.E-04
Nickel	3.E-09	3.E-09	3.E-09	3.E-09	3.E-09	4.E-08	4.E-08	3.E-08	3.E-08	3.E-08	6.E-08	6.E-08	6.E-08	5.E-08	5.E-08

Table 13-40. Calculated hazard quotients from inorganic cancer hazards assuming POOR RO removal – sum of recreational pathways

Flow Percentile:	20th (high flow)					50th (median flow)					80th (low flow)				
River Segment:	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Hydrogen Sulphide (un-ionised)	2.E-05	2.E-05	2.E-05	2.E-05	2.E-05	3.E-04	3.E-04	2.E-04	2.E-04	2.E-04	5.E-04	4.E-04	4.E-04	4.E-04	4.E-04
Nickel	3.E-08	3.E-08	3.E-08	3.E-08	3.E-08	4.E-07	4.E-07	3.E-07	3.E-07	3.E-07	6.E-07	6.E-07	6.E-07	5.E-07	5.E-07

13.1.3 Exposure via irrigated soil

The hypothetical soil-irrigation scenario was designed to describe a relatively intensive irrigation operation. However, since children are generally accepted to be at risk of greater (relative) exposure to soils than adults, the risk calculations assume that the irrigated area is very close to a residential property, providing the possibility of significant exposure to a small child. Carcinogenic risks associated with exposure to contaminants in soil were calculated using age-adjusted exposure factors as recommended by the US EPA (US Environmental Protection Agency 1991). Hazard quotients associated with noncarcinogenic contaminants in soil were calculated assuming exposure to children for a period of 6 years (US Environmental Protection Agency 2004c).

Risks from oral ingestion of carcinogenic contaminants in irrigated soil were calculated using Equation 13-11. The calculation assumes exposure during each of 350 days per year for a period of 30 years (ingesting 200 mg of soil per day age 1-6 and 100 mg per day age 7-31).

$$\text{Risk (R)} = \frac{C_s\ (\text{mg/kg}) \times EF_r \times IFS_{adj} \times CSF_o}{AT_c \times 365\ \text{days/year} \times 10^6\ \text{mg/kg}}$$

Equation 13-11. Calculated risk from ingestion exposure to carcinogenic contaminants in irrigated soil

Symbol	Definition (units)	Default	References
C_s	Contaminant exposure concentration in soil ($mg.kg^{-1}$)	-	
CSF_o	Cancer slope factor oral ($mg^{-1}.kg.day$)	-	(US Environmental Protection Agency 2004b; US Environmental Protection Agency 2006a; US Environmental Protection Agency 2006b; US Environmental Protection Agency 2006c; US Environmental Protection Agency 2006d)
AT_c	Averaging time – carcinogens (years)	70	(US Environmental Protection Agency 1989; US Environmental Protection Agency 1991)
EF_r	Exposure frequency – residential ($day.year^{-1}$)	350	(US Environmental Protection Agency 1989; US Environmental Protection Agency 1991)
IFS_{adj}	Age-adjusted ingestion factor, soils ($[mg\text{-}year].[kg\text{-}day]^{-1}$)	114	(US Environmental Protection Agency, 1989; US Environmental Protection Agency 1991)

Hazard quotients from oral ingestion of noncarcinogenic contaminants in irrigated soil were calculated using Equation 13-12. The calculation assumes exposure by a child during each of 350 days per year for a period of 6 years (ingesting 200 mg of soil per day).

$$HQ = \frac{C_s\ (\text{mg/kg}) \times EF_r \times ED_c \times IRS_c}{BW_c \times RfD_o \times AT_n \times 365\ \text{days/year} \times 10^6\ \text{mg/kg}}$$

Equation 13-12. Calculated hazard quotient from ingestion exposure to noncarcinogenic contaminants in irrigated soil

Symbol	Definition (units)	Default	References
C_s	Contaminant exposure concentration in soil ($mg.kg^{-1}$)	-	
RfD_o	Reference dose oral ($mg.kg^{-1}.day^{-1}$)	-	(US Environmental Protection Agency 2004b; US Environmental Protection Agency 2006a; US Environmental Protection Agency 2006b; US Environmental Protection Agency 2006c; US Environmental Protection Agency 2006d)
AT_n	Averaging time – noncarcinogens (years)	ED (6)	(US Environmental Protection Agency 1989; US Environmental Protection Agency 1991)
EF_r	Exposure frequency –	350	(US Environmental Protection Agency 1989; US Environmental

	residential (day.year^{-1})		Protection Agency 1991)
ED_c	Exposure duration – child (years)	6	(US Environmental Protection Agency 2004c)
IRS_c	Soil ingestion –child (mg.day^{-1})	200	(US Environmental Protection Agency 2004c)
BW_c	Body weight, child (kg)	15	(US Environmental Protection Agency 2004c)

Risks from dermal exposure of carcinogenic contaminants in irrigated soil were calculated using Equation 13-13. The calculation assumes exposure during each of 350 days per year for a period of 30 years (6 years as a child and 24 years as an adult).

$$\text{Risk (R)} = \frac{C_s\ (\text{mg/kg}) \times EF_r \times SFS_{adj} \times ABS_d \times CSF_o}{AT_c \times 365\ \text{days/year} \times 10^6\ \text{mg/kg}}$$

Equation 13-13. Calculated risk from dermal exposure to carcinogenic contaminants from irrigated soil

Symbol	Definition (units)	Default	References
C_s	Contaminant exposure concentration in soil (mg.kg^{-1})	-	
CSF_o	Cancer slope factor oral (mg^{-1}.kg.day)	-	(US Environmental Protection Agency 2004b; US Environmental Protection Agency 2006a; US Environmental Protection Agency 2006b; US Environmental Protection Agency 2006c; US Environmental Protection Agency 2006d)
AT_c	Averaging time – carcinogens (years)	70	(US Environmental Protection Agency 1989; US Environmental Protection Agency 1991)
EF_r	Exposure frequency – residential (day.year^{-1})	350	(US Environmental Protection Agency 1989; US Environmental Protection Agency 1991)
SFS_{adj}	Age-adjusted dermal factor, soils ([mg-year].[kg-day]$^{-1}$)	361	(US Environmental Protection Agency 2004c)
ABS_d	Dermal adsorption fraction	Chem.-specific	(US Environmental Protection Agency 2004a)

Hazard quotients from oral ingestion of noncarcinogenic contaminants in irrigated soil were calculated using Equation 13-14. The calculation assumes exposure by a child during each of 350 days per year for a period of 6 years.

$$HQ = \frac{C_s\ (\text{mg/kg}) \times EF_r \times ED_c \times SA_c \times AF_c \times ABS_d}{BW_c \times AT_n \times 365\ \text{days/year} \times RfD_o \times 10^6\ \text{mg/kg}}$$

Equation 13-14. Calculated hazard quotient from dermal exposure to noncarcinogenic contaminants from irrigated soil

Symbol	Definition (units)	Default	References
C_s	Contaminant exposure concentration in soil (mg.kg^{-1})	-	
RfD_o	Reference dose oral (mg.kg^{-1}.day^{-1})	-	(US Environmental Protection Agency, 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency, 2006b; US Environmental Protection Agency, 2006c; US Environmental Protection Agency, 2006d)
AT_n	Averaging time – noncarcinogens (years)	ED (6)	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)
EF_r	Exposure frequency – residential (day.year^{-1})	350	(US Environmental Protection Agency, 1989; US Environmental Protection Agency, 1991)
ED_c	Exposure duration – child (years)	6	(US Environmental Protection Agency, 2004c)
SA_c	Exposed surface area,	2800	(US Environmental Protection Agency, 2004a; US Environmental

	child in soil ($cm^2.day^{-1}$)		Protection Agency, 2004c)
AF_c	Adherence factor, child ($mg.cm^{-1}$)	0.2	(US Environmental Protection Agency, 2004a; US Environmental Protection Agency, 2004c)
ABS_d	Dermal adsorption fraction	Chem.-specific	(US Environmental Protection Agency, 2004a)
BW_c	Body weight, child (kg)	15	(US Environmental Protection Agency, 2004c)

Risks from inhalation of carcinogenic contaminants volatilised from irrigated soil were calculated using Equation 13-15. The calculation assumes exposure during each of 350 days per year for a period of 30 years (6 years as a child and 24 years as an adult).

$$\text{Risk (R)} = \frac{C_a\ (\mu g/m^3) \times EF_r \times InhF_{adj} \times CSF_i}{AT_c \times 365\ \text{days/year} \times 1000\ \mu g/mg}$$

Equation 13-15. Calculated risk from inhalation exposure to carcinogenic contaminants in air over irrigated soil

Symbol	Definition (units)	Default	References
C_a	Contaminant exposure concentration in air ($\mu g.m^3$)	-	
CSF_i	Cancer slope factor inhaled ($mg^{-1}.kg.day$)	-	(US Environmental Protection Agency, 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency, 2006b; US Environmental Protection Agency, 2006c; US Environmental Protection Agency, 2006d)
AT_c	Averaging time – carcinogens (years)	70	(US Environmental Protection Agency, 1989)
EF_r	Exposure frequency – residential ($day.year^{-1}$)	350	(US Environmental Protection Agency, 2004c)
$InfF_{adj}$	Age-adjusted inhalation factor, air ($[m^3\text{-year}].[kg\text{-day}]^{-1}$)	11	(US Environmental Protection Agency, 2004c)

Hazard quotients from inhalation of non-carcinogenic contaminants volatilised from irrigated soil were calculated using Equation 13-16. The calculation assumes exposure by a child during each of 350 days per year for a period of 6 years.

$$HQ = \frac{C_a\ (\mu g/m^3) \times EF_r \times ED_c \times IRA_c}{RfD_i \times BW_c \times AT_n \times 365\ \text{days/year} \times 1000\ \mu g/mg}$$

Equation 13-16. Calculated hazard quotients from inhalation exposure to noncarcinogenic contaminants in air over irrigated soil

Symbol	Definition (units)	Default	References
C_a	Contaminant exposure concentration in air ($\mu g.m^3$)	-	
RfD_i	Reference dose inhaled ($mg.kg^{-1}.day^{-1}$)	-	(US Environmental Protection Agency, 2004b; US Environmental Protection Agency, 2006a; US Environmental Protection Agency, 2006b; US Environmental Protection Agency, 2006c; US Environmental Protection Agency, 2006d)
BW_c	Body weight, child (kg)	15	(US Environmental Protection Agency, 2004c)
AT_n	Averaging time – noncarcinogens (years)	ED (6)	(US Environmental Protection Agency, 1989)
IRA_c	Inhalation rate – child ($m^3.day^{-1}$)	10	(US Environmental Protection Agency, 2004c)
EF_r	Exposure frequency – residential ($day.year^{-1}$)	350	(US Environmental Protection Agency, 2004c)
ED_c	Exposure duration – child	6	(US Environmental Protection Agency, 2004c)

(years)

Calculated cancer exposure risks (Table 13-41) and hazard quotients (Table 13-43) for organic chemicals in irrigated soil are provided below.

Table 13-41. Calculated risks from organic cancer hazards assuming GOOD and POOR RO removal – oral, dermal and inhalation exposure

Exposure route:	SOIL - ORAL						SOIL - DERMAL						AIR - INHALATION					
RO Performance:	GOOD			POOR			GOOD			POOR			GOOD			POOR		
Flow percentile:	20th	50th	80th	20th	50th	80th	20th	50th	80th	20th	50th	80th	20th	50th	80th	20th	50th	80th
Acrylonitrile	7.E-13	6.E-12	8.E-12	8.E-13	7.E-12	9.E-12	2.E-13	2.E-12	3.E-12	3.E-13	2.E-12	3.E-12	6.E-08	5.E-07	7.E-07	7.E-08	6.E-07	7.E-07
Aldrin	1.E-09	1.E-08	1.E-08	1.E-08	1.E-07	1.E-07	3.E-10	3.E-09	4.E-09	3.E-09	3.E-08	4.E-08	1.E-10	2.E-09	2.E-09	1.E-09	2.E-08	2.E-08
Atrazine	2.E-12	3.E-11	4.E-11	2.E-11	3.E-10	4.E-10	7.E-13	8.E-12	1.E-11	7.E-12	8.E-11	1.E-10	9.E-12	1.E-10	2.E-10	9.E-11	1.E-09	2.E-09
Benz(a)anthracene	1.E-10	1.E-09	2.E-09	1.E-09	1.E-08	2.E-08	4.E-11	5.E-10	8.E-10	4.E-10	5.E-09	8.E-09	7.E-12	8.E-11	1.E-10	7.E-11	8.E-10	1.E-09
Benzene	1.E-14	4.E-14	3.E-14	1.E-14	4.E-14	4.E-14	3.E-15	1.E-14	1.E-14	4.E-15	1.E-14	1.E-14	4.E-09	1.E-08	1.E-08	4.E-09	1.E-08	1.E-08
Benzene Hexachloride (Alpha)	3.E-11	4.E-10	7.E-10	3.E-10	4.E-09	7.E-09	1.E-11	1.E-10	2.E-10	1.E-10	1.E-09	2.E-09	3.E-10	3.E-09	6.E-09	3.E-09	3.E-08	6.E-08
Benzo(a)pyrene	1.E-09	2.E-08	2.E-08	1.E-08	2.E-07	2.E-07	6.E-10	7.E-09	1.E-08	6.E-09	7.E-08	1.E-07	2.E-11	3.E-10	4.E-10	2.E-10	3.E-09	4.E-09
Benzo(b)fluoranthene	1.E-10	2.E-09	2.E-09	1.E-09	2.E-08	2.E-08	6.E-11	7.E-10	1.E-09	6.E-10	7.E-09	1.E-08	4.E-12	5.E-11	8.E-11	4.E-11	5.E-10	8.E-10
Carbon Tetrachloride	6.E-16	2.E-15	2.E-15	6.E-15	2.E-14	2.E-14	2.E-16	6.E-16	5.E-16	2.E-15	6.E-15	5.E-15	3.E-10	9.E-10	8.E-10	3.E-09	9.E-09	8.E-09
Chloroform	1.E-15	4.E-15	4.E-15	1.E-14	3.E-14	3.E-14	4.E-16	1.E-15	1.E-15	3.E-15	1.E-14	9.E-15	2.E-08	6.E-08	5.E-08	2.E-07	5.E-07	4.E-07
Dibenz(ah)anthracene	2.E-09	2.E-08	3.E-08	2.E-08	2.E-07	3.E-07	8.E-10	8.E-09	1.E-08	8.E-09	8.E-08	1.E-07	2.E-13	2.E-12	3.E-12	2.E-12	2.E-11	3.E-11
Dibromochloromethane	2.E-14	6.E-14	6.E-14	2.E-13	6.E-13	6.E-13	6.E-15	2.E-14	2.E-14	6.E-14	2.E-13	2.E-13	8.E-09	3.E-08	2.E-08	8.E-08	3.E-07	2.E-07
Dichlorobenzene (1,4)	9.E-15	4.E-14	4.E-14	9.E-14	4.E-13	4.E-13	3.E-15	1.E-14	1.E-14	3.E-14	1.E-13	1.E-13	6.E-11	3.E-10	2.E-10	6.E-10	3.E-09	2.E-09
Dichlorobenzidine	3.E-10	4.E-09	6.E-09	3.E-09	4.E-08	6.E-08	9.E-11	1.E-09	2.E-09	9.E-10	1.E-08	2.E-08	5.E-10	6.E-09	1.E-08	5.E-09	6.E-08	1.E-07
Dichloroethane (1,2)	4.E-14	2.E-13	1.E-13	4.E-14	2.E-13	2.E-13	1.E-14	5.E-14	5.E-14	1.E-14	6.E-14	5.E-14	2.E-08	8.E-08	8.E-08	2.E-08	9.E-08	9.E-08
Dichloromethane	3.E-15	1.E-14	9.E-15	3.E-15	1.E-14	1.E-14	9.E-16	3.E-15	3.E-15	1.E-15	4.E-15	3.E-15	1.E-09	5.E-09	4.E-09	1.E-09	5.E-09	5.E-09
Dieldrin	7.E-10	9.E-09	1.E-08	7.E-09	9.E-08	1.E-07	2.E-10	3.E-09	4.E-09	2.E-09	3.E-08	4.E-08	7.E-10	8.E-09	1.E-08	7.E-09	8.E-08	1.E-07
Diphenylhydrazine	7.E-11	8.E-10	1.E-09	7.E-10	8.E-09	1.E-08	2.E-11	3.E-10	4.E-10	2.E-10	3.E-09	4.E-09	1.E-09	2.E-08	3.E-08	1.E-08	2.E-07	3.E-07
Heptachlor-epoxide	4.E-10	4.E-09	6.E-09	4.E-09	4.E-08	6.E-08	1.E-10	1.E-09	2.E-09	1.E-09	1.E-08	2.E-08	9.E-10	1.E-08	2.E-08	9.E-09	1.E-07	2.E-07
Indeno(1,2,3-cd)pyrene	2.E-10	2.E-09	3.E-09	2.E-09	2.E-08	3.E-08	8.E-11	8.E-10	1.E-09	8.E-10	8.E-09	1.E-08	1.E-13	2.E-12	2.E-12	1.E-12	2.E-11	2.E-11
Polychlorinated Biphenyls (As Aroclor 1254)	2.E-10	2.E-09	2.E-09	2.E-09	2.E-08	2.E-08	7.E-11	7.E-10	1.E-09	7.E-10	7.E-09	1.E-08	3.E-11	3.E-10	4.E-10	3.E-10	3.E-09	4.E-09
Tetrachloroethene	1.E-14	5.E-14	4.E-14	1.E-13	5.E-13	4.E-13	5.E-15	2.E-14	1.E-14	5.E-14	2.E-13	1.E-13	1.E-10	4.E-10	4.E-10	1.E-09	4.E-09	4.E-09
Trichloroethene	2.E-15	6.E-15	6.E-15	2.E-14	6.E-14	6.E-14	6.E-16	2.E-15	2.E-15	6.E-15	2.E-14	2.E-14	2.E-09	5.E-09	5.E-09	2.E-08	5.E-08	5.E-08

Table 13-42. Calculated risks from organic cancer hazards assuming GOOD and POOR RO removal – sum of exposure pathways

Exposure route:	TOTAL (soil-oral + soil-dermal + air-inhalation)					
RO Performance:	GOOD			POOR		
Flow percentile:	20th (high flow)	50th (median flow)	80th (low flow)	20th (high flow)	50th (median flow)	80th (low flow)
Acrylonitrile	6.E-08	5.E-07	7.E-07	7.E-08	6.E-07	7.E-07
Aldrin	1.E-09	1.E-08	2.E-08	1.E-08	1.E-07	2.E-07
Atrazine	1.E-11	1.E-10	2.E-10	1.E-10	1.E-09	2.E-09
Benz(a)anthracene	2.E-10	2.E-09	3.E-09	2.E-09	2.E-08	3.E-08
Benzene	4.E-09	1.E-08	1.E-08	4.E-09	1.E-08	1.E-08
Benzene Hexachloride (Alpha)	3.E-10	4.E-09	6.E-09	3.E-09	4.E-08	6.E-08
Benzo(a)pyrene	2.E-09	2.E-08	3.E-08	2.E-08	2.E-07	3.E-07
Benzo(b)fluoranthene	2.E-10	2.E-09	4.E-09	2.E-09	2.E-08	4.E-08
Carbon Tetrachloride	3.E-10	9.E-10	8.E-10	3.E-09	9.E-09	8.E-09
Chloroform	2.E-08	6.E-08	5.E-08	2.E-07	5.E-07	4.E-07
Dibenz(ah)anthracene	3.E-09	3.E-08	4.E-08	3.E-08	3.E-07	4.E-07
Dibromochloromethane	8.E-09	3.E-08	2.E-08	8.E-08	3.E-07	2.E-07
Dichlorobenzene (1,4)	6.E-11	3.E-10	2.E-10	6.E-10	3.E-09	2.E-09
Dichlorobenzidine	9.E-10	1.E-08	2.E-08	9.E-09	1.E-07	2.E-07
Dichloroethane (1,2)	2.E-08	8.E-08	8.E-08	2.E-08	9.E-08	9.E-08
Dichloromethane	1.E-09	5.E-09	4.E-09	1.E-09	5.E-09	5.E-09
Dieldrin	2.E-09	2.E-08	3.E-08	2.E-08	2.E-07	3.E-07
Diphenylhydrazine	1.E-09	2.E-08	3.E-08	1.E-08	2.E-07	3.E-07
Heptachlor-epoxide	1.E-09	2.E-08	2.E-08	1.E-08	2.E-07	2.E-07
Indeno(1,2,3-cd)pyrene	3.E-10	3.E-09	4.E-09	3.E-09	3.E-08	4.E-08
Polychlorinated Biphenyls (As Aroclor 1254)	3.E-10	3.E-09	4.E-09	3.E-09	3.E-08	4.E-08
Tetrachloroethene	1.E-10	4.E-10	4.E-10	1.E-09	4.E-09	4.E-09
Trichloroethene	2.E-09	5.E-09	5.E-09	2.E-08	5.E-08	5.E-08

Table 13-43. Calculated hazard quotients for organic noncancer hazards assuming GOOD and POOR RO removal– oral, dermal and inhalation exposure

Exposure route:	SOIL - ORAL						SOIL - DERMAL						AIR - INHALATION					
RO Performance:	GOOD			POOR			GOOD			POOR			GOOD			POOR		
Flow percentile:	20th	50th	80th	20th	50th	80th	20th	50th	80th	20th	50th	80th	20th	50th	80th	20th	50th	80th
Total Chloramines (as monochloramine)	2.E-08	3.E-07	4.E-07	2.E-08	3.E-07	5.E-07	6.E-09	7.E-08	1.E-07	7.E-09	8.E-08	1.E-07	1.E-21	1.E-20	2.E-20	1.E-21	1.E-20	2.E-20

Table 13-44. Calculated hazard quotients for organic noncancer hazards assuming GOOD and POOR RO removal– sum of exposure pathways

Exposure route:	TOTAL (soil-oral + soil-dermal + air-inhalation)					
RO Performance:	GOOD			POOR		
Flow percentile:	20th	50th	80th	20th	50th	80th
Total Chloramines (as monochloramine)	3.E-08	3.E-07	5.E-07	3.E-08	4.E-07	6.E-07

13.2 Interpretation of calculated risks and hazard quotients

A summary of the maximum risks for each of the 27 chemicals considered is shown in Table 13-45.

13.2.1 Non-Cancer Risks

Hazard quotients (for non-cancer risks) are easily interpreted as they are calculated as a simple ratio between calculated (predicted) exposure levels and exposure levels determined to be protective of human health. Therefore, they are interpreted according to whether they are greater than or less than the value of 1. Monochloramine, hydrogen sulphide and nickel were the only chemicals assessed in terms of their noncancer Hazard Quotient.

Calculated hazard quotients were less than 1 for all three of these chemicals under each of the three considered exposure scenarios (hydrogen sulphide and nickel were not considered for the irrigation scenario since these inorganic chemicals are suitable for the necessary fugacity modelling for non-water phases). Accordingly, no unacceptable concentrations of non-cancer-risk chemicals were identified.

13.2.2 Cancer Risks

Risk estimations for carcinogenic chemicals can be interpreted according to the accepted benchmark of a cancer risk of 1 in 10^6 (US Environmental Protection Agency 1989; US Environmental Protection Agency 1991). That is, risks are assumed to be negligible where calculated risk values are less than 10^{-6}.

Calculated risk values were less than 10^{-6} for all individual chemicals under the following exposure scenarios:

- **Oral consumption of drinking water; and**
- **Exposure via irrigated soils.**

A few chemicals were calculated to be equal to or slightly above the benchmark under some circumstances for the recreational exposure scenarios (Table 13-18). These were:

- Aldrin (river segment A under low flow conditions and assuming poor RO removal);
- Benzo(a)pyrene (river segments A under low or median flow conditions and assuming poor RO removal);
- Dibenz(ah)anthracene (river segment A under low or median flow conditions and segment B under low flow conditions and poor RO removal).

While these risks are calculated as the sum of four discrete pathways, it is clear that they are predominantly influenced by dermal contact with river mud (sediment) in river segments A and B (Table 13-14).

It is important to note, however, that the identified chemicals may not pose a problem in reality. All three risk estimate sets, with risks exceeding the 10^{-6} risk benchmark were calculated using detection limit values rather than actual 95th percentile concentrations. None of these three compounds, Aldrin, Benzo(a)pyrene and Dibenz(ah)anthracene was detected in the 75 samples (3 analytes x 25 measurements) assayed. It should also be noted that Aldrin has been banned for use in Australia. The overall risks posed by these chemicals were thus assessed as 'Low' to 'Moderate' (Table 11-1)**.**

Closely chemically related chemicals may often contribute to the same physiological toxic endpoints. Accordingly, risks with individual related chemicals are cumulative in nature and thus it is common practice for calculated risks to be summed.

The legitimacy of summing risks is, however, detracted from in circumstances where:

- Data is only available for a limited number of related chemicals that may be present in similar concentrations;
- Significant numbers of data points are below the analytical detection limit, thus preventing the possibility of adding meaningful concentrations.

Both of these criteria are applicable to the current chemical data-set and therefore, the cumulation of additive risks was not undertaken. This limitation is further identified in the uncertainties section of this report.

Table 13-45. Risk for Each Chemical Posing a Potential Concern for each Scenario Group

Contaminant of Potential Concern	**Scenario Group**					**Scenario of Concern**
	Domestic Consumption untreated water, Penrith	Domestic Consumption untreated water, North Richmond	Recreational Exposure Penrith	Recreational Exposure North Richmond	Exposure via irrigation of soils	
Acrylonitrile	[3]risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Aldrin	risk $<10^{-6}$	risk $<10^{-6}$	**risk = $1x10^{-6}$**	risk $<10^{-6}$	risk $<10^{-6}$	@ Poor removal & Low flow only
Arsenic	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Atrazine	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Benz(a)anthracene	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Benzene	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Benzene Hexachloride (Alpha)	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Benzo(a)pyrene	risk $<10^{-6}$	risk $<10^{-6}$	**risk 2-3 $x10^{-6}$**	risk $<10^{-6}$	risk $<10^{-6}$	@ Poor removal & Low or medium flow
Benzo(b) fluoranthene	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Carbon Tetrachloride	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Chloroform	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Dibenz(ah)anthracene	risk $<10^{-6}$	risk $<10^{-6}$	[1]**risk 1-5 $x10^{-6}$**	risk $<10^{-6}$	risk $<10^{-6}$	@ Poor removal & Low or medium flow
Dibromo chloromethane	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Dichlorobenzene (1,4)	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Dichlorobenzidine	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Dichloroethane (1,2)	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Dichloromethane	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Dieldrin	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Diphenylhydrazine	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Heptachlorepoxide	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Hydrogen Sulphide (unionised)[2]	[3]HQ<1	HQ<1	HQ<1	HQ<1	HQ<1	-

Indeno (1,2,3-cd) pyrene	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	
Nickel[2]	HQ<1	HQ<1	HQ<1	HQ<1	HQ<1	-
Polychlorinated Biphenyls	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Tetrachloroethene	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-
Total Chloramines (as monochloramine)[2]	HQ<1	HQ<1	HQ<1	HQ<1	HQ<1	-
Trichloroethene	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	risk $<10^{-6}$	-

Note:

1. Similar risk seen at Emu Plains 4 km north of this point. Further downstream all scenarios have risk $<10^{-6}$.
2. These chemicals did not pose a cancer concern so assessment of their significance is based on HQ estimation. For the other chemicals their cancer causing potential was of most concern and they are compared.
3. Risk or HQ value is the maximum or range for the 6 different scenarios considered - High flow+Good RO removal, High flow+Poor RO removal, Median flow+Good RO removal, Median flow+Poor RO removal, Low flow+Good RO removal, Low flow+Poor RO removal.

13.3 Risk matrix analysis

The final step in the risk assessment process involves interpretation and communication of risk assessment findings. In this study 'interpretation' means in practice converting the quantitative findings to clear conclusions on risks as far as the available information allows.

Quantitative data provide key data for the assessments of what hazardous events are important, what their likelihood is (Table 13-46) and what their consequences are (Table 13-47). This in turn will determine the 'level of risk' (Table 13-48).

Table 13-46. Qualitative measures of likelihood (from draft National Guidelines for water recycling)

Descriptor	Example description
Rare	May occur only in exceptional circumstances. May occur once in 100 years
Unlikely	Could occur within 20 years or in unusual circumstances
Possible	Might occur or should be expected to occur within a 5 to 10 year period
Likely	Will probably occur within the next 1 to 5 year period
Almost certain	Is expected to occur with a probability of multiple occurrences within a year

Table 13-47. Qualitative measures of consequence or impact (from draft National Guidelines for water recycling)

Descriptor	Example description
Insignificant	Insignificant impact or not detectable
Minor	Health – Minor impact for small population Environment – Potentially harmful to local ecosystem with local impacts contained to site
Moderate	Health – Minor impacts for large population Environment – Potential harmful to regional ecosystem with local impacts primarily contained to on-site
Major	Health – Major impacts for small population Environment – Potentially lethal to local ecosystem. Predominantly local, but potential for off-site impacts
Catastrophic	Health – Major impacts for large population Environment – Potentially lethal to regional ecosystem or threatened species. Widespread on-site

	and off-site impacts.

Table 13-48. Qualitative risk analysis matrix: level of risk (from draft National Guidelines for Water Recycling)

Likelihood	Consequences				
	Insignificant	**Minor**	**Moderate**	**Major**	**Catastrophic**
Rare	Low	Low	Low	Low	High
Unlikely	Low	Low	Moderate	High	Very High
Possible	Low	Moderate	High	Very High	Very High
Likely	Low	Moderate	High	Very High	Very High
Almost certain	Low	Moderate	High	Very High	Very High

Key exposure scenarios were assessed in terms of chemicals risks. Consequences of these risks were judged according to the benchmark of 10^{-6} for carcinogenic hazards. Those chemicals for which carcinogenic risk was determined to be less then this benchmark were assigned a consequence descriptor of 'negligible'. Those that were determined to be slightly above the benchmark (less than an order of magnitude greater) were assigned 'minor' consequences where a relatively small population is expected to be affected. It was not necessary to categorise more significant risks.

The highest calculated risks for the various assessed exposure scenarios are summarised and provided with qualitative risk-ratings in Table 13-49.

Table 13-49. Highest calculated risks for the various assessed exposure scenarios.

Exposure pathway	Assessment point	Scenario	Highest risk		Subjective assessment of scenario		
			Chemical	**Cancer risk**	**Consequences**	**Likelihood**	**Risk rating**
Direct drinking consumption of untreated water for domestic use	Penrith	High flow, Good RO removal	Acrylonitrile	9×10^{-9}	Insignificant	Possible	Low
		High flow, Poor RO removal	Acrylonitrile	1×10^{-8}	Insignificant	Possible	Low
		Median flow, Good RO removal	Acrylonitrile	1×10^{-7}	Insignificant	Possible	Low
		Median flow, Poor RO removal	Acrylonitrile	1×10^{-7}	Insignificant	Possible	Low
		Low flow, Good RO removal	Acrylonitrile	2×10^{-7}	Insignificant	Possible	Low
		Low flow, Poor RO removal	Acrylonitrile	2×10^{-7}	Insignificant	Possible	Low
Direct drinking consumption of untreated water for domestic use	North Richmond	High flow, Good RO removal	Dichloroben zidine	2×10^{-12}	Insignificant	Almost certain	Low
		High flow, Poor RO removal	Dichloroben zidine	2×10^{-11}	Insignificant	Possible	Low
		Median flow, Good RO removal	Dichloroben zidine	2×10^{-11}	Insignificant	Almost certain	Low
		Median flow, Poor RO removal	Dichloroben zidine	2×10^{-10}	Insignificant	Possible	Low
		Low flow, Good RO removal	Dichloroben zidine	3×10^{-11}	Insignificant	Almost certain	Low
		Low flow, Poor RO removal	Dichloroben zidine	3×10^{-10}	Insignificant	Possible	Low
Recreational Exposure	Penrith	High flow, Good RO removal	Dibenz(ah)a nthracene	3×10^{-8}	Insignificant	Possible	Low

Exposure pathway	Assessment point	Scenario	Highest risk		Subjective assessment of scenario		
			Chemical	Cancer risk	Consequences	Likelihood	Risk rating
		High flow, Poor RO removal	Dibenz(ah)anthracene	3×10^{-7}	Insignificant	Possible	Low
		Median flow, Good RO removal	Dibenz(ah)anthracene	4×10^{-7}	Insignificant	Possible	Low
		Median flow, Poor RO removal	Dibenz(ah)anthracene	4×10^{-6}	Minor	Possible	**Moderate**
		Low flow, Good RO removal	Dibenz(ah)anthracene	5×10^{-7}	Insignificant	Possible	Low
		Low flow, Poor RO removal	Dibenz(ah)anthracene	5×10^{-6}	Minor	Possible	**Moderate**
Recreational exposure	North Richmond	High flow, Good RO removal	Dibenz(ah)anthracene	1×10^{-10}	Insignificant	Almost certain	Low
		High flow, Poor RO removal	Dibenz(ah)anthracene	1×10^{-9}	Insignificant	Possible	Low
		Median flow, Good RO removal	Dibenz(ah)anthracene	1×10^{-9}	Insignificant	Almost certain	Low
		Median flow, Poor RO removal	Dibenz(ah)anthracene	1×10^{-8}	Insignificant	Possible	Low
		Low flow, Good RO removal	Dibenz(ah)anthracene	2×10^{-9}	Insignificant	Almost certain	Low
		Low flow, Poor RO removal	Dibenz(ah)anthracene	2×10^{-8}	Insignificant	Possible	Low
Exposure via irrigation of soils	Emu Plains	High flow, Good RO removal	Acrylonitrile	6×10^{-8}	Insignificant	Possible	Low
		High flow, Poor RO removal	Acrylonitrile	7×10^{-8}	Insignificant	Possible	Low
		Median flow, Good RO removal	Acrylonitrile	5×10^{-7}	Insignificant	Possible	Low
		Median flow, Poor RO removal	Acrylonitrile	6×10^{-7}	Insignificant	Possible	Low
		Low flow, Good RO removal	Acrylonitrile	7×10^{-7}	Insignificant	Possible	Low
		Low flow, Poor RO removal	Acrylonitrile	7×10^{-7}	Insignificant	Possible	Low

14 Uncertainties in Chemical Assessment

As in any risk assessment, uncertainties exist in all steps of the assessment process. In many cases, the quantitative uncertainties have been somewhat accounted for by assuming worst-case (or close to worst-case) scenarios. **A key conservative example here is the use of 95th percentile concentrations for many chemicals which had never been detected above their analytical detection limit and thus are possibly only present at significantly lower concentrations in tertiary treated wastewater.**

Characterisation of uncertainties is presented below according to the main sections of the analysis.

14.1 Hazard Assessment

14.1.1 Hazard identification

The hazard identification was limited first to chemicals for which historical quantitative data exists for the relevant sewage treatment plants. For this purpose, it was limited to the 111 organic and inorganic chemical parameters included in Schedule 10 monitoring activities. Schedule 10 monitoring was not undertaken for the purposes of providing data for chemical risk assessment of treated effluents and thus sampling regimes, analytical methods, and the range of analytes were not necessarily optimum for this purpose.

A very large number of data points for Schedule 10 chemicals were below the analytical detection limit. Accordingly, it was not appropriate to use arithmetic means for chemical concentrations (as is normal practice). Instead, the more conservative 95th percentile value was used. For the majority of chemicals (which were never detected above the detection limit), the 95th percentile concentration is simply equal to the analytical detection limit.

Other chemicals not included in Schedule 10 monitoring (as well as those without suitable toxicology data) could not be quantitatively assessed and thus represent some uncertainties for the chemical risk assessment. Important examples are expected to be endocrine disrupting chemicals (EDCs) and disinfection/biofouling control by-products

Protocols for EDCs risk assessments are the subject of current research efforts internationally. Until human toxicity thresholds have been established, a detailed risk assessment is unlikely to provide further insight into the risks associated with these substances. These will remain unresolved issues, which will need to be further monitored and risks re-assessed as new information emerges and our knowledge advances.

Toxic threshold data exists for many halogenated organic disinfection/biofouling control by-products such as trihalomethanes (see chloroform and dibromochloromethane in the 'dose-response' section of this report). However, the anticipated production of these contaminants is significantly dependant on precise design, operating conditions and influent water quality of the treatment plant. Until more information is available, it is not possible to realistically assess the formation potential of these chemicals and hence not possible to assess the risks associated with them.

Chloramines have been widely adopted as drinking-water disinfection agents of choice in many places precisely because of their significantly decreased potential for halogenated by-

product formation (Adams *et al.* 2005). Accordingly, the use of chloramines for biofouling control in the proposed scheme can also largely be expected to provide minimal formation of halogenated by-products.

The benefits of chloramination to control halogenated by-product formation arise by the minimisation of the occurrence of high free-chlorine concentrations in the presence of dissolved organic matter (Adams *et al*, 2005). Disinfection protocols that do not avoid this occurrence would therefore require closer consideration in terms of anticipated free chlorine concentrations and exposure times.

Chlorination of secondary wastewater effluent has been reported to result in the formation of between 20 and 100 $ng.L^{-1}$ NDMA (Mitch & Sedlak 2002a). However, nitrification of wastewater to remove ammonia prior to hypochlorite addition reduces NDMA formation by approximately an order of magnitude resulting in concentrations less than the trigger value of 10 $ng.L^{-1}$ (Mitch & Sedlak 2002b; Mitch *et al.* 2003). All of the conventionally treated effluents to be further treated at the proposed plant would be fully nitrified to meet current environmental regulations.

Chloramination of the nitrified and denitrified effluent is required in the proposed treatment process to control biofouling on the microfiltration membranes. If this process is not carefully controlled, there is potential for NDMA production. However, current research indicates that careful control of the process can be effective for minimising NDMA formation (Mitch *et al.* 2005). This involves the minimisation of the (localised) co-occurrence of dichloramine and organic NDMA-precursors. Options include the pre-formation of monochloramine or the pre-chlorination of NDMA-precursors in the case of fully nitrified effluent.

By adopting a carefully controlled chloramination method, it is likely that NDMA concentration prior to membrane filtration could be maintained at significantly less than the Californian action level of 10 $ng.L^{-1}$. Partial further removal (~50 %) of NDMA has been reported by subsequent reverse osmosis (Mitch *et al.*, 2003). Reverse osmosis also effectively removes remaining NDMA precursors, preventing subsequent later formation of NDMA (Mitch & Sedlak 2004).

Photolysis of NDMA by exposure to sunlight is also effective for its removal (Mitch *et al.*, 2003). NDMA is rapidly degraded in the aquatic environment, with half-lives ranging from hours to days, through photolysis (Pehlivanoglu-Mantas & Sedlak, 2006) and biotransformation (Yang *et al.* 2005; Pehlivanoglu-Mantas & Sedlak 2006). Therefore, residence in the Hawkesbury-Nepean River offers an additional effective barrier for NDMA removal over the 17.5 km between Penrith and the North Richmond Water Treatment Plant.

Where necessary, effective removal of NDMA could be ensured by UV photolysis (Stefan & Bolton 2002; Mitch *et al.* 2003). Low pressure UV lamps emitting mainly monochromatic light at 254 nm, medium-pressure lamps emitting polychromatic light and pulsed UV systems have all been used for NDMA removal (Mitch *et al.* 2003). UV treatment was added to the Orange County Water District scheme for the removal of NDMA in 2000/2001 (OCWD 2000).

NDMA is not currently regulated in Australia and no public health guideline concentrations are available. However, an action level of 10 $ng.L^{-1}$ was set in 2002 by the California

Department of Health Services, based in part on the discovery of NDMA as a by-product of chlorination and chloramination of drinking water.

Additional emerging chemicals of concern considered for inclusion in the risk assessment include pharmaceutically active compounds (PhACs), and personal care products (including that antiseptic agent triclosan). However, no suitable human toxicity threshold could be identified, thus excluding the possible of quantitative assessment. The implications of low concentrations of these chemicals must therefore remain uncertain.

14.1.2 Hazard identification screening assessment

The hazard identification screening assessment was undertaken in order to allow the focusing of efforts towards chemicals that are considered to be of most (quantifiable) concern in water. While a number of comprehensive sources were consulted, this process was necessarily limited to information contained in those sources. Other chemicals, including emerging chemicals of concern may not be duly represented according to their true significance in these sources.

In some cases, the interpretation of acceptable screening concentrations from sources also involved a degree of uncertainty. In particular, the parameters used in calculation of acceptable drinking water concentrations from ADI data assume a fraction of intake of each chemical attributable to consumption of water as F=0.1. This fraction might underestimate risk in some cases since exposure is dependant on the source for each chemical. A higher F may be expected for industrial chemicals, and a lower F for common chemicals such as Cu and Zn. F is also affected by differences in environmental partitioning. Dichloromethane for example, partitions preferentially to the atmosphere, so will quickly volatilise from a surface water body.

The equations used to calculate US EPA Preliminary Remediation Goals (PRGs) are (by design) conservative in their approach to variable factors. It should be emphasised that the purpose of the PRGs is not to provide accurate numerical risk data, but to provide screening-level concentrations, which, if exceeded, should trigger closer (site-specific) investigation. As a consequence of this purpose, the PRG calculations include, in many cases, blanket volatilisation factors to account for inhalation exposure of volatile chemicals from water.

14.2 Dose-response assessment of identified chemicals

Qualitative hazard characterisation for identified hazards was obtained from information sourced from the World Health Organization and the United States Environmental Protection Agency. Quantitative dose-response data was sourced from the Unites Stated Environmental Protection Agency.

Dose-response data has historically been obtained by various means, with by far the most common being the extrapolation of observed dose-response in animals to humans. Such extrapolation techniques involve uncertainty, both in terms of whether a similar response can be achieved in humans, as well as the precise dose necessary to achieve it. In all cases, extrapolations from animal studies to humans involve the application of safety factors to account for uncertainty. Qualitative descriptions (where available) of chemical characterisation confidence are provided in the report from the US EPA “weight of evidence” toxicity classifications (US Environmental Protection Agency 2006b).

14.3 Exposure assessment

The exposure assessment incorporates an unavoidable degree of uncertainty. The key sources of uncertainty include:

- Initial chemical concentrations in tertiary treated effluents (many were consistently below analytical detection limits during Schedule 10 monitoring activities);
- The effectiveness of reverse osmosis treatment process had to be estimated based on limited chemical removal data and extrapolated to other chemicals. However, the actual effectiveness will necessarily be dependant on the chemical, the specific treatment design and operational conditions;
- The reverse osmosis treatment process was modelled as a single-pass system when the final plant design may possibly incorporate multiple-pass stages;
- This assessment does not account for 'background concentrations' of chemicals already present in the river from other sources (*e.g.* agricultural runoff, other sewage treatment plants, septic tanks, *etc*.);
- Environmental partitioning is dependant on specific characteristics of the environmental system including the concentrations and organic-carbon content of dissolved and suspended sediment. Standardised parameters were used in the current fugacity modelling, however their applicability to the real system is unconfirmed;
- Environmental biodegradation was assumed to be negligible due to the high degree of uncertainty involved with allocating model degradation rates;
- Photolysis of volatile chemicals was modelled by quantitative structure-activity relationship (QSAR) model in the absence of sufficient analytical data relevant to the studied system;
- An illustrative example was used for a hypothetical irrigation scenario. This is not intended to represent any specific real scenario, but to provide an estimation of the chemical risks based on upper-level exposure resulting from the irrigation of soils.

While the level of uncertainty is significant, this has been addressed, in part, by the incorporation of conservative estimations wherever possible.

14.4 Risk characterisation

Risk characterisation is reported based on the relationship between 'hazard assessment' outcomes and 'exposure assessment' outcomes. Accordingly, the uncertainties associated with the hazard assessment and exposure assessments are carried over into the risk characterisation.

Further uncertainty is introduced by the limitations of risk and hazard quotient calculations being based on point estimates which do not include measurement of variability. Examples of such point estimate assumptions include:

- Residential ingestion of 2 litres of water by adults, 350 days per year over a period of 30 years was assumed;
- Risks and hazard quotients associated with residential exposure to drinking water were calculated including only the oral pathway (drinking), whereas additional pathways including inhalation exposure and dermal exposure may be of varying significance for some chemicals;
- Recreational activities in the Hawkesbury-Nepean River were characterised as a person making 26 recreational visits to the river per year (1 per week during 6 months of the year). Each visit was assumed to include:

    - Accidental ingestion of 50 mL water from the river;
    - Swimming, involving 1 hour total immersion;
    - Significant body contact with river mud (sediment);
    - Inhalation of volatile contaminants in the air above the river (for the full day);
- Risks and hazard quotients associated with exposure due to recreational activities in the Hawkesbury-Nepean River were calculated including four pathways (which were subsequently added together to give an overall scenario risk/hazard quotient):
    - Direct ingestion of the water from the river;
    - Dermal absorption of contaminants from water while swimming;
    - Dermal absorption of contaminants from river mud (sediment);
    - Inhalation of volatile contaminants from air;
- Risks and hazard quotients (of organic chemicals only) associated with exposure due to irrigation of soil were calculated including three pathways (which were subsequently added together to give an overall scenario risk/hazard quotient):
    - Oral ingestion of soil;
    - Dermal exposure to soil;
    - Inhalation exposure to chemicals volatilised from soil;
- Additional unassessed exposure scenarios of unknown significance include:
    - Bioaccumulation and consumption of fish caught in the Hawkesbury-Nepean River;
    - Root-uptake and consumption of fruit and vegetable products grown using irrigation water sourced from the Hawkesbury-Nepean River;
    - Exposure to aerosols during spray-type irrigation activities.

Dermal exposure to chemicals in water, soil and sediment involves additional uncertainties regarding the permeability of specific chemicals across human skin. This permeability was estimated by calculation processes described by the US EPA (US Environmental Protection Agency 2004a). These estimation processes are based on relatively simply molecular properties such as molecular weight and octanol-water partitioning coefficient. A degree of uncertainty is inherent in all such calculations.

The risks associated with closely related chemicals can often be cumulative in nature. Accordingly, it is common practice to add calculated risks for such chemicals together. This procedure was not undertaken in the current assessment due to the lack of suitable comprehensive data. Further investigation would be required to identify realistic concentrations (not based on analytical detection limits), before such additive risks can be properly estimated.

15 Management

The recommendation of specific management regimes for the scheme was not identified as a major function of the current screening level risk assessment. The process has however revealed a range of data gaps and uncertainties, as well as exposure situations for which the significance may be assessed in a subsequent more detailed study. This section identifies some of these key issues that may be addressed by appropriate management practices.

15.1 Chemical screening and endpoint toxicity testing

Screening for individual chemical contaminants is recommended for some key chemicals of concern. The selection of such chemicals may be guided by this risk assessment, with particular reference to those determined to pose the highest risks. However, before instituting a final list of monitorable chemicals, careful consideration should be given the actual likeliness of a chemical to be present in tertiary treated wastewater. As was demonstrated for benzidine, listing in Schedule 10 is not necessarily reflective of this likelihood. Additional chemicals, not included in Schedule 10 may also be identified for screening.

However, chemical screening is obviously limited by the number and range of chemicals that can be realistically monitored. An alternative approach involves implementation of endpoint toxicity testing. Water produced from the treatment plant can be identified and monitored by a series of biological assays testing for key biological endpoints. This approach is non-chemical specific and thus has the ability to detect impacts arising from chemicals that may not have been otherwise considered.

15.2 Treatment plant performance and variability monitoring

The operational integrity of the reverse osmosis treatment process can be routinely monitored by standard online measurements such as conductivity or total organic carbon (TOC). These criteria are commonly used for monitoring water quality in other areas of water management. However, their applicability to reverse osmosis treatment may be limited by their sensitivity at the very low salinity and TOC concentrations expected for a well-performing reverse osmosis plant. The effectiveness of these (or other suitable) tools should be investigated. Target operational values should be carefully identified and justified. Furthermore, detailed plans should be developed for operational procedures to be undertaken when the target values are exceeded.

15.3 Management of disinfection and biofouling control by-products

The generation of disinfection and biofouling control by-products could not be quantitatively assessed for this risk assessment due to a lack of specific plant design information. However, some by-products of human health concern have been identified in the uncertainties section of this report. These include chlorinated organics (trihalomethanes and haloacetic acids) as well as N-nitrosodimethylamine (NDMA). The formation of these chemicals and persistence into plant effluents (or RO permeates) should be investigated.

One approach to controlling NDMA formation includes preformation of monochloramine in the absence of dissolved organic carbon to prevent the reaction of locally formed dichloramine with organic NDMA precursors.

15.4 Treatment plant challenge testing

Evidence that shows that microfiltration/reverse osmosis systems are very effective under normal operating conditions already exists. The construction of a small pilot test unit may provide further useful data on the functioning of a full-scale plant, however, it is the effect of failure conditions on risk that needs further investigation. Thus it is considered that testing would be more appropriate on the full-scale constructed system with suspension of its operation when malfunctions are detected and close studies of such malfunctions. Such work could include:

- confirmation of predicted performance;
- confirmation of capacity of failure detection systems;
- challenge testing of seasoned units taken off line;
- challenge testing of an operational part of the treatment train taken off-line, using safe surrogate microorganisms (*e.g.* bacteriophage) and chemicals (*e.g.* fluorescent dyes).

The efficacy of membranes in removal of chemicals under a range of conditions should be investigated at pilot scale to verify the outcomes of the risk assessment. This will assist in optimising the membranes to be used at the full-scale plant and to determine whether any chemicals require further management. This may include specific trade waste and source control options.

Whilst the number and range of chemicals that can be realistically monitored limit chemical screening itself, biological endpoint testing can be included to detect potential impacts from chemicals not considered here or from cumulative impacts from chemicals that may be present at trace concentrations.

Once operational at full-scale the highly treated water should be monitored to verify removal to levels based on relevant guideline values and after plant commissioning an ongoing program of testing should be agreed with NSW Health using the guideline values, biological endpoint testing (which in time will cover emerging issues such as EDCs) and compliance with the Australian Drinking Water Guidelines at North Richmond Water Filtration Plant. Some investigation of disinfection by-product formation, removal efficiencies and fate is recommended to further assess the risks.

15.5 Background water concentration identification

The lack of knowledge regarding background water concentrations of specific chemicals was identified as a key uncertainty of this assessment. This uncertainty could be partially addressed by the implementation of a monitoring survey to be undertaken in relevant reaches of the Hawkesbury-Nepean River.

A (not insurmountable) difficulty with this recommendation is the issue of analytical detection limits. It will not be useful to undertake a survey reporting large numbers of 'non-detects' at analytical detection limits that fail to reach minimal significant concentrations. In order to demonstrate that background concentrations in ambient water are significantly less than those assumed to be present in the RO-treated water, specialised analytical methods may be required in some cases.

15.6 Sediment (river mud) contamination survey

The risk assessment identified sediment (river mud) as a potential exposure pathway, via the dermal route, for some chemicals. This was a calculated risk based on limit of detection concentrations; these three chemicals were not detected in the sewage samples used in the study. It is recommended to undertake a sediment survey following commissioning of the plant to refine the risk assessment outcomes.

15.7 Exposed populations survey

A detailed characterisation of exposed populations and relevant uses of water from the Hawkesbury-Nepean River would better inform future risk assessment activities. For example, it would be valuable to determine:

- the actual degree of access to various reaches of the river;
- the populations that extract water from the river for drinking or other purposes without treatment;
- the fishing activities that are undertaken in various reaches of the river;
- the nature and typical frequencies (for individuals) of various recreational activities at the river.

In addition, the assessment of consumption of aquatic biota for chemicals requires further collection of data of the amount and types of fish consumed from the river.

Part D. Cyanobacteria

16 Issue Identification

Cyanobacterial bloom impacts on human populations are extensively documented in the NH&MRC (2005) guidelines. The risks arising from direct consumption, inhalation and skin contact are also extensively documented in these guidelines.

The major difference between risks from cyanobacterial toxins and other chemicals is that normal assessment of chemical risks is based on the quantity of contaminant in the starting material and its subsequent fate and transport. In the case of bloom toxins they would arise not as a direct result of exposure to materials in the replacement water but by its stimulation of cyanobacterial blooms. Thus risk assessment was focused on the potential for bloom stimulation.

Three bloom susceptibility factors were identified in the guidelines that could be influenced by the replacement water:

- Total phosphorus;
- Water temperature; and
- Thermal stratification.

Risk assessment was focused on assessing whether the above would negatively perturbed by replacement water flows.

17 Hazard Assessment

17.1 Source Water Composition

Phosphorus concentrations in Sydney's inland STP effluent are known as being a factor contributing to cyanobacterial blooms. So the best approach to risk assessment in the current situation was seen as assessing the extent to which water releases increased the concentration of phosphorus in the river. A recent set of data from the Penrith STP is shown in Table 17-1.

Table 17-1. Total Phosphorus in Penrith STP Effluent

Statistic	$mg.L^{-1}$	Basis
Arithmetic Average	0.0929	2003 Measurements (n=61)
Minimum	<0.005	
10^{th} Percentile	0.0055	
Median	0.05	
90^{th} Percentile	0.15	
Maximum	1.17	
Arithmetic Average	0.0923	Probability Density Function (log normal) for 2003 data with coefficients calculated using @Risk
Median	0.0455	
90^{th} Percentile	0.21	

17.2 Treatment – Reduction by Reverse Osmosis

As would be expected from its ability to exclude small negative ions such as chloride, RO is also capable of significantly reducing phosphate ion concentrations. Data collected by van Voorthuizen (Table 17-2) indicates that this varies between 91 and 98 % (DR = 1.1 - 1.7) depending on the membrane and origin of the effluent. Based on this data a median DR value of 1.4 is proposed for risk assessment.

Similarly Oron *et al.* (2006) observed a 96% reduction using a test unit using ultrafiltration plus RO. In the latter study most reduction was achieved by the RO stage. It was noteworthy that there was also a 50% reduction in phosphate by the ultrafilter, presumably because of removal of particle bound phosphorus as ammonium ion was not reduced to any significant extent indicating soluble material was unaffected by Ultrafiltration.

Table 17-2. % Removal of Ammonium and Phosphate from Sewage Effluents

Reverse Osmosis Membrane Product Code	Ammonium		Phosphate	
	Mixture	Anaerobic Effluent	Mixture	Anaerobic Effluent
BWLE	86	90	91	98
XLE	93	93	93	98
BW30	29	93	92	98

Notes:
1. Adapted from Table 7 in van Voorthuizen, E. M., Zwijnenburg, A. and Wessling, M. (2005)

17.3 Fate and Transport

Dilution in the river would tend to reduce the influence of phosphorus releases on algal bloom potential. As part of general risk assessment the extent of dilution was estimated under

3 different flow conditions on the basis of modelling data provided by Sydney Water. The estimated dilution factors are reproduced in Table 17-3.

Table 17-3. Modelled riverine flow scenarios

Description	Flow percentile	Dilution at Penrith Weir	Comments
Low flow conditions	80th percentile	0.272	Modelled Hawkesbury-Nepean River data supplied by Sydney Water
Median flow conditions	50th percentile	0.178	
High flow conditions	20th percentile	0.0128	

Note:
1. See also Table 5-9.

Further, upon release to the river the water temperature will be increased or decreased depending on the volume of replacement water released and the flow and temperature of the water already in the river. The current scale and extent of the effect is summarised in Table 17-4. The RO plant would not alter the temperature of the water but the increased volume would mean that temperature perturbations would tend to be increased.

Table 17-4. Temperature (^{o}C) Upstream and Downstream of Penrith Weir (2004-2005)

Statistic	Upstream Penrith Weir	Downstream Penrith Weir	Change at Penrith	Upstream Winmalee
10th%ile	13.2	13.7	0.5	14
90th%ile	25.5	23.9	-1.6	26.2
MAX	26.4	25.6	-0.8	27.2
MEAN	20.2	19.9	-0.3	20.7
MEDIAN	21	20.3	-0.7	22
MIN	11.7	12.7	1	11.7

17.4 Consumption and Exposure

The NH&MRC (2005) guidelines detail a range of potential impacts arising from algal blooms. However these were not immediately relevant in the present risk assessment as the task being undertaken was to assess whether there was likely to be any increase in risk.

17.5 Benchmarks

Risk Assessment of the kind proposed for pathogens and chemicals is not yet possible for cyanobacterial toxins. While toxin dose responses are reasonably well documented there is not useful in-river toxin concentration data that could be used for risk assessment. Collection of such a set is probably not yet practical.

However the NH&MRC (2005) guidelines identify 4 factors predisposing water bodies to cyanobacterial blooms (Table 17-5), three of which are relevant to replacement water use as discussed above and which appear to be suitable as Benchmarks:

- water concentration of phosphorus – should not be increased; specifically total P should be < 10 $\mu g.L^{-1}$ to minimise cyanobacterial bloom suceptibility;

- water temperature – should not be promoted where water temperature is already warm; < 15°C there is unlikely to be a problem; > 15°C increases in water temperature increase susceptibility;
- thermal stratification – should not be promoted.

Table 17-5. Susceptibility Categories for Water Bodies

Environmental factors (singly or in combination)				
History of cyanobacterial blooms	**Water temperature (°C)**	**Nutrients: total phosphorus (µg/L)**	**Thermal stratification**	**Susceptibility category**
No	< 15	< 10	Never present	Very low (good)
Yes	15–20	< 10	Infrequent	Low
Yes	20–25	10–25	Occasional	Moderate
Yes	> 25	25–100	Frequent and persistent	High
Yes	> 25	> 100	Frequent and persistent/strong	Very high (poor)

Notes:
1. Reproduced from Table 6.4 in NH&MRC (2005).

18 Exposure Assessment

18.1 Exposure Pathways

The exposed population was people exposed directly to riverwater via oral consumption, inhalation or skin adsorption.

The assessment point was in the first instance Penrith Weir, but the method of risk assessment applied to the whole river.

The five different exposure pathways identified in the initial qualitative risk assessment are illustrated in Figure 18-1 in flow diagram form (see Figure 3-4 for template diagram showing all possible pathways).

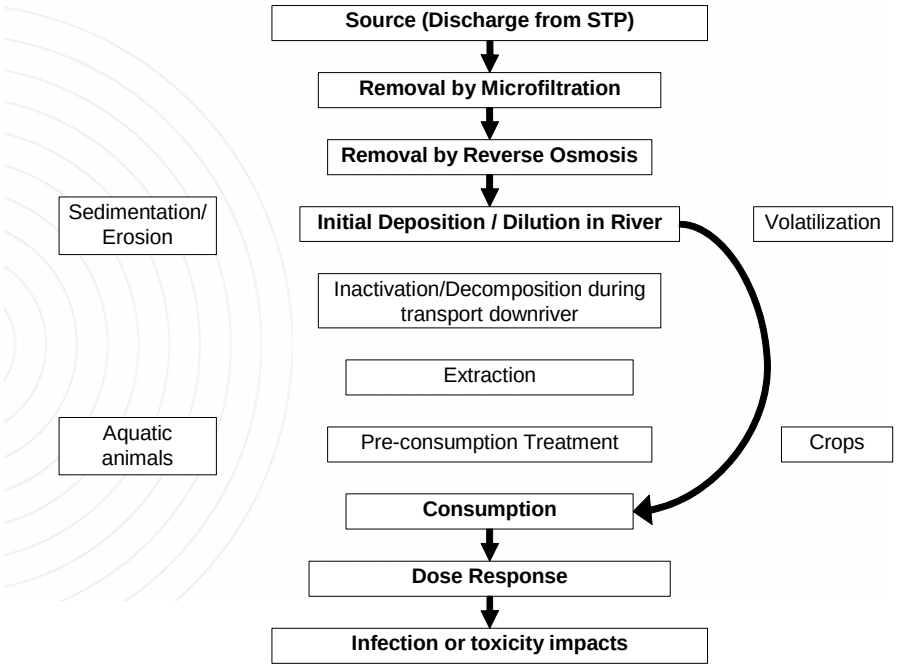


Figure 18-1. Exposure pathways considered in respect to cyanobacterial blooms:

Notes:
1. Consumption in pathway shown can be as a result of recreation or the use of untreated drinking water for potable domestic use, and involve direct consumption, inhalation or skin adsorption.

18.2 Risk Estimation

Relative risk estimation was based on assessment of whether there would be any significant change in the river's susceptibility to cyanobacterial blooms.

18.2.1 Phosphorus

The increase in phosphorus added to the river was estimated assuming that the MF-RO plant was operating the majority (98.5% based on Singapore performance) of the time.

18.2.2 Temperature

The risk of increased susceptibility due to river water temperature change was assessed based on comparison of water temperature up and downstream of the existing STP (Table 17-4)

18.2.3 Stratification

The risk of increased susceptibility due to river stratification change was based on the likelihood of a change in water velocity and thermal differences.

19 Risk Characterisation

19.1 Changes in River Susceptibility

19.1.1 Phosphorus

Phosphate ions are large and should be extensively removed by the RO membrane more effectively than salts but probably less than large organic molecules. The results of Kitis *et al.* (2003a, 2003b) indicate that the DR for Total P should be between 1.8 and 4. Together with the dilution factors apply at Penrith (0.01-0.027) these and other data reviewed suggest that a DR of 2 and probably greater should be routinely achieved. When combined with the average Total P concentration (0.09 $mg.L^{-1}$) in the treated STP effluent this suggests that the MF-RO plant should increase the concentration in the river by on average 1 $\mu g.L^{-1}$ and at worst 4 $\mu g.L^{-1}$ in the event there was no flow in the river.

19.1.2 Temperature

The data in Table 17-4 indicates that upon mixing the effect of replacement water on its ambient temperature would be to marginal. And it may reduce the peak summer temperatures experienced in the river. And a short way downstream the temperature would tend to return to its normal range (indicated by an increase at Winmalee compared to upstream of Penrith Weir).

19.1.3 Stratification

No advice is given in the guidelines as to when stratification is likely to be a concern in a river like the Hawkesbury-Nepean. However it is likely to be encouraged by a decrease in river velocity and poor mixing. The introduction of replacement water seems unlikely to decrease the velocity as the additional water will tend to increase velocity and it is understood that mixing should be rapid downstream of Penrith in dry periods due to its shallowness and the various fords *e.g.* at North Richmond.

19.2 Overall Risk

The likelihood of increased cyanobacterial risk from increased phosphorus presence was seen as ‘Rare’ to ‘Unlikely’ given the small increase in phosphorus introduced by the replacement water (0.9 - 4 $\mu g.L^{-1}$). Any algal bloom would be likely to be limited because of the low level of additional nutrient, and rapidly recognised by the existing monitoring system. So the consequences from phosphorus from the MF-RO should be ‘Minor’ again yielding an overall risk rating of ‘Low’.

Similarly the likelihood of increased cyanobacterial risk from water temperature changes or due to increased stratification was also seen as ‘Rare’ to ‘Unlikely’.

19.3 Uncertainties

No uncertainties of significance were identified in respect to the potential for increased cyanobacterial blooms.

Part E. Concluding Points

20 Generic Uncertainties

20.1 Report Limitations and the Lack of Precedents

There appear to be only limited precedents for the assessment undertaken here. This is not to suggest that risk assessment of recycled water has not been undertaken previously (for a range of case studies see Petterson and Ashbolt (2003)). And the principles involved in the risk assessment are well tried and documented (NHMRC/NRMMC, 2005). Rather what is limited, especially in relation to microbial risk assessment, is:

- assessment of the impact of returning wastewater to the natural environment where the reuse anticipated is very general such that a great many exposure scenarios hypothetically need risk assessment *i.e.* any water use existing downstream of the release point;
- sufficient example assessment to provide a basis at an early stage in the risk assessment process.

These limitations reflect the current state of quantitative assessments. Salgot *et al.* (2003) provide a useful review of the issues and conclude their review as follows indicating more is needed than the advanced risk assessment guidelines currently in preparation at national and level:

> *"A common and discussed and agreed development of treated wastewater reuse guidelines and/or regulations will improve the possibilities for the establishment of risk assessment and management tools. There is the need to develop such risk-related tools for the future wastewater recycling and reuse correct development. Among these tools, we can mention by: exposition scenarios, mathematical models, structure-activity relationships, and decision support systems. Even though the risk calculation methods are a good tool for risk assessment, it still exists a certain lack of confidence that seems logical. In this sense, the precautionary principle appears. Svedin indicates that the precautionary principle is a policy rule in the European Union and it is creating brand new and complex problems to the scientists and politicians. It constitutes a new discipline even a research field."*

20.2 Other HRA Process Components

This screening level risk assessment used the EnHealth Council (2002) guidelines as a model. But in doing so it omitted the following three processes included in a full risk assessment:

- Community Consultation;
- Management; and
- Reality Checks.

Management was necessarily limited to identification of data gaps and recommendations on how these could be addressed. Again this is seen as reasonable for a screening level risk assessment.

Internal review has been an ongoing feature of this assessment. But verification of risk assessed and uncertainties identified is only possible in a desktop manner. Fuller verification would require implementation of the relevant management recommendations.

20.3 Relative Contribution of Contaminants from Other Sources

The risk assessment here only considers the impacts of the replacement water on the environment. Thus it does not consider additive effects of any contaminants that are added to the existing loads arriving from upstream.

That said the proposed scheme is expected to generally reduce the loads being emitted currently by Penrith STP. As a consequence conceptually the project should improve water quality in the river irrespective of the contaminants derived from other sources. This issue of relative risk is discussed further in Appendix 5 (Section 23.5).

20.4 Appropriate Level of Risk Assessment

In respect to the 'Screening Level' Risk assessment, the EnHealth (2001) guideline was that this should be determined by the approving authority. But for a project like the current one there was insufficient information to apply the UK model recommended by EnHealth (2001).

In respect to risk assessment for broad impact assessment projects scoping the problem raised is that there are via indirect pathways far more exposure routes and scenarios than it is logistically feasible to assess. This difficulty is recognised in the EnHealth Council (2002) document as the following quotes demonstrate.

> *"Due to the complexity and scale of the environmental health risk assessment process a concise 'cookbook' is not practicable. Similarly, the situation-specific issues are often sufficiently complex and 'situation-specific' that a manageable and complete algorithm for decision-making cannot be drafted; the document provides a series of guidelines and checklists to assist the decision-making process." (pg. viii)*
>
> *"In many instances, situation-specific health risk assessments may not be necessary as the nature and magnitude of the risks will be quite apparent, there may be no population at risk, or decisions on risk management may be made on other grounds. In such cases, the significant resources required for a detailed risk assessment would be better directed to risk management steps". (pg. xiv)*

Deciding what might be the appropriate level of risk assessment was difficult because of the wide range of potential indirect and well as direct exposure pathways and the lack of sufficiently similar precedents that could act as model.

20.5 The Need for Full Risk Assessment and Strategic Implications of such a decision

In the longer term the risk assessment presented in this report may be only a starting point and a trigger for a more in depth investigation of MF-RO based water recycling. Such an assessment would likely need to be both complex and multifaceted and lead to the establishment of guidelines that minimise the health risks due to exposure to contaminant. Such an assessment would need to recognise that exposure can occur:

- directly (which is what was assessed at screening level in this report);
- indirectly (Indirect exposure could be associated with water extraction from the river and use for drinking and domestic use, as well as through land application of re-used water (soil contact and via the food chain)).

The indirect exposure would need to be addressed in a second-tier, detailed risk assessment, and incorporate the report uncertainties outlined above. The detailed risk assessment could also consider the effect of chemicals biodegradation, bioaccumulation characteristics and intermedia transport, and integrate these with various exposure scenarios and therefore provide cumulative risk estimates for potentially exposed individuals.

The benefits gained by such an assessment in respect to knowledge of the viability of water recycling and the institutional issues requiring consideration and policy development, would be invaluable not only for Sydney but also nationally and internationally.

21 Acknowledgements

The authors wish to acknowledge the assistance of Adam Lovell, Mark Angles and Rodney Kerr from Sydney Water, Kaye Power and Paul Byleveld for NSW Health, Daniella Leonte from UNSW Safety Science and Lyn Menzies from CWWT.

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23 Appendices

23.1 Appendix 1. Reaches of the River Proposed for Risk Assessment (Extracted Using GoogleEarth)

Penrith Weir



Winmalee



North Richmond



D/S South Creek



Sackville



Wisemans Ferry



23.2 Appendix 2. QMRA Source/Barrier/Response Descriptors (i.e. PDFs)

Table 23-1. Source, Barrier and Receptor Quantitative Descriptors

Compartment / Attribute	Micro-organism	Simulation	PDF Coefficient (s)	PDF Coefficient Values	Units	References, Data Sources and Notes
1. Source Water (secondary and tertiary undisinfected effluents) / Microorganism Concentration	*a. Crypto-sporidium*	i. Nominal	Triangular	0, 0.03, 0.15*	$.L^{-1}$	Rouse Hill and Hornsby Data from Sydney Water
		ii. High value	Uniform	2.9, 13		Rose *et al.* 1996
	b. Campylobacter	i. Nominal	Triangular	30, 1000, 10000*		Koenraad *et al.* 1994
		ii. High value	Point Est.	10000		
	c. Rotavirus	i. Nominal	Triangular	0,750,1500*		Bates *et al.* 1984
		ii. High value	Point Est.	3225		Rao *et al.* 1988
	d. Adenovirus	i. Nominal 1	Triangular	1, 300, 800		WSL 2003
		ii. Nominal 2	Gamma	520, 12.6		Bolivar data (N. Ashbolt pers. com.)
		iii. High value	Point Est.	40,000		WSL 2003 (New Zealand Data)
	e.Enterococci	i. Nominal	Triangular	0, 940, 4400*		Annual reports for western Sydney treatment plants
		ii. High value	Point Est.	120,000		
2. Microfiltration Process /Decimal Reduction in Pathogen Concentration	*a. Crypto-sporidium*	i. Nominal	Normal	4.8478, 1.4883*	DRs	PDF estimated using Singapore MF data on *Clostridium* removal [$]
		ii. Event	Point Est.	2*		Based on removal in small and large units after compromise; see Kitis *et al.* 2003
	b. Campylobacter	i. Nominal	Normal	7.9162, 2.116*		PDF estimated using Singapore MF data on thermotolerant coliform removal [$]
		ii. Event	Point Est.	2*		Based on removal in small and large units after compromise; see Kitis *et al.* 2003
	c. Enteric viruses	i. Nominal 1	Normal	5.1041, 1.7393		PDF estimated using Singapore MF data on somatic coliphage removal [$]
		ii. Nominal 2	Uniform	2.5, 3.5*		Lovins *et al.* 2002 and other data
		iii. Event	Point Est.	1*		Jacangelo *et al.* 1995 (Small unit worst case)
	d. Enterococci	i. Nominal	Normal	7.4047, 1.8842*		PDF estimated using Singapore MF data on Enterococci removal [$]
		ii. Event	Point Est.	2*		Based on removal in small and large units after compromise; see Kitis *et al.* 2003
3. Reverse Osmosis Process	*a. Crypto-*	i. Nominal	Point Est.	6.5*#	DRs	Various *e.g.* Kitis *et al.* 2003

Compartment / Attribute	Micro-organism	Simulation	PDF Coefficient (s)	PDF Coefficient Values	Units	References, Data Sources and Notes
/Decimal Reduction in Pathogen Concentration	*sporidium*	ii. Event 1	Point Est.	2*		Based on removal in small and large units after compromise; see Kitis *et al.* 2003
	b. Campylobacter	i. Nominal	Point Est.	6.5*#		Various *e.g.* Kitis *et al.* 2003
		ii. Event 1	Point Est.	*2#		Based on removal in small and large units after compromise; see Kitis *et al.* 2003
	c. Enteric viruses	i. Nominal	Point Est.	6.5*#		Various *e.g.* Kitis *et al.* 2003
		ii. Event 1	Point Est.	2*		Based on removal in small and large units after compromise; see Kitis *et al.* 2003
	d. Enterococci	i. Nominal	Point Est.	6.5*#		Various *e.g.* Kitis *et al.* 2003
		ii. Event 1	Point Est.	2*		Based on removal in small and large units after compromise; see Kitis *et al.* 2003
4. Microfiltration and or Reverse Osmosis /Proportion of time under specified simulation conditions	a. All	i. Nominal	Point Est.	1.0*	Pro-portion of time	assumes nominal conditions operating
		ii. Nominal+ Event	Discrete	*0.985,0.015		Singapore MF data - maximum breakdown frequency simulation conditions apply
5. River / Travel Time required for a particle to reach receptor exposure assessment station corresponding to indicated percentile flow	a. All micro-organisms	i. Penrith Weir 20%ile	Point Est.	0*	days	Sydney Water Model for Hawkesbury-Nepean River flows was used to calculate the travel time for a typical particle introduced into the river at Penrith. The 20th , 50th , and 80th percentile flows were selected to assess risks under high dilution +rapid downstream transport, median dilution and flow, and low dilution + slow transport downstream respectively.
		ii. Penrith Weir 50%ile flow	Point Est.	0*		
		iii. Penrith Weir 80 %ile flow	Point Est.	0*		
		Winmalee 20%ile flow	Point Est.	0.8		
		Winmalee 50%ile flow	Point Est.	8.91		
		Winmalee 80 %ile flow	Point Est.	14.78		
		iv. Nth Richmond 20%ile flow	Point Est.	1.39*		

Compartment / Attribute	Micro-organism	Simulation	PDF Coefficient (s)	PDF Coefficient Values	Units	References, Data Sources and Notes
		v. Nth Richmond 50%ile flow	Point Est.	12.18*		
		vi. Nth Richmond 80 %ile flow	Point Est.	20.7*		
		Windsor 20%ile flow	Point Est.	2.83		
		Windsor 50%ile flow	Point Est.	17.43		
		Windsor 80 %ile flow	Point Est.	31.49		
		Sackville 20%ile flow	Point Est.	5.22		
		Sackville 50%ile flow	Point Est.	25.7		
		Sackville 80 %ile flow	Point Est.	49.37		
		Wisemans Ferry 20%ile flow	Point Est.	11.12		
		Wisemans Ferry 50%ile flow	Point Est.	43.14		
		Wisemans Ferry 80%ile flow	Point Est.	93.19		
6. River / Dilution of particles and chemicals at receptor exposure assessment station corresponding to indicated percentile flow	a. All micro-organisms	i. Penrith Weir 20%ile	Point Est.	0.01279*	Multi-plication factor	Sydney Water Model for Hawkesbury-Nepean River flows was used to calculate the concentration of a contaminant after mixing with the ambient flow. The 20^{th} , 50^{th} , and 80^{th} percentile flows were selected to assess risk under high dilution +rapid downstream transport, median dilution and flow, and low dilution + slow transport downstream respectively.
		ii. Penrith Weir 50%ile flow	Point Est.	0.178*		
		iii. Penrith Weir 80 %ile flow	Point Est.	0.2724*		

Compartment / Attribute	Micro-organism	Simulation	PDF Coefficient (s)	PDF Coefficient Values	Units	References, Data Sources and Notes
		Winmalee 20%ile flow	Point Est.	0.01259		
		Winmalee 50%ile flow	Point Est.	0.1213		
		Winmalee 80 %ile flow	Point Est.	0.22386		
		iv. Nth Richmond 20%ile flow	Point Est.	0.01053*		
		v. Nth Richmond 50%ile flow	Point Est.	0.07769*		
		vi. Nth Richmond 80 %ile flow	Point Est.	0.17272*		
		Windsor 20%ile flow	Point Est.	0.00913		
		Windsor 50%ile flow	Point Est.	0.0517		
		Windsor 80%ile flow	Point Est.	0.13814		
		Sackville 20%ile flow	Point Est.	0.00707		
		Sackville 50%ile flow	Point Est.	0.02583		
		Sackville 80 %ile flow	Point Est.	0.10408		
		Wisemans Ferry 20%ile flow	Point Est.	0.00467		
		Wisemans Ferry 50%ile flow	Point Est.	0.01255		

Compartment / Attribute	Micro-organism	Simulation	PDF Coefficient (s)	PDF Coefficient Values	Units	References, Data Sources and Notes
		Wisemans Ferry 80%ile flow	Point Est.	0.05139		
7. River / Decimal Reduction Inactivation Functions for Different Pathogen Groups[@]	*a. Crypto-sporidium*	i. Nominal	Uniform	0.01, 0.0344*		see literature review table
		ii. Low value	Point Est.	0.004*		
	b. Campylobacter	i. Nominal	Point Est.	0.286*		Sinton *et al.* 2006
		ii. Low value	Point Est.	0.181*	DR $.d^{-1}$ dark 10 ^{o}C	Evison 1988 *b. Campylobacter fetus* in dark
	c. Rotavirus	i. Nominal	Uniform	0.24-0.48*	DR day^{-1}	Medema *et al.*(2001a)
		ii. Low value	Point Est.	0.04*		Evison 1988 bacteriophage in dark 15-25 ^{o}C
	d. Adenovirus	i. Nominal	Point Est.	0.25		Noble *et al.* 2004 MS 2 phage in low light
		ii. Low value	Point Est.	0.0417		Evison 1988 bacteriophage in dark 15-25 C
	e. Enterococci	i. Nominal	Point Est.	2.537*		Noble *et al.* 2004
		ii. Low value	Point Est.	0.17*		Medema *et al.*(2001a)
8. North Richmond WTP / Decimal Reduction Functions Defining Physical Removal of Inactivation effect	*a. Crypto-sporidium*	i. DAF	Normal	1.72, 0.61*	DR	Signor 2006 PhD optimal for yeast
		ii. Rapid Sand Filtration	Normal	1.43, 0.56*		
		iii. Chlorination	Triangular	0, 0.4, 1*		Westrell 2003 thesis
	b. Campylobacter	i. DAF	Normal	2.38, 0.38*		Signor 2006 PhD optimal for total coliforms
		ii. Rapid Sand Filtration	Normal	2.05, 0.35*		
		iii. Chlorination	Triangular	2.5, 3.5, 5*		Westrell 2003 thesis
	c. Enteric viruses	i. DAF	Triangular	0.3, 3, 1.6*		Westrell 2003 thesis - use flocculation process
		ii. Rapid Sand Filtration	Triangular	0.7, 1.2*		Westrell 2003 thesis use filtration figures
		iii. Chlorination	Triangular	1.5, 2, 3*		Westrell 2003 thesis
9. Consumer / Drinking water consumption rate	a. All pathogens	i. Nominal	Poisson	3.368*	$L.d^{-1}$	Mons *et al.* 2005; Melbourne consumption is equivalent to 0.75 $L.person^{-1}.d^{-1}$ on average
		ii. High Value	Point Est.	6		G. Medema pers. com. - aerobics recreationists
10. Consumer / water consumed during primary recreation exposure	a. All pathogens	i. Nominal	Triangular	0.01,0.03,0.05*	L	various - see table in Part A
		ii. High Value	Point Est.	0.1		Various - compiled by Steyn *et al.* 2004

Compartment / Attribute	Micro-organism	Simulation	PDF Coefficient (s)	PDF Coefficient Values	Units	References, Data Sources and Notes
11. Consumer / frequency of exposure	a. All pathogens	i. Nominal	Point Est.	26*	$d.y^{-1}$	conceptual assumed 1 day per weekend per summer month – used for recreation and shellfish
		ii. High Value	Point Est.	91		assumes half of summer days
12. Consumer / Water consumed during vegetable ingestion	a. All pathogens	i. Nominal	Point Est.	0.005*	L	The water on 1 serving of lettuce (40 g) is consumed with no die off -see Table 3.3. Draft 2005 guidelines
		ii. High Value	Point Est.	0.011		The water on 100g of lettuce is consumed with no die off -see Table 3.3. Draft 2005 guidelines
13. Consumer /Water consumed by Shellfish ingestion	a. All pathogens	i. Nominal	Uniform	0.06-0.24*	L	Based on water equivalent to the weight of 6 to 12 oysters is consumed see AWT 1997 page 48
		ii. High Value	Point Est.	0.24	L	
14. Shellfish/ Concentration of pathogens following ingestion	a. All pathogens	i. Nominal	Point Est.	-3*	DR	Based on a AWT 1997 page 33; minus sign indicates increase rather than decrease
15. Consumer / Infection Response	*a. Crypto-sporidium*	i. Nominal	Beta Poisson	0.115 , 0.176*	Infections per ingested organism	various - see Part A table; high value in each case is the Maximum likelihood curve – see Haas *et al.* 1999
		ii. High Value	Exponential	P=1-exp(-d)		
	b. Campylobacter	i. Nominal	Beta Poisson	0.024, 0.011*		
		ii. High Value	Exponential	P=1-exp(-d)		
	c. Rotavirus	i. Nominal	Beta Poisson	0.253, 0.422*		
		ii. High Value	Exponential	P=1-exp(-d)		
	d. Adenovirus	i. Nominal	Exponential	2.397		
		ii. High Value	Exponential	P=1-exp(-d)		
16. Consumer / Disease Burden following infection	*a. Crypto-sporidium*	i. Nominal DALY	Point Est.	0.00180*	Multi-plication factor	Havelaar and others (see 3 references in Part A table); Adenovirus assumed to have the same DALY conversion as Rotavirus
	b. Campylobacter		Point Est.	0.00208*		
	c. Rotavirus		Point Est.	0.000864*		
	d. Adenovirus		Point Est.	0.000864		

Notes:

1. DR = decimal reduction – where this abbreviation is used it is the $\log_{10}$ of the reduction factor – so for example a DR of 2 implies a reduction by a factor of 100 or a 99% reduction. It is assumed that such reduction functions are log normally distributed and this appears to be the generally the case.
2. The items marked * are those selected for simulations presented in Part B.
3. Data[$] for Singapore provided by Dr G. Leslie UNSW

4. Nominal Reverse Osmosis DR values[#] are conservative minimum removal estimates.
5. Surface water inactivation DR[@] values are conservative as they do not account for increases in inactivation driven by sunlight which may be several orders of magnitude greater (see Sinton *et al.* 2006; Evison 1988)
6. Coefficients for each PDF type are as follows:
    a. Triangular – minimum, mode, maximum
    b. Uniform – minimum, maximum
    c. Point Estimate – Best estimate (mode)
    d. Normal – mu (mean), sigma (standard deviation)
    e. Poisson - gamma
    f. Beta Poisson – apha, beta
    g. Exponential – 'd' is the dose
7. Some other key assumptions:
    a. The risks estimated relate only to those organisms emitted from the treatment plant. They do not cover risks from other sources *e.g.* normal STP release, urban run-off, and agricultural run-off.

Table 23-2. Source, Barrier and Receptor Quantitative Descriptors Used for Each Scenario

Exposures Pathway	Assessment Point	Scenario	Model Inputs[1]			
			Cryptosporidium	***Campylobacter***	**Rotavirus**	**Enterococci**
Direct drinking consumption of untreated river water as a result of its use for domestic uses	Penrith	High (20%ile) Flow	1ai, 2ai, 3ai, 4ai, 5ai, 6ai, 7ai, 9ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5ai, 6ai, 7bi, 9ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5ai, 6ai, 7ci,9ai, 15ci, 16ci	-
		Median Flow	1ai, 2ai, 3ai, 4ai, 5aii, 6aii, 7ai, 9ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5aii, 6aii, 7bi, 9ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5aii, 6aii, 7ci,9ai, 15ci, 16ci	-
		Low (80%ile) Flow	1ai, 2ai, 3ai, 4ai, 5aiii, 6aiii, 7ai, 9ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5aiii, 6aiii, 7bi, 9ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5aiii, 6aiii, 7ci,9ai, 15ci, 16ci	-
		Low (80%ile) Flow MF breakdown (5.3 days.y^{-1})	1ai, 2ai, 3ai, 4ai, 5aiii, 6aiii, 7ai, 9ai, 15ai, 16ai & 1ai, 2aii, 3ai, 4aii, 5aiii, 6aiii, 7ai, 9ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5aiii, 6aiii, 7bi, 9ai, 15bi, 16bi & 1bi, 2bii, 3bi, 4aiii, 5aiii, 6aiii, 7bi, 9ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5aiii, 6aiii, 7ci,9ai, 15ci, 16ci & 1ci, 2ciii, 3ci, 4aii, 5aiii, 6aiii, 7ci,9ai, 15ci, 16ci	-
		Low (80%ile) Flow RO Breakdown(5.3 days.y^{-1})	1ai, 2ai, 3ai, 4ai, 5aiii, 6aiii, 7ai, 9ai, 15ai, 16ai & 1ai, 2ai, 3aii, 4aii, 5aiii, 6aiii, 7ai, 9ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5aiii, 6aiii, 7bi, 9ai, 15bi, 16bi & 1bi, 2bi, 3bii, 4aii, 5aiii, 6aiii, 7bi, 9ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5aiii, 6ai, 7ci,9ai, 15ci, 16ci & 1ci, 2ci, 3cii, 4aii, 5aiii, 6aiii, 7ci, 9ai, 15ci, 16ci	-
		Low (80%ile) Flow RO+MF concurrent breakdown (5.3 days. y^{-1})	1ai, 2ai, 3ai, 4ai, 5aiii, 6aiii, 7ai, 9ai, 15ai, 16ai & 1ai, 2aii, 3aii, 4aii, 5aiii, 6aiii, 7ai, 9ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5aiii, 6aiii, 7bi, 9ai, 15bi, 16bi & 1bi, 2bii, 3bii, 4aii, 5aiii, 6aiii, 7bi, 9ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5aiii, 6aiii, 7ci,9ai, 15ci, 16ci & 1ci, 2ciii, 3cii, 4aii, 5aiii, 6aiii, 7ci,9ai, 15ci, 16ci	-
Direct consumption as a result of ingestion during primary recreation (26 days.y^{-1})		High (20%ile) Flow	1ai, 2ai, 3ai, 4ai, 5ai, 6ai, 7ai, 10ai, 11ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5ai, 6ai, 7bi, 10ai, 11ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5ai, 6ai, 7ci, 10ai, 11ai, 15ci, 16ci	1ei, 2di, 3di, 4ai, 5ai, 6ai, 7ei
		Median Flow;	1ai, 2ai, 3ai, 4ai, 5aii, 6aii, 7ai, 10ai, 11ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5aii, 6aii, 7bi, 10ai, 11ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5aii, 6aii, 7ci, 10ai, 11ai, 15ci, 16ci	1ei, 2di, 3di, 4ai, 5aii, 6aii, 7ei
		Low (80%ile) Flow	1ai, 2ai, 3ai, 4ai, 5aiii, 6aiii, 7ai, 10ai, 11ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5aiii, 6aiii, 7bi, 10ai, 11ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5aiii, 6aiii, 7ci, 10ai, 11ai, 15ci, 16ci	1ei, 2di, 3di, 4ai, 5aiii, 6aiii, 7ei

Exposures Pathway	Assessment Point	Scenario	Model Inputs[1]			
			Cryptosporidium	***Campylobacter***	**Rotavirus**	**Enterococci**
		Low (80%ile) Flow +MF-RO failure	1ai, 2ai, 3ai, 4ai, 5aiii, 6aiii, 7ai, 10ai, 11ai, 15ai, 16ai & 1ai, 2aii, 3aii, 4aii, 5aiii, 6aiii, 7ai, 10ai, 11ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5aiii, 6aiii, 7bi, 10ai, 11ai, 15bi, 16bi & 1bi, 2bii, 3bii, 4aii, 5aiii, 6aiii, 7bi, 10ai, 11ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5aiii, 6aiii, 7ci, 10ai, 11ai, 15ci, 16ci & 1ci, 2ciii, 3cii, 4aii, 5aiii, 6aiii, 7ci, 10ai, 11ai, 15ci, 16ci	1ei, 2di, 3di, 4ai, 5aiii, 6aiii, 7ei & 1ei, 2dii, 3dii, 4aii, 5aiii, 6aiii, 7ei
Direct consumption of mussels		Low (80%ile) Flow; 1 meal per day, 26 meals in one year	1ai, 2ai, 3ai, 4ai, 5aiii, 6aiii, 7ai, 13ai, 11ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5aiii, 6aiii, 7bi, 13ai, 11ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5aiii, 6aiii, 7ci, 13ai, 11ai, 15ci, 16ci	-
Direct consumption of irrigated lettuce		Low (80%ile) Flow; 365 normal servings of lettuce in one year)	1ai, 2ai, 3ai, 4ai, 5aiii, 6aiii, 7ai, 12ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5aiii, 6aiii, 7bi, 12ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5aiii, 6aiii, 7ci, 12ai, 15ci, 16ci	-
Direct drinking consumption of untreated river water	North Richmond	High (20%ile) Flow	1ai, 2ai, 3ai, 4ai, 5aiv, 6aiv, 7ai, 9ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5aiv, 6aiv, 7bi, 9ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5aiv, 6aiv, 7ci,9ai, 15ci, 16ci	-
		Low (80%ile) Flow	1ai, 2ai, 3ai, 4ai, 5avi, 6avi, 7ai, 9ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5avi, 6avi, 7bi, 9ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5avi, 6avi, 7ci,9ai, 15ci, 16ci	-
Direct drinking consumption of treated river water		High (20%ile) Flow	1ai, 2ai, 3ai, 4ai, 5aiv, 6aiv, 7ai, 8ai,8aii, 8aiii, 9ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5aiv, 6aiv, 7bi, 8bi,8bii, 8biii,9ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5aiv, 6aiv, 7ci, 8ci,8cii, 8ciii,9ai, 15ci, 16ci	-
		Low (80%ile) Flow	1ai, 2ai, 3ai, 4ai, 5avi, 6avi, 7ai, 8ai,8aii, 8aiii,9ai, 15ai, 16ai	1bi, 2bi, 3bi, 4ai, 5avi, 6avi, 7bi, 8bi,8bii, 8biii,9ai, 15bi, 16bi	1ci, 2cii, 3ci, 4ai, 5avi, 6avi, 7ci, 8ci,8cii, 8ciii, 9ai, 15ci, 16ci	-

Notes:

1. Scenario codes (*e.g.* (1ai) each identify a probability density function used in the scenario simulation and correspond to the numbers in the first three columns in Table 23-1. So '1' refers to Source Water, 'a' refers to *Cryptosporidium*, and 'i' refers to Nominal.

23.3 Appendix 3. Chemicals of Potential Concern in Water Reuse

Class	Chemical or Group	Source	Concerns
General	Biological oxygen demand (BOD), Dissolved Oxygen, Hardness ($CaCO_3$), Hydraulic load, Odour, pH, Suspended Solids, Temperature, Total dissolved salts, Total organic carbon, Turbidity	Just about everything that goes into sewage contributes to these 'general contaminants'. Many of the 'contaminants' listed in this category are not really contaminants at all, but characteristics of the water that result from the presence of the contaminants. They are traditional indicators of water quality and most of them will be very familiar to water and wastewater practitioners	The very general nature of these 'contaminants' results in a very diverse range of implications. The values (concentrations *etc*) associated with them, are generally interpreted as a measurement of 'quality' and potential pollution implications. To a large degree, these parameters are those which are targeted for significant removal (or improvement) during conventional water and wastewater treatment operations. Thus in many cases, they are relied upon as indicators of the effectiveness of wastewater treatment processes.
Nutrients	Boron, Calcium, Chloride, Iron , Magnesium, Nitrogen, Phosphorus, Potassium, Sodium, Sulphur	The principal source of many nutrients in sewage is degraded organic matter derived from human excretions. Inorganic sources of nutrients include detergent formulations and in many cases, industrial wastewater influxes.	Nutrients can be highly problematic since they sustain the growth of aquatic biota such as algae. In particular, nitrogen and phosphorous are typically 'limiting nutrients' for algal growth and an environmental influx of these nutrients can very often lead to blooms of a wide variety of algal species. Aquatic algae can result in taste and odour problems, the production and release of toxic chemicals, and a severe demand on dissolved oxygen leading to anaerobic conditions and death of many other aquatic species including fish. In areas with naturally high boron concentrations, additional influx of this micro-nutrient from replacement water may lead to toxicity to some sensitive crops
Metals/ metalloids/ halides	Aluminium, Arsenic, Barium, Beryllium, Bromate, Cadmium, Chromium, Copper, Cyanide, Fluoride, Iodine/Iodide, Iron, Lead, Manganese, Mercury, Molybdenum, Nickel, Selenium, Silver, Tin, Zinc	trace concentrations of many metals and halides in replacement water will reflect those from the original potable water supply. Additional contamination may be sourced from industrial discharges dependant on the nature of industries within the catchment area.	Some heavy metals such as cadmium, chromium and mercury have been associated with a number of human health concerns and thus significant concentrations can render recycled waters unsuited to many crop irrigation schemes. Furthermore, the physical-chemical nature of many of these metals may cause them to be strongly adsorbed to soils and efficiently taken up in foods, thus effectively accumulating smaller concentrations over time.

Class	Chemical or Group	Source	Concerns
Surfactants	Alkane ethoxy sulphonates (AES), Linear alkylbenzene sulphonates (LAS), Secondary alkanesulphonates	The listed compounds are anionic surfactants used in commercial and domestic detergent products. Applications include dishwashing and clothes washing detergents as well as hair shampoos. Linear alkylbenzene sulphonates are the most common.	Concerns regarding anionic surfactants are most likely to originate from their particularly high concentrations in raw sewages (1-20 $mg.L^{-1}$). Such concentrations may potentially be detrimental to some environmental organisms. However, conventional wastewater treatment is effective for the removal from the aqueous phase, significantly reducing associated risks. On the other hand, some anionic surfactants can be significantly adsorbed to biomass and concentrations may be enhanced in aerobically stabilised biosolids applied to land.
Organic compounds	Acrylamide, Alkyl phenols, Alkyltin compounds, Bisphenol A, Chlorinated dioxins, Chlorobenzene, Dichlorobenzenes, EDTA, Epichlorohydrin, Hexachloro-butadiene, Nitrilotriacetic acid, Polyaromatic hydrocarbons, Polychlorinated biphenyls, Phthalates, Styrene, Trichloro-benzenes, Vinyl chloride monomer	The majority of compounds listed in this category are synthetic industrial chemicals. Acrylamide is used to produce polyacrylamide and both of these compounds are used in the production of flocculants for water treatment. Alkyl phenols such as nonylphenol are widely used as non-ionic industrial surfactants. Alkyltins are widely used as biocides mainly in antifouling paints. Furthermore, dibutyltin is known to leach from polyvinylchloride (PVC) piping for which it is used as a heat stabiliser. Bisphenol A is used to make polycarbonate plastic and epoxy resins. Chlorinated dioxins may be formed as by-products of chlorination disinfection processes or of chlorine bleaching at pulp and paper mills. Chlorobenzene is used as a solvent for some pesticide formulations, as a degreaser, and to make other chemicals. 1,2- and 1,3-dichlorobenzenes are used as solvents in the manufacture of pesticides, medicines, and dyes. 1,4-Dichlorobenzene is used in mothballs and in toilet-deodoriser blocks. Ethylenediaminetetraacetic acid (EDTA) is widely used in many industrial processes and in food production as a metal chelating agent. It is also used in some detergents as a phosphate-substitute. Epichlorohydrin is used to make glycerine and various polymers, some of which are used in water supply systems. It has also been used as a water coagulating agent in some countries. Hexachlorobutadiene is a by-product of the manufacture of chlorinated hydrocarbons, but is also used to make rubber compounds, as a solvent, to make lubricants, as a heat transfer liquid, and as a hydraulic fluid. Nitrilotriacetic acid is a chelating agent, with many	Many of the industrial chemicals listed in this section are known to be highly toxic to a diverse range of organisms including humans. Due to their molecular structures, many are also highly lipophilic, thus having the strong potential to accumulate in sludge, soils and animal tissue. Furthermore, many of these compounds are highly to resistant to biodegradative removal and thus very stable in sewage and the environment.

Class	Chemical or Group	Source	Concerns
		industrial applications and is used in some detergents as a phosphate-substitute. Polyaromatic hydrocarbons originate primarily from petrochemical products and may contaminate sewage via industrial discharges, stormwater influxes, or household disposal of petrochemicals to sewage. Polychlorinated biphenyls have been widely used in the manufacture of many industrial products, but their use is now restricted. Nonetheless, their considerable persistence can account for continuing measurable concentrations in sewage. Phthalates are used in the production of various plastics including PVC and are among the most common industrial chemicals. They may (potentially) be released into wastewater during manufacture, use, and disposal. Styrene is used in the manufacture of polystyrene and other polymers. Styrene monomer can contaminate wastewater through sewage disposal of unsaturated polyester resin products used in fibreglass boat construction and repair, and as auto body fillers and casting plastics. Trichlorobenzenes are used in the production of pesticides, pigments and dyes. Vinyl chloride monomer is used industrially to produce PVC, other polymers and some chlorinated solvents.	
Volatile organics	Benzene, Carbon tetrachloride, Dichloroethanes, Dichloromethane, Ethylbenzene, Tetrachloroethene, Toluene, 111-trichloroethane, Trichloroethene, Xylenes	Volatile organic compounds (VOCs) are widely used as industrial solvents. The non-halogenated compounds are constituents of many petrochemical products, while the most of the halogenated compounds may be formed as by-products of chlorine disinfection.	Most of the VOCs listed above are suspected to be teratogenic or carcinogenic to humans. Because of their high potential to contaminate potable water sources and supplies, they are highly regulated in drinking waters. Many of them are environmentally conservative, so careful control will be particularly important in cased where planned or unplanned indirect potable reuse is likely.
Pesticides or their metabolites	2,4-D, Aldicarb, Aldrin/Dieldrin, Atrazine, Carbamates, Chlordane, Chlorpyrifos, DDT, Diuron, Diazinon, Endosulfan,	Pesticides may enter municipal wastewater systems by a variety of means including storm water influx and illegal direct disposal to sewage systems. Additional routes, of unknown significance, include washing fruit and vegetables prior to household consumption; insect repellents washed from human skin; flea-rinse shampoos for pets; washing clothes and equipment used for applying pesticides.	Pesticides have been designed and used to have detrimental effects on a wide range of biological species. Most of them are highly unspecific in their toxicity and thus may be expected to have significant deleterious impacts on the aquatic environment. Some pesticides are highly persistent in the environment.

Class	Chemical or Group	Source	Concerns
	Fungicides, Heptachlor and epoxide, Lindane, Organic mercurials, Organo-phosphates, Pyrethroids		
Algal toxins	Cylindro-spermospin, Microcyctins, Nodularin, Saxitoxins	Microcyctins, nodularins, cylindrospermopsin and saxitoxins are all produced by freshwater cyanobacteria (blue-green algae). Under suitable conditions, cyanobacteria may grow in recycled effluents, producing these and other toxins. Cyanobacterial growth and toxin production may occur subsequent to water treatment processes in environments such as storage tanks, ponds or distribution systems.	Numerous algal toxins have been implicated as having serious impacts on human and animal health by the consumption of contaminated water. Many of these toxins are hepatotoxic and some are neurotoxic.
Disinfection by-products	Chloral hydrate, Chlorate, Chloride, Chlorine dioxide, Monochloramine, Halogenated furonones, Chlorite, Chlorophenols, Chloropicrin, Cyanogen, Formaldehyde, Haloacetic acids, Haloacetonitriles, Haloaldehydes, Haloketones, Trihalomethanes	Disinfection by-products are formed by reactions between disinfection agents and other constituents of water. High initial concentrations of organic components or ammonia may lead to excessive production of disinfection by-products. The vast majority of the compounds listed here originate primarily from chlorine-based disinfectants. However, some (such as formaldehyde) can be produced by other oxidising disinfectants such as ozone. Some more recent by-products of concern (not listed here) include bromate (from ozone treatment) and nitrosodimethylamine (NDMA).	Disinfection by-products have been the source of much public health concern due to their widespread identification in drinking waters.
Radionuclides	Radium -226 and 228, Radon -222, Uranium generated (Cs137, Sr90 *etc*)	Radionuclides may enter sewage by natural run-off or as a result of medical or industrial usage. In most parts of the world, radium is a constituent of bedrock and hence a natural contaminant in groundwater. In some cases, radium is removed from drinking waters by coagulation and the concentrated sludge is transferred to sewage systems. Radon is a carcinogenic gas which comes from the radioactive breakdown of radium. Uranium-generated radionuclides (including Cs137 and Sr90) are produced during uranium	Radionuclides are carcinogenic and mutagenic substances. Most heavy radionuclides are heavily concentrated in sludges and may be of significant concern when applied to agricultural soils or areas which may later be developed for housing.

Class	Chemical or Group	Source	Concerns
		fission reactions. Uranium fission is used to generate electricity in some countries, but not in Australia.	
Pharmaceuticals	Oral contraceptives, Levonorgestrel, Ethinylestradiol, Analgesics, Ibuprofen, Paracetamol, Morphine, Naproxen, Ketoprofen, Other pharmaceuticals, Methamphetamine, Phenytoin, Carbamazepine, - Radiopharmaceuticals, Sedatives, Temazepam, Cardiovascular drugs, Beta blockers, Atenolol, Cholesterol lowering, Simvastatin, - Gemfibrozil, H. receptor agonists, Ranitidine, Antibiotics, Cephalexin, Cefaclor, Amoxicillin, - Metronidazole	Pharmaceuticals (and their metabolites) may be discharged to sewage via human excretions as well as direct disposal of unused drugs by households. Industrial discharge is a relatively very minor contributor due to the tight regulation of pharmaceutical industries.	Since pharmaceuticals are designed to instigate biological responses, their inherent biological activity and diverse range of compounds identified in sewages (and the environment) have been cause for considerable concern during the last decade. Specific concerns have not been raised for most classes of drugs, but…
Estrogenic and androgenic hormones	17 β-estradiol, Estrone, Testosterone	The estrogenic and androgenic hormones listed here are natural steroids excreted by people. For example, in the normal menstrual cycle 10-100 µg/day of 17 β -estradiol is typically excreted by women depending on the stage of the cycle. During pregnancy, up to 30 mg/day may be excreted. After menopause, estrogen excretion typically drops to around 5-10 µg/day. Men also excrete oestrogens at a rate of about 2-25 µg/day (Williams & Stancel, 1996). During metabolism, estradiol is primarily converted to estrone and further to estriol, which is the major urinary metabolite. Testosterone,	During the last two decades, natural steroidal hormones have been widely implicated in a range of endocrinological abnormalities in aquatic species impacted by sewage effluents. Impacts have been identified by a number of bioindicators, most commonly elevated production of the vitellogenin which is an essential precursor for egg production.

Class	Chemical or Group	Source	Concerns
		secreted by the testis is the main androgen in men, along with its similarly active metabolite dihydrotestosterone. These natural androgens are metabolised and excreted in urine as both free steroids and water-soluble conjugates.	
Antiseptics	Triclosan, Salicylic acid	Antiseptics such as triclosan are commonly used in face washes and anti-gum-disease toothpaste. Following trends from the USA, they are increasingly being used in a wider range of household products including deodorants, antiperspirants, detergents, dishwashing liquids, cosmetics and anti-microbial creams, lotions, and hand soaps.	Triclosan has been detected in sewage effluents and impacted surface waters (Kolpin *et al.*, 2002; Lindström *et al.*, 2002; Bester, 2003) as well as in the bile of wild fish in proximity to sewage treatment plant effluents (Adolfsson-Erici *et al.*, 2002). Toxic effects of triclosan have been reported for a diverse range of aquatic organisms (Orvos *et al.*, 2002).

23.4 Appendix 4. Sydney Water Catchment Survey Outcome

Sydney WATER

MEMORANDUM

To	Adam Lovell, S&T Program Manager
From	Phil Evans, Business Development Officer, CICS
Subject	Catchment Survey for Western Sydney Recycled Water Initiative
Date	6 June 2006

Sydney Water Corporation ABN 49 776 225 038

A desk audit was carried out by staff of Commercial and Industrial Customer Services to identify potential sources of certain chemicals in the catchments of Penrith, St Marys and Quakers Hill Sewage Treatment Plants. The chemicals were:

Common Chemical Name	Chemical Abstracts Registry Number
acrylonitrile	107-13-1
benzidine	92-87-5
chloroform	67-66-3
dibromochloromethane	124-48-1
2,2'-dichlorobenzidine	84-68-4
3,3'-dichlorobenzidine	91-94-1
1,2-diphenylhydrazine	122-66-7
trichloroethene	79-01-6

Acrylonitrile was not detectable in any samples collected for Sydney Water's Ecological and Human Health Risk Assessment (1995). Acrylonitrile is a reportable substance for the National Pollutant Inventory. Only two sources were identified in New South Wales and both were volatile (gaseous) emissions: from a municipal tip and from a steel mill. None of the sources were within the study area. Acrylonitrile is listed under the synonym 2-propenenitrile on the Australian Inventory of Chemical Substances.

Benzidine was not detectable in any samples collected for Sydney Water's Ecological and Human Health Risk Assessment (1995). Benzidine dyes are actively avoided because of their well-known health hazards, according to a survey of customers (undertaken in May 2006) in the study area who might be expected to either dyestuffs or re-process recycled containers containing dyestuffs. Benzidine is not a reportable substance under the National Pollutant Inventory. Benzidine is listed under the synonym [1,1'-Biphenyl]-4,4'-diamine on the Australian Inventory of Chemical Substances.

Chloroform is a common disinfection by-product commonly found at below 5 microgram per litre levels in potable water and sewage. The only discharges to water that were identified in the National Pollutant Inventory consisted of sewage treatment facilities. Chloroform is listed under the synonym trichloro-methane, on the Australian Inventory of Chemical Substances.

Dibromochloromethane is a disinfection by-product that is occasionally detected at or below 5 microgram per litre levels in potable water and sewage. Dibromochloromethane is not a reportable substance under the National Pollutant Inventory. Dibromochloromethane is not listed on the Australian Inventory of Chemical Substances, indicating that it is not an existing industrial chemical in Australia.

2,2'-Dichlorobenzidine is not a reportable substance under the National Pollutant Inventory. 2,2'-Dichlorobenzidine is not listed on the Australian Inventory of Chemical Substances, indicating that it is not an existing industrial chemical in Australia. No products could be located that had this substance listed on a material Safety Data Sheet.

3,3'-Dichlorobenzidine was not detectable in any samples collected for Sydney Water's Ecological and Human Health Risk Assessment (1995). It is not a reportable substance under the National Pollutant Inventory. It is listed under its synonym 3,3'-dichloro-[1,1'-Biphenyl]-4,4'-diamine on the Australian Inventory of Chemical Substances. No products could be located that had this substance listed on a material Safety Data Sheet.

1/2 7/06/06

1,2-Diphenylhydrazine was not detectable in any samples collected for Sydney Water's Ecological and Human Health Risk Assessment (1995). It is not a reportable substance under the National Pollutant Inventory. 1,2-Diphenylhydrazine is listed on the Australian Inventory of Chemical Substances. No products could be located that had this substance listed on a Material Safety Data Sheet.

Trichloroethene was detectable in 5 out of 193 sewage treatment plant effluent samples collected for Sydney Water's Ecological and Human Health Risk Assessment (1995), but not in any of the catchments considered in this study. The synonym trichloroethylene is a reportable substance under the National Pollutant Inventory, but no sources were reported for the study area other than diffuse sources. The quality of raw sewage is checked in each sewage catchment four times per year for trichloroethene and it was last detected above 5µg/L in the study area on one occasion in 1997.

Summary of findings

In conclusion, it is not expected that any point sources of acrylonitrile, benzidine, dichlorobenzidine or diphenylhydrazine will be detected within the study area. However, chloroform and dibromochloromethane are disinfection by-products and will be detectable wherever chlorine-based disinfection occurs. Also, trichloroethene is still commercially available especially in products used for cleaning metals prior to industrial processing.

23.5 Appendix 5. Relative Risks – Generic Changes in Contaminant Exposure Levels and the Likelihood that the Project will increase or decrease risks to exposed Populations

23.5.1 The Trade-off Between Increasing Treated Wastewater Hydraulic Loads and Improving in Water Quality

In undertaking this risk assessment the main concern was to assess whether the MF-RO facility would discharge water of a quality such that risk to exposed populations would be low in absolute terms (*e.g.* probability of infection <1 μDALY or prob. of infection < 10^{-4}.peson^{-1}.y^{-1}).

A second way of considering the change in risk levels posed by the project was to assess whether construction of the treatment plant would decrease relative risks compared to the current situation. Given that the proposal involved installation of additional high efficiency water treatement, two outcomes were seen as likely:

- Either the (relative) risk arising from contaminants in current STP discharges to the river would be likely to be decreased for all pathogens and chemicals; or
- whether the large majority of contaminants would be decreased while a small number would be increased to minor extent reflecting increased hydraulic load.

In the first instance it was considered that there would likely be no disbenefit from the replacement water. In the second it was perceived that increased risk arising from the increase in volume of STP-derived water discharged might be counterbalanced by the improved overall water quality of the discharge.

To provide the basis for assessing changes in relative risk the following specific question was considered – When would the risk arising from discharging *ca* 30 gigalitres.y^{-1} per year MF-RO polished wastewater be much less or greater than the risk arising from the current discharge of tertiary treated sewage at Penrith (*ca* 10 Gigalitres.y^{-1})?

The change in risk at the point of discharge would not be constant but be moderated by dilution with existing environmental flows, the extent of which varies markedly with total river flow. Table 23-3 shows a range of flows the river experiences and the protective effect from Penrith STP discharges obtained by dilution alone at different flow rates. The effect at different flows is calculated as a 'Protection Factor' which is defined here as:

= [Concentration of a contaminant in tertiary Penrith STP wastewater]/[Concentration of a contaminant following release].

The effect of increasing the volume of STP-derived but MF-RO polished 'replacement water' on the 'Protection Factor' is shown in Table 23-4. The relative magnitude of this change in risk has been estimated assuming:

- The composition of the wastewater from the other two STPs would be the same as that currently discharged by Penrith STP; and
- The volume released from the MF-RO plant would be 3 times that currently discharged by Penrith STP.

It can be seen that provided the polishing plant reduces the concentration of any given contaminant by 68% then a similar set of protection factors will be achieved for similar upstream flows. And once 90% removal of a contaminant is achieved the protective factor will be sufficient for the resulting receiving water quality to be better than the current

situation under virtually all flow conditions. Table 3 shows the effect in a modified format. That is, it shows the %increase in concentration in the river of STP-derived contaminants. This illustrates that in the worst case of zero removal the increase in concentration is at most 200% (*i.e.* a factor of 3).

Under nominal operating conditions all pathogens, including viruses, should be reduced by a factor $>10^6$. But even under membrane failure conditions available data suggests the reductions should still be at least 10^2 (99% removal), equivalent to a protective factor of at least 100. Thus the risk of acquiring an infectious disease would always be greatly reduced relative to the current situation. Similarly as phosphate ions should be reduced by at least 90% an MF-RO plant should also markedly reduce the relative potential for cyanobacterial blooms.

In respect to chemicals the situation is slightly different. While the majority of organic and inorganic species are reduced in concentration by >90%, a few are less well removed, notably disinfection by-products and some inorganic toxic compounds such as H_2S (see Tables 12.2 and 12.5). Further, disinfection by-products can also be formed to varying degrees as a result of the operation of MF-RO plants.

On the whole this assessment suggests that the relative risk variation is as follows:

- Pathogen risk would be reduced many orders of magnitude even in the event of occasional breakdowns;
- Cyanobacterial bloom risk would be markedly reduced;
- The risk from most chemicals would be reduced by one or more orders of magnitude;
- Some disinfection by-products and inorganic chemicals would remain whose concentration should increase by no more that 3 times the current levels;
- Additional disinfection by-products might be formed at the MF-RO plant whose impact also needs to be considered.

Another potentially important relative benefit is the reduction in risks to users of those streams which drain the other STP discharge (South Ck and Eastern Ck?). The main consideration here is whether such benefits would create significant disbenefits to main river users

Table 23-3. Initial Protective Effect Provided by Dilution in River of Contaminants in Discharged in Tertiary Treated Wastewater at Penrith (*i.e.* Current Situation)

Gigalitres.y^{-1} (ML.d^{-1}) of Other Upstream Flow in River	% of Initial Wastewater Contaminant Concentration Remaining after dilution	Protection Factor for Penrith STP Contaminant Concentration Obtained by Dilution Alone
1000 (2739)	0.99	101
500 (1369)	1.96	51
200 (547)	4.7	21
100 (273)	9.1	11
50 (136)	16.7	6
30 (82)	25.0	4
20 (54)	33.3	3
10 (27)	50.0	2
5 (13)	66.7	1.5
2 (5)	83.3	1.2
1 (2)	90.9	1.1

Notes:
1. Assumes Penrith STP releases 10 Gigalitres of Tertiary Treated Wastewater per year.
2. Shading is as follows:
    a. Dark grey – protection factor < 2
    b. Light grey – 2 < protection factor < 5
    c. No shading – protection factor > 5

Table 23-4. Protective Effect as Total Protection Factor Provided by Dilution in River + Additional Treatment Provided by MF+RO Plant to Exposure from Contaminants in Discharged Treated Wastewater

Gigalitres.y^{-1} (ML.d^{-1})	%Reduction [Decimal Reduction Factor] by MF+RO						
	0% [0]	37% [0.2]	68%[0.5]	90% [1]	97%[1.5]	99% [2]	99.9%[3]
1000 (2739)	34	54	109	343	1086	3433	34333
500 (1369)	18	28	56	177	559	1767	17667
200 (547)	7.7	12	24	77	242	767	7667
100 (273)	4.3	6.9	14	43	137	433	4333
50 (136)	2.7	4.2	8.4	27	84	267	2667
30 (82)	2.0	3.2	6.3	20	63	200	2000
20 (54)	1.7	2.6	5.3	17	53	167	1667
10 (27)	1.3	2.1	4.2	13	42	133	1333
5 (13)	1.2	1.8	3.7	12	37	117	1167
2 (5)	1.1	1.7	3.4	11	34	107	1067
1 (2)	1.0	1.6	3.3	10	33	103	1033

Notes:
1. Shading is as follows:
    a. Dark grey – protection factor < 2
    b. Light grey – 2 < protection factor < 5
    c. No shading – protection factor > 5

Table 23-5 % Increase in Concentration of Contaminants from SW Treated Wastewater in River Under Varying River Flow and MF-RO Removal Enhancement Scenarios

Gigalitres.y^{-1} (ML.d^{-1}) from Upstream	%Reduction [Decimal Reduction Factor] by MF+RO						
	0% [0]	37% [0.2]	68%[0.5]	90% [1]	97%[1.5]	99% [2]	99.9%[3]
1000 (2739)	194%	86%	-7%	-71%	-91%	-97.1%	-99.7%
500 (1369)	189%	82%	-9%	-71%	-91%	-97.1%	-99.7%
200 (547)	174%	73%	-13%	-73%	-91%	-97.3%	-99.7%
100 (273)	154%	60%	-20%	-75%	-92%	-97.5%	-99.7%
50 (136)	125%	42%	-29%	-78%	-93%	-97.8%	-99.8%
30 (82)	100%	26%	-37%	-80%	-94%	-98.0%	-99.8%
20 (54)	80%	14%	-43%	-82%	-94%	-98.2%	-99.8%
10 (27)	50%	-5%	-53%	-85%	-95%	-98.5%	-99.9%
5 (13)	29%	-19%	-59%	-87%	-96%	-98.7%	-99.9%
2 (5)	13%	-29%	-64%	-89%	-96%	-98.9%	-99.9%
1 (2)	6%	-33%	-66%	-89%	-97%	-98.9%	-99.9%

Notes.
1. Assumptions
    a. All three treatment plants generate similar quality tertiary effluent.
    b. Current inflow at Penrith is 10 GL/year compared to 30 GL/y when replacement water added
    c. Does not include contaminants in environmental flows.
2. A negative value indicates a % decrease in concentration.

3. Shading is as follows:
    a. Dark grey – Increase in concentration > 100%
    b. Intermediate grey – Increase in concentration 50-100%
    c. Light grey – Increase in concentration < 50%
    d. No shading – Decrease in concentration

23.5.2 Microbial River Contaminants from Other Sources

The relative risk assessment in the previous section also informs the question of how the project would impact on pathogen levels in the river. If implemented the outcome would be that pathogens originating from the STP would be reduced by 2 orders of magnitude most of the time and probably much more.

Since the influence on relative pathogen risks of an MF-RO plant should always be highly beneficial, alternate situations can be expected:

- Where a given pathogen's population downstream of Penrith is dominated by discharge from the STP, there would be a great decrease in exposure; or
- Where pathogen populations are dominated by those from upstream of the STP, a more limited improvement would occur due to:
    - The replacement of some river water by cleaner MF-RO water;
    - Greater dilution by the MF-RO water.

Either way the MF-RO plant should be beneficial.

23.5.3 Uncertainties and Assumptions

The assessment of relative risks here is considered to be relatively robust. The main uncertainties are seen as:

- The acceptability of moderate (from an order of magnitude perspective) increases in some specific contaminant concentrations; and
- The significance of MF-RO by-products.

The issue of small toxicant impacts is again the major consideration as is the case with estimation of absolute risks for toxic chemicals. It is conceivable though as many are very volatile or may be rapidly reduced to tolerable concentrations by environmental processes. Thus the key concern for decision makers may be whether their fate and transport near the point of discharge is sufficient to make their concentrations tolerable.

Appendix E

Terrestrial ecology assessment



Replacement Flows Project

Terrestrial Ecology Assessment

- FINAL
- 24 October 2006

Replacement Flows Project

Terrestrial Ecology Assessment

- FINAL
- 24 October 2006

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1. Introduction

1.1 Project Description

The Replacement Flows Project is an integrated water management system that would increase water availability from Warragamba Dam. The project consists of the construction and operation of works to enable the discharge of up to 50 ML/day of highly treated recycles water to the Hawkesbury-Nepean River below the existing Penrith Weir. The intent of this discharge is to provide replacement flows for water currently discharged from the Warragamba Dam to maintain flows in the river for irrigation and environmental health. The infrastructure to provide this recycled water comprises:

- an Advanced Water Treatment Plant (AWTP) at the St Marys STP site
- pumping stations and pipelines which would transfer tertiary treated wastewater from Quakers Hill, Penrith and St Marys STPs to the proposed AWTP at St Marys
- pumping station and pipeline for the transfer of the concentrate stream from the AWTP, via Quakers Hill STP to the Northern Suburbs Ocean Outfall Sewer (NSOOS) at Vineyard Creek, Dundas
- a pipeline for the transfer of recycled water from the AWTP to the existing outlet into Boundary Creek at Penrith STP, which discharges into the Hawkesbury-Nepean River below Penrith Weir or discharge directly into the Hawkesbury-Nepean River.

For the purposes of this investigation the 'study area' refers to the land directly subject to the proposed pipeline works and associated infrastructure development as well as immediately adjacent areas within proximity to the works, which may be indirectly affected by construction activities including naturally vegetated areas.

1.2 Objectives

This report documents the results of a flora and fauna assessment conducted by Sinclair Knight Merz to investigate the proposed pipeline routes associated with the Replacement Flows Project. The information presented in the report is based on a review of available data and site investigations to assess the potential impacts of the proposal in relation to relevant State and Commonwealth environmental and threatened species legislation. The report provides reference to the flora and fauna assessment previously prepared for the proposed AWTP site at St Marys (SKM 2006).

The specific objectives of this report are to:

- describe the type, condition and distribution of native flora and fauna species in the area
- evaluate the significance of native flora, fauna and fauna habitat in the local and regional context
- assess the potential impact of the proposal on native flora and fauna, including threatened species listed under the *Threatened Species Conservation Act* 1995 and Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999, which occur in or in the general vicinity of the study area;
- assess the proposal in accordance with the DEC's *Guidelines for Threatened Species Assessment* and *Guidelines for Developments Adjoining National Park Lands*
- provide management recommendations to ameliorate the identified direct or indirect impacts of this proposal on flora and fauna.

1.3 Planning Context

1.3.1 Environment Protection and Biodiversity Conservation Act 1999

Under the Commonwealth *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act), approval of the Commonwealth Minister for the Environment is required for any action that may have a significant impact on matters of National environmental significance. These matters are:

- World heritage properties
- Ramsar wetlands
- cetaceans, migratory species, threatened species, critical habitats or ecological communities listed in the EPBC Act
- Commonwealth land, marine areas or reserves
- nuclear actions.

The potential impact of the Replacement Flows Project on matters of National environmental significance, in relation to flora and fauna impacts is addressed in **Section 4.3**.

1.3.2 Threatened Species Conservation Act 1995

The *Threatened Species Conservation Act 1995* provides protection for threatened plants and animals native to NSW (excluding fish and marine vegetation, which are protected under the *Fisheries Management Act 1994*), endangered ecological communities and critical habitat. It integrates the conservation of threatened species into development control processes under the *Environmental Planning and Assessment Act 1979.*

A licence is not required under the TSC Act to harm a threatened species, population or community for any activity undertaken in accordance with a development consent granted under the EP&A Act, as the consent authority is required to assess the impact of the proposal on threatened species, populations or communities prior to granting development consent. Part 3A guidelines also indicate that an SIS would not be required for a project approved under Part 3A of the *Environmental Planning and Assessment Act 1979.*

A description of the potential impacts of the proposed Replacement Flows Project on threatened species, populations and/or communities is contained in **Section 4**.

1.3.3 Rare or Threatened Australian Plants

The Rare or Threatened Australian Plants (ROTAP) list and associated coding system was developed and has been maintained by CSIRO since 1979, and lists taxa that are Presumed Extinct, Endangered, Vulnerable, Rare or Poorly Known at the national level.

ROTAP is used as the basis for Schedule 1 of the Commonwealth Endangered Species Protection Act 1992 and is also the defining reference for rare taxa within the Australian National Botanic Gardens and Australian Network for Plant Conservation.

2. Preliminary Review

2.1 Regional Setting

The Replacement Flows Project is situated within the Cumberland Plain of Western Sydney. The broad shallow basin of the Cumberland Plain stretches from Ryde in the east to the Nepean River in the west; from Cattai in the north to Thirlmere in the south. The native vegetation of the Cumberland Plain is varied, reflecting its range of soil types, landforms and drainage. Vegetation communities of the Cumberland Plain range from open woodlands with a grassy understorey, to forests with tall ironbarks and turpentine trees, and from dry rainforests to floodplain communities on the Hawkesbury-Nepean River.

2.2 Existing Environment

A considerable body of literature currently exists on the vegetation of the Cumberland Plain of Western Sydney. Of these, NPWS (2000) provides the most comprehensive mapping of the vegetation of this area based on aerial photographic interpretation and plot-based data. This work links broad structural and floristic differences in vegetation to major geology types, namely alluvial, shale and sandstone and associated transitional soil types. This has provided the major work upon which strategic planning has been made in Western Sydney to date and the scientific data to support the listing of endangered ecological communities on the Cumberland Plain.

Native Vegetation of the Cumberland Plain (NPWS 2000)

NPWS (2000) broadly mapped and described the vegetation occurring on the Cumberland Plain. Eighteen map units were described, of which 6 were shown to occur in the area from Penrith to Quakers Hill and south west to Warragamba Dam [including Shale Hills Woodland (9); Shale Plains Woodland (10); Castlereagh Ironbark Forest (3); and Shale-Sandstone Transition Forest (1) each of which are listed as endangered ecological communities under the TSC Act; in addition to Alluvial Woodland (11) and Riparian Forest (12)]. This work provides an understanding of the vegetation present on the Cumberland Plain of Western Sydney, and forms the background upon which the current assessment is based.

2.3 Biodiversity Databases

Data sources used in this review included the:

- DEC Atlas of NSW Wildlife
- database of the Royal Botanic Gardens PlantNET and Australian Museum FaunaNET
- records published in scientific journals, reports and general flora and fauna distribution texts
- results of local environmental studies, and studies done to support various environmental impact assessments (e.g. SKM and PPK 2000)

- other relevant databases including the National Herbarium, Department of Environment and Heritage (nationally threatened species, EPBC Act), and records published in the Birds Australia database.

All of the threatened flora and fauna species, endangered populations and ecological communities known to occur within the study locality have been tabulated. This information would be utilised in the preparation of lists of threatened species deemed potential inhabitants of the proposed pipeline routes (i.e. potential subject species).

2.4 Threatened Flora

A total of 53 threatened flora species are known from the greater Sydney area (**Table 1**). Of these species at least 20 are considered likely to occur in the study area on the basis of potential habitat being present. The remaining 33 species have either very marginal or have no habitat elements present in the study area and are therefore highly unlikely to occur.

Table 1 Threatened Flora Species recorded from the greater Sydney area.

Threatened Flora	Status			Likely presence in study area
	Cwlth	NSW	RoTAP	
Acacia bynoeana	V	E	3VC-	None
Acacia gordonii	E	E	2K	None
Acacia pubescens	V	V	3VCa	Potential to occur
Acrophyllum australe	V	V	2VCi	None
Ancistrachne maidenii	-	V	2KC-	None
Allocasuarina glareicola	E	E	2E	None
Astrotricha crassifolia	V	V	2VC-	None
Cynanchum elegans	E	E	3ECi	None
Darwinia biflora	V	V	2VCa	None
Darwinia peduncularis	-	V	3RCi	None
Dillwynia tenuifolia	V	V	2RCa	Potential to occur
Diuris aequalis	V	E	3VC-	Potential to occur
Epacris purpurascens var. purpurascens	-	V	2KC-	Potential to occur
Epacris sparsa	V	V	2VCi	None
Eucalyptus benthamii	V	V	2VCi	Potential to occur
Eucalyptus camfieldii	V	V	2VCi	None
Eucalyptus spp. cattai	-	E	-	None
Galium australe	V	V	-	Potential to occur
Genoplesium baureri	-	V	3RC-	None
Grevillea juniperina subsp. juniperina	-	V	-	Potential to occur
Grevillea parviflora subsp. parviflora	V	V	-	Potential to occur
Grevillea parviflora subsp. supplicans	-	E	-	None

Threatened Flora	Status			Likely presence in study area
	Cwlth	NSW	RoTAP	
Gyrostemon thesioides	-	E	2KC-	None
Haloragis exalata subsp. exalata	V	V	3VCa	Potential to occur
Hibbertia superans	-	E	-	Potential to occur
Hypsela sessiliflora	Ex	E	2X	Potential to occur
Kunzea rupestris	V	V	2VCa	None
Lasiopetalum joyceae	E	E	2RC-	None
Leptospermum deanei	V	V	2V	None
Leucopogon exolasius	V	V	2VC-	None
Leucopogon fletcheri subsp. fletcheri	-	E	2RC-	Potential to occur
Melaleuca biconvexa	V	V	-	None
Melaleuca deanei	V	V	3RC-	None
Micromyrtus blakelyi	V	V	2VCi	None
Micromyrtus minutiflora	V	E	2V	Potential to occur
Persicaria elatior	V	V	3V	Potential to occur
Persoonia acerosa	V	V	2VC-	None
Persoonia bargoensis	V	E	2V	None
Persoonia hirsuta	E	E	3KCi	None
Persoonia mollis subsp. maxima	E	E	2E	None
Persoonia nutans	E	E	2ECi	Potential to occur
Pilularia novae-hollandiae	-	E	-	Potential to occur
Pimelea curviflora var. curviflora	V	V	-	Potential to occur
Pimelea spicata	E	E	3ECi	Potential to occur
Pomaderis brunnea	V	V	2VC-	Potential to occur
Pterostylis saxicola	E	E	-	None
Pultenaea parviflora	V	E	2E	Potential to occur
Pultenaea pedunculata	-	V	-	None
Rulingia prostrata	E	E	2ECi	None
Syzygium paniculatum	V	V	3VCi	None
Tetratheca glandulosa	V	V	2VC-	None
Wilsonia backhousei	-	V	-	None
Zieria involucrata	E	V	2VCa	None

Note: V – vulnerable, E – endangered, Ex – extinct.

RoTAP Plant Distribution: 2 - Restricted distribution - range extending over less than 100km, 3 - Range more than 100km but in small populations. Conservation Status: X – Presumed extinct - not collected for 50 years or the only known populations destroyed, E** - Endangered - at serious risk in the short term (one or two decades), V** - Vulnerable - at risk over a longer period (20-50 years), R– Rare but with no current identifiable threat, K - Poorly known species suspected of being at risk. Reservation Status: - - Species is recordered from a reserve but the population size is unknown, t - Total known species population is within a reserve, Px Western Australian Department of Conservation and Land Management (CALM) Priority Flora Code. Range from P1 (highest priority) to P4 (lowest priority), + - Species also occurs outside of Australia

2.5 Endangered Ecological Communities

A number of Endangered Ecological Communities (EECs) listed under the TSC Act and EPBC Act are represented within the Cumberland Plain area of Western Sydney. The presence of these within the study area has been investigated as part of this study and is documented in the following chapter.

2.6 Threatened Fauna

A total of 35 threatened fauna species have previously been recorded from the greater Sydney area (**Table 2**). An assessment of the potential for these species to occur was conducted indicating that 13 of these species have suitable habitat elements present within the study area.

Table 2 Threatened Fauna Species recorded from the greater Sydney area

Threatened Fauna	Status		Likely presence in study area
	NSW	C'wlth	
Green and Golden Bell Frog *Litoria aurea*	E	V	Unlikely, no suitable habitat
Regent Honeyeater *Xanthomyza phrygia*	E	E	Unlikely, no suitable habitat
Swift Parrot *Lathamus discolor*	E	E	Unlikely, no suitable habitat
Spotted-tailed Quoll *Dasyurus maculatus*	V	V	Unlikely, no suitable habitat
Grey-headed Flying-fox *Pteropus poliocephalus*	V	V	Potential foraging habitat present
Cumberland Land Snail *Meridolum corneovirens*	E		The habitat is marginal and populations of this species are well represented in the locality. Could potentially occur.
Koala *Phascolarctos cinereus*	V		The habitat is marginal although no populations occurring in the study area; not expected.
Eastern Pygmy-possum *Cercartetus nanus*	V		Unlikely, no suitable habitat
Yellow-bellied Glider *Petaurus australis*	V		Unlikely, no suitable habitat
Squirrel Glider *Petaurus norfolcensis*	V		Potential habitat at St Marys
East Coast Freetail-bat *Mormopterus norfolcensis*	V		Potential foraging habitat present.
Eastern Bent-wing Bat *Miniopterus schreibersii*	V		Potential foraging habitat present, known roost sites in the Penrith area.
Large-eared Pied Bat *Chalinolobus dwyeri*	V		Unlikely, no suitable habitat
Large-footed Myotis *Myotis macropus*	V		Potential foraging habitat present. Possible roost sites with the western Sydney area
Eastern False Pipistrelle *Falsistrellus tasmaniensis*	V		Potential foraging habitat present
Greater Broad-nosed Bat *Scoteanax rueppellii*	V		
Giant Burrowing Frog *Heleioporus australiacus*	V		Unlikely, no suitable habitat
Red-crowned Toadlet *Pseudophryne australis*	V		Unlikely, no suitable habitat
Freckled Duck *Stictonetta naevosa*	V		Potential as vagrant visitor to treatment ponds at STP's, no impacts on habitat from the development
Blue-billed Duck *Oxyura australis*	V		
Australasian Bittern *Botaurus poicilioptilus*	V		Unlikely, no suitable habitat
Black Bittern *Ixobrychus flavicollis*	V		

Threatened Fauna	Status		Likely presence in study area
	NSW	C'wlth	
Square-tailed Kite *Lophoictinia isura*	V		Unlikely, no suitable habitat
Grey Falcon *Falco hypoleucos*	V		
Glossy Black-Cockatoo *Calyptorhynchus lathami*	V		Unlikely, no suitable habitat
Superb Parrot *Polytelis swainsonii*	V		Unlikely, no suitable habitat
Turquoise Parrot *Neophema pulchella*	V		
Barking Owl *Ninox connivens*	V		Unlikely, habitat marginal
Masked Owl *Tyto novaehollandiae*	V		
Powerful Owl *Ninox strenua*	V		Habitat is marginal although too fragmented and small in size, not expected to occur.
Grass Owl *Tyto capensis*	V		Habitat is not suited to these species
Sooty Owl *Tyto tenebricosa*	V		
Black-chinned Honeyeater *Melithreptus gularis*	V		The habitat at St Marys is marginal compared to better quality woodlands in the surrounding area, not expected.
Speckled Warbler *Chthonicola sagittata*	V		
Brown Treecreeper *Climacteris picumnus*	V		

Note: V – vulnerable, E – endangered, Ex – extinct.

3. Site Assessment

Site assessments for the proposed pipeline routes and associated infrastructure areas were conducted on 24-25 July and 8-11 August 2006. The extent and quality of native vegetation, fauna habitats and species diversity were recorded, targeting the threatened species and endangered ecological communities listed previously.

Impacts on vegetation may result from the clearing for construction of the AWTP, concentrate storage pond and linking pipelines. Accordingly, the high conservation value of remnant vegetation in Western Sydney, in particular Cumberland Plain Woodland has been recognised and in all cases the proposed infrastructure associated with the project has been located to avoid impacts on native vegetation. Therefore the majority of the proposed pipeline routes would traverse along adjoining residential property boundaries and road verges such that very minimal clearing would be required.

The sensitive nature of the proposed works in terms of minimal disturbance to vegetation and the placement of pipelines through a cleared landscape precluded the necessity for detailed flora and fauna surveys using the full range of techniques available (i.e. mammal trapping, spotlighting and flora quadrats). Surveys relied on physical inspection of the routes and recording species present at the time of the survey, in addition to detailed assessment of the value of the habitat for the conservation of threatened flora and fauna species and ecological communities. In this regard a precautionary approach was adopted whereby the features of significance for threatened species were identified and protective strategies adopted for features likely to be deemed critical for these species and their habitats.

Detailed flora and fauna surveys were conducted at the proposed AWTP site at St Marys STP given the presence of remnant and regrowth vegetation with the proposal footprint and potentially impacted by the project.

3.1 Methods

For the purposes of this assessment, the proposed pipeline routes were separated into discrete areas and the vegetation and fauna habitat values in each area described. The following eight areas are used to describe ecological attributes:

Major Pipeline Route	Area 1	Penrith STP to Dunheved Golf Course
	Area 2	Dunheved Golf Course to Palmyra Avenue
	Area 3	Palmyra Avenue to Richmond Road
	Area 4	Richmond Road to the M7
	Area 5	The M7 to Quakers Hill STP

Concentrate Pipeline Extension	Area 6	Powers Road Option
	Area 7	International Peace Park to Hammers Road
	Area 8	Hammers Road to Vineyard Creek
AWTP	Area 9	St Marys STP
Concentrate Storage Pond	Area 10	Quakers Hill STP

A flora survey was conducted in each area concentrating on the lands within approximately 30 metres either side of the centreline for the proposed pipeline. The survey involved identification of the floristics and structure of the vegetation and the type and distribution of any plant communities. Field surveys were conducted as traverses along the pipeline route with closer inspections of any areas of ecological significance. The condition of any vegetation within the study area was noted, including the extent of modification and weed invasion.

Areas of remnant vegetation were assessed to determine the presence and extent of endangered ecological communities known from the greater Sydney area and listed under the TSC Act and EPBC Act (refer to Section 2.5). Where feasible, mapping of vegetation was done for the broader area surrounding the works site including lands up to 100 metres from the pipeline.

Despite the presence of intact woodland communities in the wider area, the majority of the proposed pipeline routes would traverse along cleared residential property boundaries, road verges and bushfire protection zones which are devoid of fauna habitat value. As such a detailed investigation using the full range of survey techniques was not considered necessary. The field surveys were based on precautionary habitat assessment and the adoption of protective strategies for features deemed likely to be critical habitat for threatened fauna species known from the area. During the survey, all opportunistic sightings of fauna species were recorded and in areas of remnant vegetation ground debris, such as fallen logs, rocks and leaf-litter were inspected for Cumberland Plain Snails *Meridolum corneovirens* (TSC Act).

Searches were conducted for threatened flora and fauna species listed under the TSC Act and EPBC Act (refer to Section 2), as well as rare or significant plant species (Briggs and Leigh 1996).

3.2 Results

The vegetation communities identified in the general area are typical of those documented for the Cumberland Plain region (e.g. NPWS 2000) and are primarily linked to local geology and associated shale, gravel and alluvial soils. Natural vegetation present within proximity to the pipeline routes generally comprises remnant or regrowth Grey Box *Eucalyptus molucanna* and Forest Red Gum *E.tereticornis* communities in more elevated areas and riparian vegetation dominated by Swamp Oak *Casuarina glauca* along creek lines and low depressions.

At the eastern end of the study area, in proximity to the proposed concentrate extension pipeline linking the NSOOS at Vineyards Creek, patches of disturbed remnant vegetation dominated by Sydney Blue Gum *E.saligna* and Blackbutt *E.pilularis* were noted.

3.2.1 Flora and Fauna Species Recorded

Area 1 – Penrith STP to Dunheved Golf Course

A large Freshwater Wetland adjoins the northern and eastern boundaries of the Penrith STP. Freshwater wetland communities in NSW are classified as endangered ecological communities under the TSC Act. The proposed pipeline would be restricted to a maintenance trail along the southern edge of the wetland as shown in **Plate 1** and **Figure D1a**. This wetland community is dominated by Common Reed *Phragmites australis* with tall Sedges *Carex appressa* and Cumbungi *Typha orientalis* along with numerous weed species, particularly along the fringes including Purple Top *Verbena bonariensis* and Kikuyu *Pennisteum clandestinum*. While the proposal has been designed to avoid direct impacts on this wetland, potential indirect impacts should be managed during construction through sediment and erosion control and marking the limits of clearing.

The pipeline traverses northeast through an area of disturbed remnant and regrowth woodland dominated by Grey Box occurring with Forest Red Gum, Cabbage Gum *E.ampifolia* and Thin-leaved Ironbark *E.crebra*. (refer to **Figure D1a**) The understorey is highly disturbed and dominated by African Lovegrass *Eragrostis curvula,* a noxious weed in the local area. There is a low abundance of native species in the understorey as a result of ongoing disturbances. Dominant species include Blackthorn *Bursaria spinosa* and Sydney Green Wattle *Acacia parramattensis*. This vegetation is characteristic of Shale Hills Woodland (Map Unit 9: NPWS 2000) and listed under the EPBC Act and TSC Act as Cumberland Plain Woodland.

At this location the pipeline construction would be restricted to an existing sealed pathway (refer to **Plate 2**) and no clearing of vegetation would be required.

The remainder of the proposed pipeline route through Area 1 up to Dunheved Golf Course is to be restricted to modified suburban areas including Andrews Road Baseball Complex, Andrews Road verge and a cleared and maintained Asset Protection Zone (APZ) approximately 20 metres wide along the northern edge of suburban properties including Cambridge Gardens and Werrington Downs before meeting the northern edge of Dunheved Golf Club. While relatively large fragments of Cumberland Plain Woodland associated with the former ADI site are present adjacent to the APZ and proposed pipeline such vegetation would not be directly impacted upon by the proposed works which would be restricted to cleared lands. There is a need to manage indirect impacts as discussed in the recommendations section of this report.

Habitat for fauna along the works corridor comprises cleared and modified habitats such as open grass, road verges and some planted shrubs and small trees in landscaped urban areas. Such

Figure D1a High value conservation areas



habitats are characterised by a lack of natural vegetation cover in the form of trees and shrubs and no specific fauna habitat value. These habitats are frequented by a range of common fauna species adapted to modified landscapes. Fauna includes mostly birds, including insectivores such as the Australian Magpie, Magpie Lark and Masked Lapwing, and granivores such as the Eastern Rosella and aerial foragers such as the Welcome Swallow and Fairy Martin. The cleared habitats provide some value for grazing mammals such as Eastern Grey Kangaroo which was noted within the APZ adjoining woodland areas.

The proposed pipeline would not directly impact on habitat for threatened fauna species. Low to moderate quality habitat for the Cumberland Land Snail is present within the area of Cumberland Plain Woodland immediately east of the Penrith STP and high quality habitat for fauna including threatened species is recognised throughout the former ADI site. There would be no direct impacts on high quality fauna habitat given that all infrastructure would be located in cleared lands. There is a need to manage indirect impacts as discussed in the recommendations section of this report.



Plate 1. Pipeline route adjacent to wetland (left) near Penrith STP



Plate 2. Pathway through Cumberland Plain Woodland

Area 2 – Dunheved Golf Course to Palmyra Avenue

Area 2 commences a traverse along the northern perimeter of Dunheved Golf Course along the boundary of the course and the former ADI site (refer to **Figure D1a**). At this location the pipeline would continue to traverse cleared land adjacent to property fences. The pipeline would continue east through cleared land to the pumping station on Links Road at St Marys after crossing South Creek. The riparian vegetation along the creek supports a moderately to highly disturbed community dominated by weeds, mainly Large-leaved Privet, with a sparse native canopy cover of Swamp Oak and Forest Red Gum. The presence of the later species and elevation is characteristic of the listed River-flat Eucalypt Forest, an endangered ecological community (EEC) scheduled under the TSC Act.

To avoid impacts on the EEC vegetation it is proposed to use a directional bore to lay pipeline under the creek. The bore would start and end within cleared and disturbed land and there is no requirement to clear remnant riparian vegetation.

From the pumping station the pipeline route follows Link Road through to Forrester Road by traverse along the road verge which is predominantly maintained grass and weeds. A narrow strip of Grey Box trees is present within the road verge immediately west of St Marys STP, and depending on the exact location of the pipeline route in this area some of these trees may be removed. Grey Box is a component of the Cumberland Plain Woodland EEC, which is well represented throughout the ADI site to the north and west of the STP. Areas of remnant vegetation (EEC) adjacent to Links Road including buffer vegetation at St Marys STP would be avoided, with the pipeline restricted to the cleared road verge.

The pipeline would continue along Forrester and cross Ropes Creek using a directional bore (refer to **Figure D1b**). The creek banks support disturbed remnant riparian vegetation characteristic of the listed River-flat Eucalypt Forest scheduled under the TSC Act. Canopy species along Ropes Creek include Swamp Oak and the exotic Weeping Willow *Salix babylonica* and on the northern side of the creek regenerating Cabbage Gum *Eucalyptus amplifolia* and Sydney Green Wattle are present (refer to **Plate 3**). The understorey is highly disturbed containing a diversity of exotic species including Wandering Dew *Tradescantia fluminensis* and Cleavers *Galium aparine.* The use of directional boring for construction of the pipeline would avoid the need to clear vegetation along Ropes Creek.



Plate 3. Ropes Creek vegetation (northern side)

The pipeline route traverses the verge along Forrester Road continuing northeast of Ropes Creek. Relatively large areas of remnant Shale-Gravel Transitional Forest have been identified to the north of Forrester Road (NPWS 2000) and Ropes Creek. This community is listed as an EEC under the TSC Act. The occasional small Broad-leaved Ironbark *Eucalyptus fibrosa* tree associated with this

Figure D1b High value conservation areas



community is located close to the pipeline route in the vicinity of the intersection with Palmyra Road. There is scope to avoid direct impact on these trees with the implementation of strict construction controls.

Habitat for fauna along the works corridor comprises cleared and modified habitats such as open grass, road verges and some planted shrubs and small trees in landscaped urban areas. Such habitats are characterised by a lack of natural vegetation cover in the form of trees and shrubs and no specific fauna habitat value. Habitat for the Cumberland Land Snail in Area 2 is generally limited to areas of remnant vegetation along South Creek and Ropes Creek. The habitat qualities in these areas are generally low to moderate and the use of directional bore drilling would avoid any potential direct impacts to the habitat of this species.

Area 3 – Palmyra Avenue to Richmond Road

From Palmyra Avenue at the intersection with Forrester Road the pipeline route traverses through Peter Van Hasselt Park and Shalvey Reserve both of which are predominately cleared and maintained park areas except for a small stand of remnant trees at the northern end of Shalvey Reserve (refer to **Plate 4**). These remnant trees include Grey Box, Narrow-leaved Ironbark and Forest Red Gum, however there is sufficient space between trees to avoid any significant clearing in this area (refer to **Plate 4**) or alternatively design the route to avoid impacts on these trees.

The pipeline route then traverses east along a maintained asset protection zone (APZ) separating the northern edge of residential properties in the suburbs of Shalvey and Hassall Grove from large areas of Cumberland Plain Woodland to the north (refer to **Figure D1b**). An APZ is an area of land, adjacent to a residential development, in which the bushfire fuel load is managed to significantly minimise the impact of fire on that asset. Remnant vegetation is generally restricted to areas north of the proposed pipeline route comprising Cumberland Plain Woodland with the exception of a group of trees located within the APZ approximately 500 m east of the transmission line easement through Shalvey (refer to **Plate 5**). Potentially 20 mature trees may require removal along this part of the proposed pipeline route depending upon the exact alignment. Tree species include Grey Box and Forest Red Gum 12-15 metres high with a tree girth diameter between 0.3-1 metres, and some trees contain hollows suitable for fauna usage. Construction at this location should seek to minimise tree removal.

A number of shells of the Cumberland Land Snail were located adjacent to this location, up to 20 m north of the APZ. Given the absence of ground debris and understorey vegetation within the APZ it is unlikely that individual snails would occur along the works area at this location. However, consideration should be given during the construction stage to minimise impacts on snails should they occur. Habitat for Cumberland Land Snail is absent along the remainder of the pipeline route through Area 3 based on the absence of understorey vegetation and/or ground debris.

Evidence of Emus and Eastern Grey Kangaroos was noted in the APZ through Area 3.



Plate 4. Remnant Trees in Shalvey Reserve



Plate 5. Remnant trees within pipeline route along APZ

Area 4 – Richmond Road to the Westlink M7 Motorway

Area 4 commences from Richmond Road traversing eastwards across Bells Creek to the Westlink M7 Motorway. Vegetation in this area is heavily disturbed and degraded from past clearing, rubbish dumping, weed invasion and the effects of stormwater runoff. Riparian areas are dominated by exotic Weeping Willows. Scattered remnant species include Forest Red Gum in the canopy layer and, Blackthorn and Common Silkpod *Parsonsia straminea* in the understorey. The ground cover is dominated by Kikuyu. It is likely that the natural remnant vegetation associated with the flats around Bells Creeks was characteristic of the listed River-flat Eucalypt Forest scheduled as an EEC under the TSC Act. However very few natural elements are present (refer to **Plate 6**).

West of Bells Creek, the pipeline route would proceed southeast through an area of Cumberland Plain Woodland before crossing the Westlink M7 Motorway (refer to **Plate 7**). This area of vegetation exhibits a more natural structural and floristic diversity than that present along the creek and as such has a higher conservation value. Dominant flora species include Forest Red Gum, Grey Box and Rough-barked Apple *Angophora floribunda* with a subcanopy of *Melaleuca decora*. An intact understorey was present including Blackthorn, Sydney Green Wattle, Juniper-leaved Grevillea, Weeping Grass *Microlaena stipoides*, Kangaroo Grass *Themeda australis* and Love

Creeper *Glycine clandestinum*. Some exotic species were also present including Bridal Creeper *Asparagus asparagoides* and Moth Vine.

The listed Juniper-leaved Grevilleas *Grevillea juniperina* subsp. *juniperina* (Schedule 2 TSC Act) was recorded at this location, where the species was considered locally abundant (refer to **Figure D1b**). This area of Cumberland Plain Woodland also provides good quality habitat for the Cumberland Land Snail, although no individuals were recorded during the survey.

Directional bore drilling to lay the pipeline is proposed from east of the Westlink M7 Motorway to the western side of Bell Creek, thereby avoiding any direct impacts on Cumberland Plain Woodland and the identified threatened species habitat.



Plate 6. Degraded riparian vegetation along Bells Creek



Plate 7. Cumberland Plain Woodland with an intact native understorey west of Bells Creek

Area 5 – The Westlink M7 Motorway to Quakers Hill STP

On the southeastern side of the Westlink M7 Motorway the pipeline route traverses along the edge of a small area of moderately disturbed remnant vegetation supporting a small area of Cumberland Plain Woodland. Dominant flora species include Broad-leaved Ironbark *Eucalyptus fibrosa* and Thin-leaved Stringybark *Eucalyptus eugenoides* with a mix of exotic and native shrubs and grasses in the understorey including African Lovegrass, Paddys Lucerne *Sida rhombifolia*, Blackthorn, Kangaroo Grass and Peach Heath *Lissanthe strigosa* (refer to **Plate 8**). The vulnerable plant species

Juniper-leaved Grevillea (TSC Act) was also recorded in this area in low abundance. Additionally a record from 1996 indicates the Vulnerable (TSC Act and EPBC Act) *Dillwynia tenuifolia* was present in this vegetation patch in the vicinity of the proposed pipeline route (NPWS Wildlife Atlas 2006). Despite targeted searches, this species was not recorded during this survey. An empty Cumberland Land Snail shell was found underneath some dumped garden waste in the vicinity of the proposed pipeline route in this area of Cumberland Plain Woodland. It is proposed to locate the pipeline close to the boundary of residential properties at this location thereby avoiding any direct impacts on this area of vegetation. There is a need to manage indirect impacts as discussed in the recommendations section of this report.

The pipeline route fringes the northern edge of residential properties in Dean Park along the toe of the embankment associated with the Westlink M7 Motorway (refer to **Figure D1b**). Vegetation within the easement has been cleared with a small number of regenerating juvenile Sydney Red Gums *Angophora costata* and RTA landscaped species. There are some very small patches of disturbed or regrowth Cumberland Plain Woodland adjacent to the easement in places. There is no need to manage indirect impacts at this location.



Plate 8. Small area of Cumberland Plain Woodland where *Grevillea juniperina* (TSC Act) was recorded.

At the junction with Symonds Road the pipeline route continues south within the road easement of Symonds Road before traversing east across a cleared paddock and crossing Eastern Creek. Vegetation at the crossing location is limited to a thin strip of riparian vegetation with affinities to the EEC River-flat Eucalypt Forest (TSC Act). Directional bore drilling to lay the pipeline is proposed from under Eastern Creek. There is a need to manage indirect impacts on vegetation along Eastern Creek.

The pipeline route follows an existing easement through a predominately cleared paddock with scattered tree cover before crossing Quakers Hill Road and adjoining areas of parkland also with scattered tree cover. There is scope to avoid disturbance to existing trees in this location through appropriate construction management.

The pipeline route then crosses Breakfast Creek before entering Quakers Hill STP. At this location vegetation along Breakfast Creek comprises a thin strip of Swamp Oaks dominating the canopy with the reminder of the riparian vegetation dominated by dense weed species. A small number of juvenile Eucalypts may be required to be removed in the paddock and parkland areas. Directional bore drilling would limit environmental impacts at each of the creek crossings to cleared areas outside the riparian vegetation.

Area 6 – Powers Road Option

The Powers Road Option refers to an alternative pipeline route alignment (refer to **Figure D1c**) along the northern side of the railway corridor. This option has been proposed to avoid two railway crossings, which have been proposed as part of the preferred route alignment.

The proposed pipeline route to be constructed for the concentrate extension along Powers Road is to be restricted to urban parklands, pedestrian pathways and road easements. As a result no areas of remnant or regrowth vegetation would be disturbed by these works. The creek adjacent to Powers Road supports a low density of Swamp Oaks with a range of exotic species (refer to **Plate 9**). The proposed works would not impact on this vegetation.



Plate 9. Powers Road

Area 7– International Peace Park to Hammers Road

The main concentrate pipeline route starts from the International Peace Park continuing eastwards through urban parkland and road easements along the northern fringe of residential properties (refer to **Figure D1c**). No areas of remnant or regrowth vegetation are present within the works areas.

Figure D1c High value conservation areas



Where the pipeline meets Old Windsor Road there is a weed infested area with a small number of remnant trees (refer to **Plate 10**). Any larger trees in these areas would be avoided.

At Hammers Road the pipeline route crosses Toongabee Creek which supports a strip of riparian vegetation. The gully is relatively steep in this area with Sydney Blue Gums *E. saligna* and Water Gum *Tristaniopsis laurina* 15-20 metres high and range of weed species including Privet *Ligustrum* species. A small area of vegetation may need to be removed depending on the construction method for this area (such as attachment of the pipeline to the bridge or directional bore drilling) and the exact alignment. There is a need to manage indirect impacts as discussed in the recommendations section of this report.



Plate 10. Weed Infested area

Area 8 – Hammers Road to Vineyard Creek

From Hammers Road the pipeline route traverses along cleared road easements before crossing Toongabbie Creek (refer to **Plate 11**) and the Parramatta River. Riparian vegetation along the river supports scattered Swamp Oaks and a diversity of weed species, with relatively limited flora and fauna habitat of value.

The pipeline traverses residential areas to Richie Benaud Oval where there are spaced remnant and planted landscape trees including Spotted Gum *Corybia maculata* and Turpentine *Syncarpia glomulifera* (refer to **Figure D1d**). The pipeline route then crosses Pennant Hills Road through suburban areas and parkland before connecting to existing infrastructure at Vineyard Creek. There are tall remnant and planted trees present within Fred Robertson Park including Spotted Gums and Blackbutts *E.pilularis.* There is sufficient space between trees to avoid any clearing (refer to **Plate 12**). Vineyard Creek is dominated by woody weed species including Privet and Camphor Laurel *Cinnamonum camphora*. In all areas there is considerably scope to avoid tree removal through appropriate siting of the pipeline and control measures during construction.

Figure D1d High value conservation areas





Plate 11. Remnant vegetation and Toongabbie Creek



Plate 12. Fred Robertson Park

Area 9 – AWTP

The St Marys investigation area comprises a mix of re-planted and irrigated regrowth and remnant vegetation as well as landscaped gardens and cleared mown grass. Remnant treed areas comprise an open understorey of maintained grass with a depleted shrub layer (**Plate 13**). The majority of the area in the western section of the investigation area comprises maintained grassland with spaced remnant trees to 15 metres high including Forest Red Gum (*Eucalyptus tereticornis*), Grey Box (*Eucalyptus molucanna*) and Cabbage Gum (*Eucalyptus amplifolia*). The eastern section of the investigation area is dominated by dense planted regrowth of Swamp Oak (*Casuarina glauca*) 8-10 metres high, which is irrigated with recycled water and has possibly been seeded in the past to encourage regeneration (**Plate 14**). There are also a number of planted areas included a mounded area in the east of the investigation area containing a mix of juvenile native species. There are a number of drainage lines in the investigation area including a constructed drain in the western section and a smaller creek line is present within the forested area to the east.

Habitat features of importance to threatened fauna are generally absent as a result of past clearing, modification and disturbance of the site. Trees with hollow cavities are very limited (less than 1% of the total tree-cover) and the absence of understorey and ground-layer vegetation limits the value

of the site for ground-dwelling fauna. Creek habitats are significantly modified and impacted by effluent, industrial and sediment discharge and weed invasion.

The Eastern Bentwing-bat *Miniopterus schreibersii oceanensis* is listed as a vulnerable species in NSW under Schedule 2 of the TSC Act. This species was recorded at the St Marys STP site for the AWTP. The Eastern Bentwing Bat is a cave-roosting species, which is frequently recorded in the Sydney region and is known from several roosting colonies including one at Kingswood (Hoye and Spence 2004) and situated in proximity to investigation area. The species roosts in caves, old mines, tunnels and stormwater channels and similar structures including old buildings. The presence of large culverts provides potential roosting opportunities for threatened bats such as the Eastern Bent-wing Bat *Miniopterus schreibersii* and the Large-footed Myotis *Myotis macropus*.

The habitat is only marginally suitable for the threatened Squirrel Glider *Petaurus norfolcensis* and Cumberland Plain Land Snail despite records of these species in the wider St Marys area. Neither species is expected to occur in abundance.



Plate 13. Remnant woodland with cleared and maintained understorey.



Plate 14. Planted and irrigated swamp oak regrowth.

Area 10 – Concentrate Storage Pond

The site of the proposed concentrate storage pond has been previously cleared and currently supporting degraded lands covered by a dense growth of Kikuyu with a small number of standing dead trees which exhibit hollow cavities that provide some value for hollow-dependent fauna (refer to **Plate 15**). A pair of Red-rumped Parrots were nesting in a tree hollow at this location at the time of the site assessment.



Plate 15. Proposed location of the concentrate storage pond showing hollow bearing stag.

3.2.2 Endangered Ecological Communities

The high conservation value of remnant vegetation in Western Sydney, in particular Cumberland Plain Woodland and River-Flat Eucalypt Forest was recognised in the preliminary investigations for this project. As such all proposed infrastructure was sited to avoid Endangered Ecological Communities and pipeline routes traverse urban areas, open parklands, maintained roads and walking tracks, utility easements and clearings for asset protection zones (APZ) adjoining residential properties.

While minor impacts on vegetation may result from the clearing for construction of the AWTP, concentrate storage pond and linking pipelines, this would be limited to impacts on isolated trees or small stands or regrowth within predominantly cleared easements. The removal of highly degraded and modified vegetation is not anticipated to have a significant impact on the flora and fauna of the local or regional area and its removal will not isolate any interconnecting areas of habitat. High quality Cumberland Plain Woodland is present within the former ADI site outside the works corridor suggests will not be impacted by the proposal.

3.2.3 Threatened Flora

The listed Juniper-leaved Grevilleas *Grevillea juniperina* subsp. *juniperina* (Schedule 2 TSC Act) was recorded in vegetation on the southwestern side of Bells Creek on the western side of the Westlink M7 Motorway. Several individuals were recorded at this location and appeared to be adapted to disturbed edges. A directional bore would be used at this location to avoid impacts on vegetation.

3.2.4 Threatened Fauna

Habitat for fauna along the works corridor consists of cleared and modified habitats that include open grass, road verges and fragmented shrubs and small trees in adjoining residential areas. These habitats are characterised by isolated trees and small stands with a lack of understorey vegetation cover and limited value for threatened fauna species.

Evidence of the Cumberland Land Snail was recorded in isolated portions of Areas 4 and 5, as indicated on **Figure D1b**. These sightings were recorded on the edge of the large expansive areas of woodland habitat associated with the former ADI site and the Marsden Park area, suggesting that suitable and indeed better quality habitat for the Cumberland Land Snail is well represented throughout the wider locality.

The Eastern Bentwing-bat *Miniopterus schreibersii oceanensis* is listed as a vulnerable species in NSW under Schedule 2 of the TSC Act. This species was recorded at the St Marys STP site for the AWTP. The Eastern Bentwing Bat is a cave-roosting species, which is frequently recorded in the Sydney region and is known from several roosting colonies including one at Kingswood (Hoye and Spence 2004) and situated in proximity to investigation area. The species roosts in caves, old mines, tunnels and stormwater channels and similar structures including old buildings. The presence of large culverts provides potential roosting opportunities for threatened bats such as the Eastern Bent-wing Bat *Miniopterus schreibersii* and the Large-footed Myotis *Myotis macropus*.

Fauna habitat features are generally very limited within all works areas. A small number of trees with hollow-cavities were noted within the site for the proposed concentrate storage pond at Quakers Hill and at the rear of residential properties at Hassall Grove (Area 5). In both areas there is scope to avoid or minimise disturbance to standing hollow-bearing trees.

3.3 Summary

Most areas of remnant vegetation have been highly modified with areas of native understorey vegetation restricted to a few small patches where threatened flora, fauna and ecological communities were recorded. A summary of the features of conservation value recorded within proximity to the proposed works areas is provided below.

- **Table 3 Summary of ecologically significant features**

Threatened Species/Communities/Habitats	Status	Area								
		1	2	3	4	5	6	7	8	AWTP
Cumberland Plain Woodland	EEC (EPBC Act; TSC Act)	√			√					
River-flat Eucalypt Forest	EEC (TSC Act)		√		√	√			√	√
Freshwater Wetlands	EEC (TSC Act)	√								
Grevillea juniperina	Vulnerable (TSC Act)				√	√				

Cumberland Land Snail	Vulnerable (TSC Act)				√	√				
Eastern Bentwing Bat	Vulnerable (TSC Act)									√
Hollow-bearing Trees	Locally significant			√		√				√

4. Impact Assessment

4.1 General Impacts

4.1.1 AWTP

The proposed site for the AWTP comprises low conservation value for listed threatened flora and fauna species due to the unnatural condition, small size, and the extent of modification and disturbances evident.

Construction of the AWTP would require the removal of approximately 2 hectares of vegetation comprising a mix of re-planted and irrigated regrowth and remnant vegetation as well as landscaped gardens and cleared mown grass. Removal of this vegetation is unlikely to have a significant impact on threatened flora or fauna species due to the extent of modification and low conservation value. No threatened flora species were recorded within the proposed disturbance area.

A disused building is currently located on the site for the AWTP. One issue of conservation value identified within the St Marys STP site is the presence of potential roost sites for the threatened Eastern Bentwing Bat *Miniopterus schreibersii oceanensis* and other microchiropteran bats within this building. While no bats were identified using this structure during the surveys, the building should be checked for habitation prior to demolition and any bats that are detected roosting in the roof cavity, should be relocated by a qualified ecologist.

4.1.2 Pipelines

While minor impacts on vegetation may result from the clearing for laying of pipelines, direct impacts would be limited to impacts on isolated trees or small stands or regrowth within predominantly cleared easements. Indirect impacts could result from indiscriminate clearing without prior identification of the works corridor or through inappropriate movements of vehicles straying of the works corridor.

There is potential for impacts on remnant trees where the pipeline route traverses along the APZ separating the northern edge of residential properties in the suburbs of Shalvey and Hassall Grove. Up to 20 mature trees may require removal along this part of the proposed pipeline route depending upon the exact alignment and mitigation controls. Tree species include Grey Box and Forest Red Gum 12-15 metres high with a tree girth diameter between 0.3-1 metres. Some of these trees contain hollows suitable for fauna usage. This area contains both known areas of habitat where snails have been found and areas with suitable habitat attributes where Cumberland Land Snail could occur.

The removal of vegetation along the proposed pipeline routes is limited. Vegetation to be removed includes isolated trees or small stands or regrowth. The proposed removal of this vegetation would not result in the isolation of interconnecting areas of habitat or threatened species. The degraded nature of the disturbance area indicates that it is unlikely to provide important habitat for threatened fauna species and it is considered unlikely that this proposal would reduce the long-term viability of a native fauna within the local or regional area.

High conservation value remnant vegetation including Cumberland Plain Woodland and River-Flat Eucalypt Forest would not be disturbed as a result of this proposal. Construction techniques have been incorporated into the project design including underground boring and alignment of the proposed pipeline to follow existing pathways or APZs to avoid potential impacts on endangered ecological communities.

4.1.3 Concentrate Storage Pond

Construction of the concentrate storage pond would require the removal of approximately 2ha of vegetation at the Quakers Hill STP site. The area to be disturbed has previously been cleared, is highly degraded and weed infested. The site is covered by a dense growth of exotic Kikuyu with a small number of standing dead trees, which exhibit hollow cavities that provide some value for hollow-dependent fauna. The dead trees should be checked for nesting fauna prior to removal.

No threatened flora or fauna species have been recorded within the proposed disturbance area. Due to the high level of degradation the site is unlikely to provide important habitat for threatened fauna species. The clearance of approximately 2ha of vegetation is unlikely to have a significant impact on the flora and fauna values of the local or regional area.

4.1.4 Construction Phase - General

The assessment of flora and fauna meets each of the key thresholds, set out in Step 5 of the D*raft 3A Guidelines for Threatened Species Assessment*. That is:

- the proposal will include actions to avoid or mitigate impacts through selection of the sites or routes to avoid any sensitive ecological areas and use of mitigation measures such as boring beneath creeks and important habitat sites to ensure that biodiversity values are maintained or improved
- the proposal would not accelerate the extinction of the species, population or ecological community or place any of these at risk of extinction
- no critical habitat would be adversely affected.

In addressing the *Guidelines for Developments Adjoining Department of Environment and Conservation Land* (DEC, 2006a) a series of mitigation measures would be implemented to prevent impact on the following issues:

- erosion and sediment control – mitigation measures would be implemented in accordance with Managing Urban Stormwater guidelines (Landcom 2005) and DEC's 'A Resource Guide for Local Councils: Erosion and Sediment Control' (DEC, 2006b)
- stormwater runoff to DEC land would be prevented through implementation of the controls noted above
- management implications, pets, weeds, edge effects – construction activities would be managed in accordance with Sydney Water's standard management practices to avoid introduction of weeds. No edge effects or issues associated with pets entering the site will occur as a result of construction
- fire and location of asset protection zones- construction activities would be managed in accordance with Sydney Water's standard management practices to minimise the potential for fire and impacts on asset protection zones
- visual, odour, noise, air quality and amenity – construction activities would be managed in accordance with Sydney Water's standard management practices to minimise visual, noise or air quality impacts.

4.1.5 Operational Phase - General

The assessment of flora and fauna meets each of the key thresholds set out in Step 5 of the D*raft 3A Guidelines for Threatened Species Assessment*. That is, the infrastructure would be placed within existing STP sites and pipeline routes would be located below the ground surface. This would avoid any reduction in the long-term viability of local populations or species or ecological communities.

In addressing the *Guidelines for Developments Adjoining Department of Environment and Conservation Land* (DEC, 2006a) a series of mitigation measures would be implemented to prevent impact on the following issues:

- stormwater runoff – the pipeline routes would be revegetated and no stormwater treatment measures would be required
- management implications– no significant long term impacts on management of the Regional Park zone would occur as the pipelines are to be placed within cleared bushfire protection zones
- fire –maintenance activities would be managed in accordance with Sydney Water's standard management practices to minimise the potential for fire

- boundary encroachments – the proposal would have no impact in terms of the DEC boundaries
- visual, odour, noise, air quality impacts and amenity – pipelines would be placed beneath the ground surface and the site regenerated thus avoiding visual impacts. No noise, air quality or associated amenity impacts would occur
- threats to ecological connectivity – the pipelines will be placed within cleared areas which are maintained for fire protection purposes as such the Project would have no significant long term impact on movement corridors.

4.2 Threatened Species Conservation Act, 1995

An assessment of the impacts of this proposal on species, populations and ecological communities listed Schedules 1, 1A and 2 of the TSC Act has been undertaken. The proposal is to be assessed under Part 3A of the EP&A Act and consequently this impact assessment was undertaken in accordance with the Draft Guidelines for Threatened Species Assessment (DEC 2005).

4.2.1 Critical habitat

Critical habitat is defined as an area that is critical to the survival of an endangered species, population or ecological community. The proposal would not impact on critical habitat declared under the TSC Act.

4.2.2 Endangered Ecological Communities

The proposal area contains remnant vegetation that is characteristic of two Endangered Ecological Communities scheduled under the TSC Act, namely:

- Cumberland Plain Woodland
- River-flat Eucalypt Forest on Coastal Floodplains.

AWTP

While portions of the vegetation at the AWTP site can be characterised as a modified form of the endangered ecological community referred to as River-flat Eucalypt Forest on Coastal Floodplains (TSC Act), from a local and regional perspective this vegetation would not be considered of high conservation value. Remnant trees have been retained as scattered individuals in a park-like setting with all natural understorey strata removed and maintained as mown grass. There are no juvenile trees, and very few shrubs or native ground covers typical of this community in its natural state. Similarly, formerly cleared areas of the site have been seeded and irrigated to create a dense monoculture of Swamp Oak *Casuarina glauca*, with occasional Paperbarks (*Melaleuca* spp) and non-locally native species such as Flooded Gum *Eucalyptus grandis*. Such vegetation only superficially resembles the endangered ecological community River-flat Eucalypt Forest on Coastal Floodplains.

Pipelines

The presence and high conservation value of Cumberland Plain Woodland in particular was recognised in the preliminary investigations for this project and the locations of pipeline routes have been sited to avoid sensitive areas and these traverse urban areas, open parklands, maintained roads and walking tracks, utility easements and clearings for asset protection zones (APZ) adjoining residential properties. Three remnants of Cumberland Plain Woodland occur within the proposed pipeline corridor. One remnant is located adjacent Penrith STP, while the other two remnants occur on either side of the Westlink M7 Motorway. The pipeline would be contained within an existing sealed pathway through the remnant adjacent Penrith STP and the use of directional boring techniques would be employed to avoid potential impacts on the remnant west of the Westlink M7 Motorway. To the east of the M7 Motorway the pipeline would be situated close to property fences to minimise disturbance and fragmentation of this high conservation value woodland.

Cumberland Plain Woodland

How is the proposal likely to affect the lifecycle of a threatened species and/or population?

Cumberland Plain Woodland is not a threatened species or population.

How is the proposal likely to affect the habitat of a threatened species, population or ecological community?

Impacts on vegetation may result from clearing for construction of the AWTP, concentrate storage pond and linking pipelines. Accordingly, the high conservation value of remnant vegetation in Western Sydney, in particular Cumberland Plain Woodland has been recognised and in all cases the proposed infrastructure associated with the project has been located to avoid impacts on native vegetation.

There is no requirement to clear remnant or intact Cumberland Plain Woodland or disturb associated understorey vegetation and therefore the extent of this ecological community would not be impacted. Measures to avoid impacts on Cumberland Plain woodland imposed by this development include:

- Appropriate placement of infrastructure based on the identification of remnant vegetation from preliminary desktop and field investigations. Including locating in cleared lands, and along bushfire protection zones.
- The use of a directional bore for laying pipeline in identified areas of Cumberland Plain Woodland.
- Mitigation measures enforced during the construction of the project, particularly where Cumberland Plain woodland has been identified adjacent to works areas.

These measures are combined to ensure that any impacts on Cumberland Plain Woodland would be very minimal and that no areas of remnant or intact woodland would be disturbed, thereby ensuring there is no reduction in the extent of this community.

Does the proposal affect any threatened species or populations that are at the limit of its known distribution?

Cumberland Plain Woodland is not a threatened species or population.

How is the proposal likely to affect current disturbance regimes?

Current disturbance regimes occurring in the study area include weed invasion, altered hydrology, bush fire, rubbish dumping and edge effects. Cumberland Plain Woodland in the study area ranges from low to high condition as a result of the long-term impacts from edge effects, weed invasion, rubbish dumping, urban runoff, previous agricultural activities and inappropriate fire regimes. The proposal is unlikely to exacerbate any current disturbance regimes provided adequate mitigation measures are implemented during construction. Adjacent areas of Cumberland Plain Woodland will be protected during construction and measures implemented to ensure invasive species are not spread into areas of retained remnant vegetation during construction. Storage of equipment and resources will be confined to designated areas which are not of ecological importance.

How is the proposal likely to affect habitat connectivity?

The proposal will not result in the further fragmentation of any habitats considering that it is generally restricted to existing cleared and disturbed easements and vegetation corridors along creek lines will be avoided through directional bore drilling.

How is the proposal likely to affect critical habitat?

No critical habitat has been identified for this community within the study area.

River-flat Eucalypt Forest

How is the proposal likely to affect the lifecycle of a threatened species and/or population?

River-flat Eucalypt Forest is not a threatened species or population.

How is the proposal likely to affect the habitat of a threatened species, population or ecological community?

Impacts on vegetation may result from clearing for construction of the AWTP, concentrate storage pond and linking pipelines. Accordingly, the high conservation value of remnant vegetation in

Western Sydney has been recognised and in all cases the proposed infrastructure associated with the project has been located to avoid impacts on native vegetation.

There is no requirement to clear remnant or intact River-flat Eucalypt Forest or disturb associated understorey vegetation and therefore the extent of this ecological community would not be impacted. Measures to avoid impacts on River-flat Eucalypt Forest imposed by this development include:

- Appropriate placement of infrastructure based on the identification of remnant vegetation from preliminary desktop and field investigations. Including locating in cleared lands, and along bushfire protection zones.
- The use of a directional bore for all creek line crossing where River-flat Eucalypt Forest occurs.
- Mitigation measures enforced during the construction of the project, particularly where River-flat Eucalypt Forest has been identified adjacent to works areas.

These measures are combined to ensure that any impacts on River-flat Eucalypt Forest would be very minimal and that no areas of remnant or intact woodland would be disturbed, thereby ensuring there is no reduction in the extent of this community.

Does the proposal affect any threatened species or populations that are at the limit of its known distribution?

River-flat Eucalypt Forest is not a threatened species or population.

How is the proposal likely to affect current disturbance regimes?

Current disturbance regimes occurring in the study area include weed invasion, altered hydrology, bush fire, rubbish dumping and edge effects. River-flat Eucalypt Forest in the study area generally comprises highly disturbed vegetation as a result of the long-term impacts from edge effects, weed invasion, rubbish dumping, urban runoff, previous agricultural activities and inappropriate fire regimes. The proposal is unlikely to exacerbate any current disturbance regimes provided adequate mitigation measures are implemented during construction. Adjacent areas of River-flat Eucalypt Forest will be protected during construction and measures implemented to ensure invasive species are not spread into areas of retained remnant vegetation during construction. Storage of equipment and resources will be confined to designated areas that are not of ecological importance.

How is the proposal likely to affect habitat connectivity?

Considering that directional bore drilling will be utilised to install the proposed pipeline infrastructure, the habitat connectivity provided by this community along creeklines will not be affected.

How is the proposal likely to affect critical habitat?

No critical habitat has been identified for this community within the study area.

4.2.3 Threatened Species

Throughout the majority of all proposed development areas, most remnant vegetation has been cleared or highly modified. A few small patches of remnant vegetation with native understorey vegetation occur near the Westlink M7 Motorway where threatened flora and fauna were also recorded.

Flora

Potential habitat was identified in the study area in the preliminary assessments for 20 threatened flora species (refer to Table 1). One of these *Grevillea juniperina subsp. juniperina* was recorded during the targeted threatened species surveys. The remaining 19 threatened flora species were not located during the field assessments, and areas of suitable habitat for these species are generally absent except for a few small areas of low-moderate quality habitat, which were intensively searched. It is concluded that these 19 species not recorded during field assessments are highly unlikely to be present within the proposed works area, and therefore further assessment is not required.

Grevillea juniperina subsp. juniperina

The listed Juniper-leaved Grevillea *Grevillea juniperina* subsp. *juniperina* (Schedule 2 TSC Act) was recorded in vegetation on the south-western side of Bells Creek on the western side of the Westlink M7 Motorway. Several individuals were recorded at this location and appeared to be adapted to disturbed edge habitat. The location of plants is shown in **Figure D1b**. A directional bore would be used to traverse the pipeline below this area and as such potential impacts on remnant vegetation or individual plants would be minimised. Until there is adequate protection of *Grevillea juniperina* subsp. *juniperina* all sites are considered important and the habitat considered significant, particularly larger areas of habitat, larger populations and habitats remote from high disturbance regimes (DEC 2002).

How is the proposal likely to affect the lifecycle of a threatened species and/or population?

The proposed removal of a small area of habitat for *Grevillea juniperina* subsp. *juniperina* is unlikely to disrupt the breeding cycle of this population. Only one individual will potentially be removed for the proposed infrastructure, with numerous individuals retained within the study area through the use of directional bore drilling under the areas where individuals are distributed. Additionally there are also numerous records for this species in remnant vegetation surrounding the study area. Considering that this species is wind and/or insect pollinated, the proposal is unlikely to disrupt pollination, as these processes will not be impeded by the proposal.

Plants are generally killed by fire and regeneration is only from seed, and so the production and accumulation of seed in the soil seed bank and seed germination are likely to be critical parts of the life cycle (DEC 2002). The proposal will not affect fire regimes and where works are conducted within areas of *Grevillea juniperina* subsp. *juniperina* habitat the soil seed bank will not be removed. The main distribution of this species in the study area will not be impacted as directional bore drilling will be utilised to avoid this distribution and hence the soil seed bank will not be disturbed.

How is the proposal likely to affect the habitat of a threatened species, population or ecological community?

A small area of potential habitat for threatened flora species will be removed for the proposed upgrades; however areas of suitable habitat will be retained within the study area. Provided the retained vegetation is protected during construction it is unlikely that the proposal would significantly impact on potential habitat for *Grevillea juniperina* subsp. *juniperina*. Mitigation measures implemented during construction will limit potential impacts to adjacent vegetation through limiting the spread of weed species, protecting adjacent areas of remnant vegetation and controlling stormwater and sedimentation.

Does the proposal affect any threatened species or populations that are at the limit of its known distribution?

Grevillea juniperina subsp. *juniperina* is endemic to Western Sydney. The population is centred on an area bounded by Blacktown, Erskine Park, Londonderry and Windsor with outlier populations at Kemps Creek and Pitt Town (DEC 2005). *Grevillea juniperina* subsp. *juniperina* individuals were found at Dean Park in the study area which is towards the eastern extent of the species distribution.

How is the proposal likely to affect current disturbance regimes?

Current disturbance regimes occurring in the study area include weed invasion, altered hydrology, bush fire, rubbish dumping and edge effects. The proposal is unlikely to exacerbate any current disturbance regimes provided adequate mitigation measures are implemented during construction.

Adjacent areas of *Grevillea juniperina* subsp. *juniperina* habitat will be protected during construction and measures implemented to ensure invasive species are not spread into areas of retained remnant vegetation during construction. Storage of equipment and resources will be confined to designated areas which are not of ecological importance.

How is the proposal likely to affect habitat connectivity?

Considering that directional bore drilling will be utilised to install the proposed pipeline infrastructure beneath the major occurrence of this species in the study area and across creek line vegetation, habitat connectivity will not be significantly affected.

How is the proposal likely to affect critical habitat?

Critical habitat cannot be declared for *Grevillea juniperina* subsp. *juniperina* as it is not listed on Schedule 1 of the TSC Act.

Fauna

The list of threatened fauna species recorded from the Greater Sydney area is discussed in Section 2.5. Of these species a number of threatened fauna are considered to potentially utilise habitat within the works area, at least on occasion. In this regard, the open modified habitats support a variety of insect life and in turn may provide prey for several insectivorous bat species, which can be encountered in disturbed landscapes. A number of such species are listed as threatened on the TSC Act and include the cave-roosting Eastern Bentwing-bat *Miniopterus schreibersii* and Large-footed Myotis *Myotis macropus* and the tree-roosting species; Greater Broad-nosed Bat *Scoteanax rueppellii*, and Eastern False Pipistrelle *Falsistrellus tasmaniensis*. Each of these species could potentially forage over land within the proposed development areas. These microchiropteran bats are aerial foragers which are capable of hunting for insects over a very wide range of natural and modified landscapes including urban and industrial areas. Aspects of their life-cycle most at risk from development include the removal of trees containing hollow cavities suitable for roosting and hibernation. The proposed development has potential to remove only a very small quantity of hollow-bearing trees, some of which may potentially be used by threatened bats. The impacts on potential foraging and roosting habitat are not considered critical to the life-cycle of regional populations of bats and continued foraging throughout the area can be expected following the proposed construction activities. Measures to protect hollow-dependent fauna are outlined in Section 5 of the report.

The very small area of habitat potentially affected by this proposal could potentially provide only a very small area of the habitat required within the broader home range of individuals of these species. Further, there are few critical habitat elements present for these species and significant impacts are not expected on local populations.

Cumberland Land Snail

How is the proposal likely to affect the lifecycle of a threatened species and/or population?

At present there is limited information about the biology and life history of the Cumberland Land Snail. It is hermaphroditic and eggs are laid in moist and dark areas such as under logs, fallen trees and artificial ground cover such as building refuse and car bodies. Indeed the species will persist in degraded environments provided that ground cover of logs or rubbish is available. However nothing is currently known about rates of fecundity of the species, length of life span, dispersal patterns and over what distances individuals can move.

It is currently not known what constitutes a viable population. There are over 100 records of the species throughout its small and restricted distribution and approximately 70 locations recorded within a 40 square kilometre radius centred on the Cumberland Plain and Castlereagh Woodlands. Given that records are patchily distributed and the species is hermaphroditic, small populations may be considered viable unless proven otherwise.

Evidence of the Cumberland Land Snail was recorded in isolated portions of Areas 4 and 5, as indicated on **Figure D1b**. These sightings were recorded on the edge of the large expansive areas of woodland habitat associated with the former ADI site and the Marsden Park area, suggesting that suitable and indeed better quality habitat for the Cumberland Land Snail is well represented throughout the wider local and not restricted to this small area of woodland adjoining the works area. Nonetheless there is potential for impacts on a small portion of the potential habitat for this species as a result of the construction of the pipeline at this location. Discussion on mitigation measures is provided in Section 5 of the report. The use of directional bore drilling would avoid any potential direct impacts to the habitat of this species.

Other mitigation measures include:

- clearing for the proposal through identified areas of potential habitat should be strictly monitored;
- a thorough search of the corridor should be made prior to clearing to identify any individuals and microhabitat being used;
- the clearing should be restricted to the pipeline corridor only and any potential sheltering habitat for this species (ie. logs, fallen timber, building refuse, etc) that occurs within the disturbance zone should be moved into adjoining areas outside the corridor rather then destroyed and removed completely.

Provided these mitigation measures are adopted during the construction phase a potentially significant disruption to the life cycle of the species should be avoided.

How is the proposal likely to affect the habitat of a threatened species, population or ecological community?

Evidence of the Cumberland Land Snail was recorded in isolated portions of Areas 4 and 5, as indicated on **Figure D1b**. These sightings were recorded on the edge of the large expansive areas of woodland habitat associated with the former ADI site and the Marsden Park area, suggesting that suitable and indeed better quality habitat for the Cumberland Land Snail is well represented throughout the wider local and not restricted to this small area of woodland adjoining the works area. Nonetheless there is potential for impacts on a small portion of the potential habitat for this species as a result of the construction of the pipeline at this location. Discussion on mitigation measures is provided in Section 5 of the report. The use of directional bore drilling would avoid any potential direct impacts to the habitat of this species.

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- the clearing should be restricted to the pipeline corridor only and any potential sheltering habitat for this species (ie. logs, fallen timber, building refuse, etc) that occurs within the disturbance zone should be moved into adjoining areas outside the corridor rather then destroyed and removed completely.

Provided these mitigation measures are adopted during the construction phase a potentially significant disruption to the life cycle of the species should be avoided.

Does the proposal affect any threatened species or populations that are at the limit of its known distribution?

There are over 100 records of this species throughout its small and restricted distribution and approximately 70 locations recorded within a 40 square kilometre radius centred on the Cumberland Plain and Castlereagh Woodlands. Therefore this species is at the limit of its distribution although will not be significantly impacted by the proposal.

How is the proposal likely to affect current disturbance regimes?

Current disturbance regimes occurring in the study area include weed invasion, altered hydrology, bush fire, rubbish dumping and edge effects. The proposal is unlikely to exacerbate any current disturbance regimes provided adequate mitigation measures are implemented during construction.

How is the proposal likely to affect habitat connectivity?

The pipelines will be placed within cleared areas which are maintained for fire protection purposes. As such the Project would have no significant long term impact on movement corridors.

How is the proposal likely to affect critical habitat?

- clearing for the proposal through identified areas of potential habitat should be strictly monitored;
- a thorough search of the corridor should be made prior to clearing to identify any individuals and microhabitat being used;
- the clearing should be restricted to the pipeline corridor only and any potential sheltering habitat for this species (ie. logs, fallen timber, building refuse, etc) that occurs within the disturbance zone should be moved into adjoining areas outside the corridor rather then destroyed and removed completely.

Microchiropteran Bats

How is the proposal likely to affect the lifecycle of a threatened species and/or population?

The Eastern Bentwing-bat *Miniopterus schreibersii oceanensis* and Large-footed Myotis *Myotis macropus* are listed as a vulnerable species in NSW under Schedule 2 of the TSC Act. The Eastern Bentwing-bat was recorded at the site for the AWTP. The Eastern Bentwing Bat is a cave-roosting species, which is frequently recorded in the Sydney region and is known from several roosting colonies including one at Kingswood (Hoye and Spence 2004) and situated in proximity to the investigation areas. The species roosts in caves, old mines, tunnels and stormwater channels and similar structures including old buildings. A roost site is suspected to occur on Sydney Water land at the St Marys STP in the form of a large culvert in proximity to the AWTP site. This culvert is outside of the proposed development footprint and would remain in its current condition and there would be no impacts on the potential roosting habitat of the Eastern Bentwing-bat.

This species is adapted to foraging in urban areas wherever insect prey are abundant, which may include forest and woodland or completely cleared urban areas particularly near street lighting and around water bodies such as STPs. The proposal would not impact on the foraging activities of local populations known in western Sydney.

How is the proposal likely to affect the habitat of a threatened species, population or ecological community?

The proposal will not impact on a known roost site or remove foraging habitat.

One issue of conservation value identified within the St Marys STP site is the presence of potential roost sites for the threatened Eastern Bentwing Bat *Miniopterus schreibersii oceanensis*. Several individuals of this species were recorded on the site during this survey and a possible roost site was noted in the form of the large culverts adjoining the proposed AWTP site and also a disused building at the southwestern end of the site. The large culverts will be conserved in their natural state to preserve a potential roost site for this species and the threatened Large-footed Myotis *Myotis macropus* which is also known from the locality. Further inspection of the roof cavity of the disused building on Site at St Marys should be conducted to confirm the presence / absence of roosting bats prior to demolition.

Does the proposal affect any threatened species or populations that are at the limit of its known distribution?

No, this species is not at the limit of its distribution in western Sydney

How is the proposal likely to affect current disturbance regimes?

Current disturbance regimes occurring in the study area include weed invasion, altered hydrology, bush fire, rubbish dumping and edge effects. The proposal is unlikely to exacerbate any current disturbance regimes provided adequate mitigation measures are implemented during construction.

How is the proposal likely to affect habitat connectivity?

The pipelines will be placed within cleared areas which are maintained for fire protection purposes. As such the Project would have no significant long term impact on movement corridors.

How is the proposal likely to affect critical habitat?

Critical habitat for this species includes known and potential roost sites including natural and potential artificial structures. A possible roost site was noted in the form of the large culverts adjoining the proposed AWTP site and also a disused building at the southwestern end of the site. The large culverts will be conserved in their natural state to preserve a potential roost site for this species and the threatened Large-footed Myotis *Myotis macropus* which is also known from the locality. Further inspection of the roof cavity of the disused building on Site at St Marys should be conducted to confirm the presence / absence of roosting bats prior to demolition.

Grey-headed Flying-fox

How is the proposal likely to affect the lifecycle of a threatened species and/or population?

Several populations of the Grey-headed Flying-fox *Pteropus poliocephalus* are known from the Greater Sydney region. This includes a number of known roost sites 'flying-fox camps' at the Botanic Gardens, Cabramatta, Gordon, Penrith, and Wheeney Creek and Yarramundi both in the Hawkesbury area. There are no known roost sites within the areas selected for infrastructure for the Replacement Flows Project.

Foraging resources for the Grey-headed Flying-fox occur throughout all naturally vegetated areas of western Sydney as well as urban landscapes and planted non-native gardens. The proposal would not remove important food resources nor impact on a roosting colony of this species.

How is the proposal likely to affect the habitat of a threatened species, population or ecological community?

Foraging resources for the Grey-headed Flying-fox occur throughout all naturally vegetated areas of western Sydney as well as urban landscapes and planted non-native gardens. The proposal would not remove important food resources nor impact on a roosting colony of this species.

Does the proposal affect any threatened species or populations that are at the limit of its known distribution?

No, this species is not at the limit of its distribution in the western Sydney area.

How is the proposal likely to affect current disturbance regimes?

Current disturbance regimes occurring in the study area include weed invasion, altered hydrology, bush fire, rubbish dumping and edge effects. The proposal is unlikely to exacerbate any current disturbance regimes provided adequate mitigation measures are implemented during construction.

How is the proposal likely to affect habitat connectivity?

The pipelines will be placed within cleared areas which are maintained for fire protection purposes as such the Project would have no significant long term impact on movement corridors.

How is the proposal likely to affect critical habitat?

Critical habitat for this species includes known roost sites. The proposal will not impact on any identified roost sites in western Sydney.

Green and Golden Bell Frog

How is the proposal likely to affect the lifecycle of a threatened species and/or population?

Important life-cycle activities include breeding, sheltering and foraging. Small populations of the Green and Golden Bell Frog are known from the St Marys area (DEC 2005), however the proposal will not impact on the potential or known breeding sites for this species.

How is the proposal likely to affect the habitat of a threatened species, population or ecological community?

The pipelines will cross several creeks including Toongabee Creek, Breakfast Creek, South Creek Bell Creek and Ropes Creek. None of these provide suitable habitat for the Green and Golden Bell Frog. The impacts will be minimal given that a directional bore will be used.

Treated effluent will be discharged into Boundary Creek, although this creek does not provide known or potential habitat for the Green and Golden Bell Frog. The species favours shallow open wetlands and ponds (DEC 2005) and would not occur in Boundary Creek due to a lack of suitable habitat.

Does the proposal affect any threatened species or populations that are at the limit of its known distribution?

No, the species distribution is not limited to the western Sydney region

How is the proposal likely to affect current disturbance regimes?

Current disturbance regimes occurring in the study area include weed invasion, altered hydrology, bush fire, rubbish dumping and edge effects. The proposal is unlikely to exacerbate any current disturbance regimes provided adequate mitigation measures are implemented during construction.

How is the proposal likely to affect habitat connectivity?

The pipelines will be placed within cleared areas, which are maintained for fire protection purposes. As such the Project would have no significant long-term impact on movement corridors.

How is the proposal likely to affect critical habitat?

Critical habitat would include known breeding sites. Although population are known from the St Marys area, none of these will be impacted by the proposal.

Squirrel Glider

How is the proposal likely to affect the lifecycle of a threatened species and/or population?

Important life-cycle activities include breeding and the associated provision of tree-hollow den sites as well as foraging and food resources, and movements of individual across and between habitat patches. A small area of potential habitat was identified at the St Marys AWTP site and previous records are known from the north of this location in the ADI site. No other areas of potential habitat were noted to occur at other infrastructure sites (e.g. pipelines, storage ponds).

The habitat at the St Marys site was identified in SKM (2006) as average to low quality with very few tree hollows (<1% of the total tree cover). Given the extent of suitable habitat in the adjoining ADI site, the habitat present may for a very small portion of the habitat for an individual or group of gliders. Indeed the closely related Sugar Glider (*Petaurus breviceps)* was captured at the site (SKM 2006). However the small size and low quality of the site habitat is unlikely to support an ecologically significant portion of any local population or provide seasonal foraging resources to support the life-cycle activities of the species.

How is the proposal likely to affect the habitat of a threatened species, population or ecological community?

The habitat at the St Marys site was identified in SKM (2006) as average to low quality with very few tree hollows (<1% of the total tree cover). Given the extent of suitable habitat in the adjoining ADI site, the habitat present may for a very small portion of the habitat for an individual or group of gliders.

Does the proposal affect any threatened species or populations that are at the limit of its known distribution?

No, this species is not at the limit of its distribution in the western Sydney region.

How is the proposal likely to affect current disturbance regimes?

Current disturbance regimes occurring in the study area include weed invasion, altered hydrology, bush fire, rubbish dumping and edge effects. The proposal is unlikely to exacerbate any current disturbance regimes provided adequate mitigation measures are implemented during construction.

How is the proposal likely to affect habitat connectivity?

The pipelines will be placed within cleared areas which are maintained for fire protection purposes as such the Project would have no significant long term impact on movement corridors.

How is the proposal likely to affect critical habitat?

Critical habitat includes trees with hollows, and seasonal food resources. The proposal will remove only a very small number of hollow-bearing trees (up to 2). The area of vegetation removal at the AWTP site includes a small area of remnant woodland with a cleared and maintained understorey. The site lacks a diversity of tree species, shrubs and young trees in order to maintain a population of Squirrel Gliders.

4.2.4 Key Thresholds

Limited impacts on vegetation may result from the clearing for construction of the AWTP, concentrate storage pond and linking pipelines. However from an ecological perspective the project can be justified on the basis that there is no requirement to clear remnant or intact Cumberland Plain Woodland or River-flat Eucalypt Forest or disturb associated understorey vegetation and therefore the extent of these Endangered Ecological Communities would not be impacted. Measures to avoid impacts on Endangered Ecological Communities and threatened species habitat imposed by this development include:

- Appropriate siting of infrastructure based on the identification of remnant vegetation from preliminary desktop and field investigations. Including locating in cleared lands, and along bushfire protection zones;
- The use of a directional bore for laying pipeline in areas of Cumberland Plain Woodland and River-flat Eucalypt Forest and lands identified to comprise threatened flora and fauna species;
- Mitigation measures enforced during the construction of the project, particularly where potential impacts on vegetation have been identified adjacent to works areas.
- No areas of critical habitat would be impacted.

These measures are combined to ensure that any impacts on Endangered Ecological Communities and habitat for threatened species would be very minimal and that no areas of remnant or intact woodland would be disturbed, thereby ensuring there is no reduction in the extent of areas of conservation value and the project would not accelerate the risk of extinction for an endangered ecological community or threatened species occurring in the Western Sydney region.

4.3 Environment Protection and Biodiversity Conservation Act, 1999

Sydney Water has a statutory responsibility to comply with the requirements and intent of the Commonwealth *Environment Protection and Biodiversity Conservation Act*, 1999 (EPBC Act) in relation to the protection and management of threatened species. This assessment deals specifically with the significance of impacts from the proposed Replacement Flows Project on nationally threatened species and commonwealth migratory species.

Listed endangered ecological community: *Cumberland Plain Woodland*

This assessment deals specifically with the significance of impacts from the proposed development on the nationally endangered Cumberland Plain Woodland ecological community.

1. Will the action reduce the extent of an ecological community?

Impacts on vegetation may result from clearing for construction of the AWTP, concentrate storage pond and linking pipelines. Accordingly, the high conservation value of remnant vegetation in Western Sydney, in particular Cumberland Plain Woodland has been recognised and in all cases the proposed infrastructure associated with the project has been located to avoid impacts on native vegetation.

There is no requirement to clear remnant or intact Cumberland Plain Woodland or disturb associated understorey vegetation and therefore the extent of this ecological community would not be impacted. Measures to avoid impacts on Cumberland Plain woodland imposed by this development include:

- Appropriate placement of infrastructure based on the identification of remnant vegetation from preliminary desktop and field investigations. Including locating in cleared lands, and along bushfire protection zones.
- The use of a directional bore for laying pipeline in identified areas of Cumberland Plain Woodland.
- Mitigation measures enforced during the construction of the project, particularly where Cumberland Plain woodland has been identified adjacent to works areas.

These measures are combined to ensure that any impacts on Cumberland Plain Woodland would be very minimal and that no areas of remnant or intact woodland would be disturbed, thereby ensuring there is no reduction in the extent of this community.

2. Will the action fragment or increase fragmentation of an ecological community, for example by clearing vegetation for roads or transmission lines

The majority of the proposed pipeline routes would traverse along adjoining residential property boundaries and road verges such that there would be no fragmentation of vegetation. The results of the preliminary desktop and field investigation identified large areas of intact remnant Cumberland Plain Woodland, particularly in the proposed ADI regional park in the St Marys area. In such locations the pipeline route would be placed along bushfire protection zones and adjacent clearings, and would not result in the fragmentation of Cumberland Plain Woodland.

3. Will the action adversely affect habitat critical to the survival of an ecological community

The proposed development would not reduce the area of land currently occupied by Cumberland Plain Woodland in the Western Sydney region, and hence not affect habitat critical to its survival. The high conservation value of remnant vegetation in Western Sydney, in particular Cumberland Plain Woodland has been recognised and in all cases the proposed infrastructure associated with the WSRWI project has been located to avoid impacts on native vegetation.

4. Will the action modify or destroy abiotic (non-living) factors (such as water, nutrients, or soil) necessary for an ecological community's survival, including reduction of groundwater levels, or substantial alteration of surface water drainage patterns

The proposed laying of the water supply pipelines would involve shallow excavation. This activity would not cause any alteration to groundwater drainage patterns. Potential impacts on surface water runoff from exposed soil during construction would be controlled through industry standard mitigation measures. Sediment and erosion control measures should be implemented to limit additional water, sediment and nutrients entering surrounding areas of remnant vegetation during the construction phase.

5. Will the action cause a substantial change in species composition of an occurrence of an ecological community, including causing a decline or loss of functionally important species, for example through regular burning or flora or fauna harvesting;

The proposed development would not reduce the area of land currently occupied by Cumberland Plain Woodland in the Western Sydney region. The high conservation value of remnant vegetation in Western Sydney, in particular Cumberland Plain Woodland has been recognised and in all cases the proposed infrastructure associated with the WSRWI project has been located to avoid impacts on native vegetation.

There is potential for the spread of weeds from construction machinery into adjoining remnant woodland, however this can be mitigated with the implementation of weed management measures.

6. Will the action cause a substantial reduction in the quality or integrity of an occurrence of an ecological community, including, but not limited to:

- ***assisting invasive species that are harmful to the listed ecological community, to become established; or***
- ***causing regular mobilisation of fertilisers, herbicides or other chemicals or pollutants into the ecological community which kill or inhibit the growth of species in the ecological community.***

As mentioned above with the implementation of management measures for surface water, sedimentation and erosion, weed invasion and bush fire would greatly limit the potential for impacts on preserved woodland vegetation adjoining the works areas.

7. Will the action interfere with the recovery of an ecological community?

The proposed development would not reduce the area of land currently occupied by Cumberland Plain Woodland in the Western Sydney region. The implementation of mitigation measures would further ensure that longer-term residual impacts are not imposed on preserved vegetation adjoining works areas.

Nationally Listed Threatened Species: Grey-headed Flying Fox *Pteropus poliocephalus*

This assessment deals specifically with the significance of impacts from the proposed development on the nationally vulnerable Grey-headed Flying-fox. This species is expected to utilise habitat that may be affected by the proposed activity. All remaining threatened fauna species are considered either not to occur in the study area, or the habitat is only very marginal in extent and quality (Refer Section 3) and there would be no impacts on suitable habitat resulting from the proposed activities.

The assessment of nationally threatened species present within or known to utilise the study area has been undertaken in accordance with the significant impact criteria for endangered and vulnerable species as outlined in the Significant Impact Guidelines relating to matters of national environmental significance (DEH 2006) to determine whether the proposal would have a significant impact on any of these species, and hence on a matter of national environmental significance. This assessment is provided below.

1. Lead to a long-term decrease in the size of an important population of a species.

A number of roost sites 'flying-fox camps' for the Grey-headed Flying-fox are known from the Sydney area including the Botanic Gardens, Cabramatta, Gordon, Penrith, and Wheeney Creek and Yarramundi in the Hawkesbury. There are no existing roost sites within the areas selected for development of infrastructure for the Replacement Flows Project.

Foraging resources for the Grey-headed Flying-fox occur throughout all naturally vegetated areas of western Sydney. The high conservation value of remnant vegetation in Western Sydney, in particular Cumberland Plain Woodland has been recognised and in all cases the proposed infrastructure associated with the WSRWI project has been located to avoid impacts on native vegetation. The proposal would not remove important food resources nor impact on a roosting colony of this species.

2. Reduce the area of occupancy of an important population

The proposal would not remove a significant area of native remnant or regrowth vegetation and would not result in the loss of an area currently occupied by a nationally threatened species.

3. Will the action adversely affect habitat critical to the survival of the species?

Habitat critical to the survival of a species refers to areas that are necessary:

- For activities such as foraging, breeding, roosting, or disposal;
- For the long-term maintenance of the species including the maintenance of other species essential to the survival of the species, such as pollinators;
- To maintain genetic diversity and long-term evolutionary development; or
- For the reintroduction of populations or recovery of the species.

The proposed area of disturbance represents a very small fraction of the potential foraging habitat for the Grey-headed Flying-fox in the Western Sydney region. This species typically exhibits very large home ranges and Grey-headed Flying-fox are known to travel distances of at least 15km from roost sites to access seasonal foraging resources (Tidemann 1995). No evidence of a roosting colony of the Grey-headed Flying-fox was observed from the field surveys.

4. Modify, remove, or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline.

The proposed area of disturbance represents a very small fraction of the potential foraging habitat for the Grey-headed Flying-fox in the Western Sydney region. This species typically exhibits very large home ranges and Grey-headed Flying-fox are known to travel distances of at least 15km from roost sites to access seasonal foraging resources (Tidemann 1995). No evidence of a roosting colony of the Grey-headed Flying-fox was observed from the field surveys.

5. Result in invasive species that are harmful to a vulnerable species becoming established in the threatened species habitat.

Weeds have been recorded in the study area and could potentially spread to suitable habitat areas. The implementation of a weed management actions are required to target any weed invasions which could arise from the proposal would significantly reduce the potential impacts of weed species.

6. Interferes substantially with the recovery of the species

The proposal would not conflict with the recovery actions proposed for the Grey-headed Flying-fox and would involve minimal impact to the potential habitat for this species in the regional area.

Migratory species or their habitat

A number of listed migratory bird species have been recorded from the western Sydney region which constitutes a part of the range area for migratory species such as the Satin Flycatcher and Black-faced Monarch.

The Replacement Flows Project area does not provide unique or critical habitat, preferred habitat, or habitat of significance for any of these species, and as discussed previously there would be very minimal impact on native vegetation resulting from the project. Construction of the proposed works would not affect the visitation rates and behaviours of migratory species in the region.

5. Avoidance and Mitigation Recommendations

5.1 Avoidance

Where possible the design of the proposed infrastructure should consider confining vegetation clearance to highly modified and degraded landscapes. Additionally, efforts should be made to conserve and appropriately manage the intact areas of remnant vegetation adjoining the works areas and/or restore similar modified areas of vegetation outside the proposed construction footprint to offset any potential small losses associated with individual trees.

5.2 Mitigation

In order to limit any potential indirect impacts on adjacent flora, vegetation communities and fauna habitat the following mitigation measures should be employed:

- Vegetation retention through minimising the extent of construction areas and retaining and protecting vegetation adjacent to construction areas;
- Bare earth areas should be stabilised and revegetated as soon as practicable following completion of construction to limit the potential for erosion which could affect adjacent vegetation communities and watercourses;
- Protection of large, hollow bearing trees, standing dead trees and trees with nests where possible;
- Underground boring techniques should be employed to avoid potential impacts on sensitive habitats including riparian vegetation as shown on **Figures D1a** to **D1d;**
- Construction compounds, access tracks, stockpiles, storage and depot sites would be positioned in cleared areas away from watercourses;
- Weeds should be controlled throughout the construction areas to minimise their spread to adjacent areas;
- All revegetation works should be undertaken with species that are locally native such as species representative of Cumberland Plain Woodland. Regeneration would be monitored and further management undertaken if required;
- Fallen logs encountered within the works corridor should be pushed aside and retained in their natural state. Timber felled for clearing should be retained on the ground as cover for terrestrial fauna.
- Trenches would be dug with shallow sloping ends to allow natural fauna escape and should be inspected each morning and checked for captured fauna. Any fauna captured should be removed and released into adjacent natural habitat.

6. Conclusions

The information presented in this report has utilised field investigations and a review of available data to assess the potential impacts of the proposed Replacement Flows Project in relation to relevant environmental and threatened species legislation.

The assessment has concluded that the proposed development is unlikely to impose a 'significant impact' on local populations of threatened species, endangered communities or their habitats as listed under the EPBC Act and TSC Act, provided the recommendations of this report are adequately implemented.

This conclusion is based on the fact that the proposed development would not reduce the area of land currently occupied by Endangered Ecological Communities and threatened species in the Western Sydney region. The high conservation value of remnant vegetation in Western Sydney, in particular Cumberland Plain Woodland has been recognised and in all cases the proposed infrastructure associated with the Replacement Flows Project has been located to avoid impacts on native vegetation.

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Attachment A - Flora Species List

NOTES ON SYMBOLS USED IN THE TABLE:
i = introduced (i.e. not indigenous to Australia)
n = native Australian species not considered to be indigenous to the site
c = cultivated (i.e. planted on the site)
t = listed as a threatened species under State and/or Commonwealth legislation
spp. = several species of the one genus (sometimes occurring as a hybrid swarm)
sp. = unidentified species[4]
sp. aff. = unidentified species with characteristics similar to the indicated species or genus[3]
? = unconfirmed species[4]
var. = variety
subsp. = subspecies
cv. = cultivar (i.e. a anthropogenic form of the species)
agg. = an aggregate of several yet to be defined species

Classification / Scientific name	Recent Synonyms	Common Name		St Marys AWTP	Pipeline route
SUBKINGDOM TRACHEOBIOTINA		Vascular Plants			
SUPERDIVISION SPERMATOPHYTANAE		Seed Plants			
SUPERDIVISION PTERIDOPHYTANAE		Seedless Vascular Plants			
DIVISION POLYPODIOPHYTA		Ferns			
CLASS POLYPODIOPSIDA					
Order Pteridales					
ADIANTACEAE					
Cheilanthes sieberi		Mulga Fern			1
Pellaea falcata		Sickle Fern		1	
DIVISION MAGNOLIOPHYTA		Flowering Plants			
CLASS MAGNOLIOPSIDA		Paleodicotyledons			
Order Laurales					
LAURACEAE					
Cinnamomum camphora		Camphor Laurel	i	1	1
CLASS ROSOPSIDA		Eudicotyledons			
SUBCLASS RANUNCULIIDAE					
Order Ranunculales					
RANUNCULACEAE					
Clematis glycinoides		Entire-leaf Clematis			
Order Proteales					
PROTEACEAE					
Grevillea juniperina		Juniper-leaved			1

Classification / Scientific name	Recent Synonyms	Common Name		St Marys AWTP	Pipeline route
subsp. *juniperina*		Grevillea			
SUBCLASS DILLENIIDAE					
Order Dilleniales					
DILLENIACEAE					
Hibbertia scandens		Climbing Guinea-flower		1	
Order Caryophyllales					
AMARANTHACEAE					
Alternanthera denticulata		Lesser Joyweed		1	
Alternanthera pungens		Khaki Weed	i	1	
Amaranthus viridus		Green Amaranth	i	1	
Gomphrena celosioides		Gomphrena Weed	i	1	
BASSELLACEAE					
Andredera cordifolia		Madeiera Vine	i	1	1
CHENOPODIACEAE					
Einadia hastata		Shrubby Berry-saltbush		1	1
Einadia polygonoides				1	
POLYGONACEAE					
Persicaria decipiens	*Polygonum decipiens*	Slender Knotweed		1	1
Persicaria hydropiper	*Polygonum hydropiper*	Water Pepper		1	1
Polygonum arenastrum		Common Wireweed		1	
Rumex crispus		Curled Dock	i	1	1
SUBCLASS ROSIDAE					
Order Saxifragales					
CRASSULACEAE					
Bryophyllum delagoense		Mother-of-millions	i	1	1
Order Vitales					
VITACEAE					
Cissus antarctica		Water Vine		1	
Order Geranilaes					
GERANIACEAE					
Geranium sp.		Geranium	i	1	
Order Myrtales					
MYRTACEAE					
EUCALYPTS					

Classification / Scientific name	Recent Synonyms	Common Name		St Marys AWTP	Pipeline route
Angophora costata		Smooth-barked Apple			1
Angophora floribunda		Rough-barked Apple			1
Corymbia maculata	*Eucalyptus maculata*	Spotted Gum			1
Eucalyptus amplifolia		Cabbage Gum		1	1
Eucalyptus crebra		Thin-leaved Ironbark			1
Eucalyptus globoidea		White Stringybark		1	1
Eucalyptus eugenioides		Thin-leaved Stringybark			1
Eucalyptus fibrosa		Broad-leaved Ironbark			1
Eucalyptus grandis		Flooded Gum	n	1	
Eucalyptus molucanna	*Eucalyptus hemiphloia*	Grey Box		1	
Eucalyptus pilularis		Blackbutt			1
Eucalyptus punctata		Common Grey Gum		1	1
Eucalyptus resinifera		Red Mahogany			1
Eucalyptus robusta		Swamp Mahogany		1	
Eucalyptus saligna		Sydney Blue Gum			1
Eucalyptus sideroxylon		Mugga Ironbark		1	1
Eucalyptus siderophloia		Northern Grey Ironbark		1	1
Eucalyptus tereticornis		Forest Red Gum		1	1
OTHER MYRTACEAE					
Backhousia myrtifolia		Grey Myrtle			1
Callistemon spp.					1
Callistemon salignus		Willow Bottlebrush		1	
Callistemon viminalis		Weeping Bottlebrush	n	1	
Kunzea ambigua		Tick Bush			1
Leptospermum pertersonii		Lemon-scented Tea-tree	n		
Lophostemon confertus		Brush Box	n		1
Melaleuca armillaris		Coast Paperbark		1	
Melaleuca bracteata		Black Tea-tree	n	1	
Melaleuca decora					1
Melaleuca ericifolia		Heath Paperbark		1	
Melaleuca linariifolia		Snow-in-Summer		1	1
Melaleuca nodosa		Ball Honey-myrtle			1
Melaleuca		Broad-leaved	n		1

Classification / Scientific name	Recent Synonyms	Common Name		St Marys AWTP	Pipeline route
quinquenervia		Paperbark			
Melaleuca styphelioides		Prickly Paperbark		1	1
Melaleuca trichostachya			n	1	
Syncarpia glomulifera		Turpentine			1
Syzygium spp			n		
Tristaniopsis laurina		Water Gum			1
ONAGRACEAE					
Ludwigia peploides subsp. *montevidensis*		Water Primrose			
Order Malpighales					
PASSIFLORACEAE					
Passiflora edulis		Passion-fruit	i	1	
PHYTOLACCACEAE					
Phytolacca octandra		Inkweed	i		1
SALICACEAE					
Salix babylonica		Weeping Willow	i	1	
Order Oxalidales					
OXALIDACEAE					
Oxalis exilis		Yellow Oxalis			1
Order Fabales					
FABACEAE					
CAESALPINIOIDEAE					
Senna septemtrionalis		Cassia	i		1
FABOIDEAE					
Glycine clandestina agg.		Twining Glycine		1	1
Daviesia ulicifolia		Gorse Bitter-pea			1
Hardenbergia violacea		Purple Twining-pea			1
Indigofera australis		Australian Indigo			1
Medicago polymorpha		Burr Medic	i	1	1
Trifolium repens		White Clover	i		1
MIMOSOIDEAE					
Acacia binervia		Coast Myall		1	
Acacia decora		Western Silver Wattle			
Acacia decurrens		Fine-leaf Green Wattle			
Acacia elongata var. *elongata*		Swamp Wattle			
Acacia falcata		Sickle Wattle			1
Acacia floribunda		Sally Wattle		1	
Acacia implexa		Hickory		1	
Acacia irrorata					1

Classification / Scientific name	Recent Synonyms	Common Name		St Marys AWTP	Pipeline route
Acacia parramattensis		Sydney Green Wattle		1	1
Acacia saligna		Golden-wreath Wattle	i		
CASUARINACEAE					
Allocasuarina littoralis		Black She-oak			1
Casuarina glauca		Swamp Oak		1	1
Order Rosales					
MALACEAE					
Cotoneaster glaucophyllus		Cotoneaster	i	1	
ROSACEAE					
Rubus fruticosus agg.		Blackberry	i	1	1
Order Cucurbitales					
CUCURBITACEAE					
Cucurbita maxima		Pumpkin	i	1	
CAPRIFOLIACEAE					
Lonicera japonica		Honeysuckle	i		1
Order Brassicales					
BRASSICACEAE					
Brassica juncea		Indian Mustard	i	1	
Lepidium africanus		Peppercress	i	1	
Lepidium bonariense		Peppercress	i		
Rorippa nasturtium-aquaticum		Watercress	i	1	
Order Malvales					
EUPHORBIACEAE					
Chamesayce drummondii		Caustic Weed		1	
Euphorbia peplus		Petty Spurge	i		
Ricinus communis		Castor Oil Plant	i		1
MALVACEAE					
Pavonia hastata		Pavonia	i	1	
Malva parviflora		Small-flower Mallow	i	1	1
Modiola caroliniana		Red-flowered Mallow	i	1	1
Sida rhombifolia		Paddys Lucerene	i	1	1
Order Sapindales					
MELIACEAE					
Melia azedarach		White Cedar			
SAPINDACEAE					
Cardiospermum		Small Balloon Vine			1

Classification / Scientific name	Recent Synonyms	Common Name		St Marys AWTP	Pipeline route
halicacabum					
SUBCLASS ASTERIDAE					
Order Ericales					
ERICACEAE					
Lissanthe strigosa		Peach Heath			1
MYRSINACEAE					
Anagallis arvensis		Pimpernell	i	1	
Order Gentianales					
APOCYNACEAE					
Araujia hortorum		Moth Vine	i	1	1
Gomphocarpus fruticosus		Narrow-leaved Cotton Bush	i		
Parsonsia straminea		Common Silkpod			1
RUBIACEAE					
Galium asparine		Cleavers	i	1	1
Richardia stellaris			i	1	
Order Lamiales					
ACANTHACEAE					
Pseuderathemum variable		Pastel Flower			1
LAMIACEAE					
Stachys arvensis		Stagger Weed	i	1	
OLEACEAE					
Ligustrum lucidum		Large-leaf Privet	i	1	1
Ligustrum sinense		Small-leaf Privet	i	1	1
Olea europaea subsp. *africana*		African Olive	i	1	1
PLANTAGINACEAE					
Plantago lanceolata		Plantain	i	1	1
Plantago major		Large Plantain	i		
SCROPHULARIACEAE					
Veronica calycina		Common Speedwell			1
VERBENACEAE					
Duranta repens		Pigeonberry	i	1	
Lantana camara		Lantana	i		1
Verbena bonariensis		Purple Top	i	1	1
Order Solanales					
CONVOLVULACEAE					
Convolulus erubescens		Pink Bindweed		1	
Dichondra repens		Kidney Weed		1	1
Ipomoea purpurea		Purple Morning Glory	i		1
SOLANACEAE					

Classification / Scientific name	Recent Synonyms	Common Name		St Marys AWTP	Pipeline route
Lycopersicon esculentum		Tomato	i	1	
Solanum americanum		Glossy nightshade			
Solanum mauritianum		Wild Tobacco	i	1	1
Solanum pseudocapsicum		Jerusalem Cherry	i	1	
Solanum sisymbriifolium					
Order Apiales					
APIACEAE					
Apium graveolens		Celery	i	1	
Centella asiatica		Swamp Pennywort		1	
Hydrocotyle laxiflora		Stinking Pennywort		1	
PITTOSPORACEAE					
Bursaria spinosa		Blackthorn			1
Pittosporum undulatum		Sweet Pittosporum			1
Order Asterales					
ASTERACEAE					
Ageratina adenophora	*Eupatorium adenophorum*	Crofton Weed	i	1	1
Aster subulatus		Wild Aster	i		
Bidens pilosa		Cobblers Peg	i	1	1
Calotis cunefolia		Purple Burr Daisy			1
Cirsium vulgare		Scotch Thistle	i	1	
Conyza canadiensis		Canadian Fleabane	i	1	
Helianthus annuus		Common Sunflower	i		
Hypochoeris radicata		Flatweed	i	1	1
Ozothamnus diosmifolius	*Helichrysum diosmifolia*	Tall Paperdaisy			1
Senecio madagascariensis		Fireweed	i	1	1
Soliva sessilis		Bindyi	i	1	1
Sonchus oleraceus		Common Sow-thistle	i	1	1
Tagetes minuta		Stinking Roger	i	1	
Taraxacum officinale		Dandelion	i	1	
CLASS LILIOPSIDA		Monocotyledons			
SUBCLASS LILIIDAE					
Order Alismatales					
LEMNACEAE					

Classification / Scientific name	Recent Synonyms	Common Name		St Marys AWTP	Pipeline route
Lemna disperma	*Lemna minor*	Duckweed			
Order Asparagaceae					
ASPARAGACEAE					
Agave americana		Century Plant	i		1
Myrsiphyllum asparagoides	*Asparagus asparagoides*	Florists Smilax	i	1	1
Protasparagus plumosus	*Asparagus plumosus, Asparagus setaceus*	Climbing Asparagus Fern	i	1	
LOMANDRACEAE					
Lomandra longifolia subsp. *longifolia*		Spiny Mat-rush		1	1
Lomandra multiflora		Mat-rush			1
SUBCLASS COMMELINIDAE					
Order Poales					
CYPERACEAE					
Carex appressa		Tussock Tassel-sedge			1
Cyperus eragrostis		Umbrella Sedge	i	1	
Cyperus gracilis		Slender Flat Sedge		1	
Cyperus tenellus		Tiny Flat Sedge	i	1	
Eleocharis sphacelata		Tall Spike-rush			1
Isolepis prolifera	*Scirpus prolifer*	Club-rush	i	1	
Schoenoplectus mucronatus	*Scirpus mucronatus*	Angled Club-rush			
JUNCACEAE					
Juncus polyanthemus		Many-flowered Rush			
Juncus usitatus		Common Rush		1	
POACEAE					
Aristida ramosa		Purple Wiregrass			1
Aristida vagans		Three Awn Speargrass			1
Arundo tenax		Giant Reed	i		1
Austrodanthonia spp.		Wallaby Grass			1
Axonopus affinis		Carpet Grass			1
Bambusa vulgaris				1	
Bromus catharticus	*Bromus uniloides*	Prarie Grass	i		
Chloris gayana		Rhodes Grass	i	1	
Chloris truncata		Windmill Grass		1	
Chloris ventricosa		Tall Windmill Grass			
Chloris virgata		Feathertop Rhodes Grass		1	1
Cortadieria selloana		Pampas Grass	i		

Classification / Scientific name	Recent Synonyms	Common Name		St Marys AWTP	Pipeline route
Cynodon dactylon		Common Couch		1	1
Dichamtheum sericeum subsp. *sericeum*		Queensland Bluegrass		1	
Ehrharta erecta		Panic Veldtgrass	i	1	1
Eragrostis curvula		African Lovegrass	i	1	1
Microlaena stipoides		Weeping Grass			1
Oplismenus aemulus		Broad-leaf Beard-grass		1	
Paspalidium distans		Paspalidium		1	
Paspalum dilatatum		Paspalum	i	1	
Paspalum urvillei		Vasey Grass	i	1	
Paspalum vaginatum	*Paspalum distichum*	Salt-water Couch			
Pennisetum clandestinum		Kikuyu	i	1	1
Phragmites australis		Common Reed			1
Setaria gracilis		Slender Pigeon Grass	i	1	
Sporobolus africanus	*Sporobolus indicus* var. *capensis*	Parramatta Grass	i	1	
Themeda australis	*Themeda triandra*	Kangaroo Grass		1	1
TYPHACEAE					
Typha orientalis		Broad-leaf Cumbungi		1	1
Order Commelinales					
COMMELINACEAE					
Commelina cyanea		Scurvy Weed		1	1
Tradescantia albiflora		Wandering Jew	i	1	1

TOTALS		109	68
Total Flora Species	*126*		
Total Flora Species St Marys	*109*		
Total Flora Species Penrith	*68*		
Total Number of Families	*42*		
Total Monocotyledons	*33*		
Total Dicotyledons	*92*		
Total Fern Species	*1*		
Total Conifer & Cycad Species	*0*		
Total Indigenous Native Species	*56*		
Total Exotic Species	*69*		
Total Non-indigenous Native Species	*7*		
Total Threatened Species	*0*		

NOTES:

1. Recent 'synonyms' include misapplied names.

2. The inclusion of Boraginaceae in Lamiales in tenative.

3. A sample flora assemblage obtained from a short term survey, such as the present one, cannot be considered to be comprehensive, but rather indicative of the actual flora assemblage. It can take many years of flora surveys to record all of the plant species occurring within any area, especially species that are only apparent in some seasons.

4. Not all species can be accurately identified in a 'snapshot' survey due to absence of flowering or fruiting material, etc.

SCIENTIFIC NAMES & AUTHORITIES:

Scientific names & families are those used in the *Flora of New South Wales* as maintained by the Royal Botanic Gardens (http://.plantnet.rbgsyd.gov.au).

Orders and higher taxa are based on Angisperm Phylogeny Group (2003).

For sake of simplicity, scientific names in this list do not include authorities. These can be found in the *Flora of New South Wales.*

Attachment B - Fauna Species List

NOTES ON SYMBOLS USED IN THE TABLE

HABITATS

1 Woodland
2 Swamp Sclerophyll Forest
3 Riparian / Creek
4 Modified Grass / Cleared land
5 Ponds

OBSERVATION TYPE

O Observed
W Heard call
P Scat
E Nest/roost
T Trapped
BC Bat Call (Recorded)

Nomenclature follows Stanger *et al* (1997)
(V) = Schedule 2 Vulnerable Species (TSC Act 1995)
(M) = Migratory species protected under the China-Australia Migratory Bird Agreement (CAMBA)
***** = denotes introduced / exotic species

FAMILY **Scientific Name**	**Common Name**	**St Marys AWTP**	**Pipeline Route**	**Obs Type**
MAMMALS				
PETAURIDAE				
Petaurus breviceps	Sugar Glider	1		T
PSEUDOCHEIRIDAE				
Pseudocheirus peregrinus	Common Ringtail Possum	2		P,E
PHALANGERIDAE				
Trichosurus vulpecula	Common Brushtail Possum	1		O,P
MACROPODIDAE				
Macropus giganteus	Eastern Grey Kangaroo	1	4	O,P
CANIDAE				
*Vulpes vulpes **	Fox		4	P
LEPORIDAE				
*Lepus capensis **	Brown Hare	1,2,3,4	4	O
MOLOSSIDAE				
Mormopterus sp. 2	Eastern Freetail Bat		5	BC
VESPERTILIONIDAE				
Miniopterus schreibersii oceanensis	Eastern Bent-wing Bat **(V)**	1,4		BC
Nyctophilus sp.	A Long-eared Bat		5	BC
Chalinolobus gouldii	Gould's Wattled Bat		5	BC
Chalinolobus morio	Chocolate Wattled Bat	1,4		BC
REPTILES				
CHELIDAE				
Chelodina longicollis	Eastern Long-necked Turtle	3		O
AGAMIDAE				
Pogona barbata	Bearded Dragon	1		O
SCINCIDAE				
Lampropholis delicata	Delicate Skink	1,2	4	O
Lampropholis guichenoti	Grass Skink	3	4	O
ELAPIDAE				
Pseudechis porphyriacus	Red-bellied Black Snake		4	O
Pseudonaja textilis	Eastern Brown Snake		4	O

FAMILY Scientific Name	Common Name	St Marys AWTP	Pipeline Route	Obs Type
AMPHIBIANS				
MYOBATRACHIDAE				
Crinia signifera	Common Eastern Froglet	3	4	W
Limnodynastes peronii	Striped Marsh Frog		4	O
Uperoleia laevigata	Red-groined Toadlet		4	W
BIRDS				
PHASIANIDAE				
Coturnix australis	Brown Quail	4		O
ANATIDAE				
Chenonetta jubata	Australian Wood Duck	3	4,5	O
Anas superciliosa	Pacific Black Duck	3	4,5	O
Anas castanea	Chestnut Teal	3	4,5	O
Anas gracilis	Grey Teal	3	4,5	O
Anas rhynchotis	Australasian Shoveler		5	O
Aythya australis	Hardhead		5	O
ARDEIDAE				
Egretta novaehollandiae	White-faced Heron	3	4,5	O
THRESKIORNITHIDAE				
Threskiornis molucca	Australian White Ibis		4,5	O
FALCONIDAE				
Falco cenchroides	Nankeen Kestrel		4	O
RALLIDAE				
Fulica atra	Eurasian Coot		5	O
Gallinula tenebrosa	Dusky Moorhen	3	4,5	O,W
Porphyrio porphyrio	Purple Swamphen		4,5	O,W
CHARADRIIDAE				
Vanellus miles	Masked Lapwing		4	O,W
COLUMBIDAE				
Streptopelia chinensis *	Spotted Turtledove	4	4	O
Ocyphaps lophotes	Crested Pigeon	4		O
CACATUIDAE				
Cacatua roseicapilla	Galah	1,4	1,4	O,W
Cacatua sanguinea	Little Corella	1	1	O,W
Cacatua galerita	Sulphur-crested Cockatoo	1		W
PSITTACIDAE				
Trichoglossus haematodus	Rainbow Lorikeet	1		O,W
Trichoglossus chlorolepidotus	Scaly-breasted Lorikeet	1		O,W
Platycercus eximius	Eastern Rosella	1,3,4		O
PODARGIDAE				
Podargus strigoides	Tawny Frogmouth	2		O
HALCYONIDAE				
Dacelo novaeguineae	Laughing Kookaburra	1,4		O
MALURIDAE				
Malurus cyaneus	Superb Fairy-wren	2,3	4	O
PARDALOTIDAE				
Pardalotus striatus	Striated Pardalote	1,2		W

FAMILY Scientific Name	Common Name	St Marys AWTP	Pipeline Route	Obs Type
Acanthiza pusilla	Brown Thornbill	1,2,3		O
Acanthiza nana	Yellow Thornbill	2,3	4	O
MELIPHAGIDAE				
Anthochaera carunculata	Red Wattlebird	1		O,W
Manorina melanocephala	Noisy Miner	1,2,3,4		O,W
Lichenostomus penicillatus	White-plumed Honeyeater		1	O
NEOSITTIDAE				
Daphoenositta chrysoptera	Varied Sitella	1,2		O
PACHYCEPHALIDAE				
Pachycephala pectoralis	Golden Whistler	2,3		O,W
DICRURIDAE				
Rhipidura leucophrys	Willie Wagtail	1,4	4	O
Rhipidura fuliginosa	Grey Fantail	2		O
Grallina cyanoleuca	Magpie-lark	4	4	O
CAMPEPHAGIDAE				
Coracina novaehollandiae	Black-faced Cuckoo-shrike	1,2,3	4	O
ARTAMIDAE				
Gymnorhina tibicen	Australian Magpie	1,4	1,4	O
CORVIDAE				
Corvus coronoides	Australian Raven	1,2	4	O,W
PASSERIDAE				
Neochmia temporalis	Red-browed Firetail		4	O
HIRUNDINIDAE				
Hirundo neoxena	Welcome Swallow	4	4,5	O
PYCNONOTIDAE				
Pycnonotus jocosus	Red-whiskered Bulbul		4	O,W
STURNIDAE				
Acridotheres tristis *	Common Myna	1,4	4	O

Appendix F

Noise and vibration assessment



Replacement Flows Project

Noise and Vibration Assessment

- FINAL
- 24 October 2006

Replacement Flows Project

Noise and Vibration Assessment

- FINAL
- 24 October 2006

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1. Introduction

This report addresses potential noise and vibration impacts associated with the proposed Replacement Flows Project, including construction and operation activities. Operational noise has been generally assessed in accordance with the NSW Department of Environment and Conservation (DEC) *Industrial Noise Policy* (INP). Construction noise has been generally assessed in accordance with DECs Environmental Noise Control Manual (ENCM, 1994).

1.1 Project Description

The Replacement Flows Project (the Project) is an integrated water management system that would increase water availability from Warragamba Dam. The project consists of the construction and operation of works to enable the discharge of up to 50 ML/day of highly treated recycled water to the Hawkesbury-Nepean River below the existing Penrith Weir. The intent of this discharge is to provide replacement flows for water currently discharged from Warragamba Dam to maintain adequate flows in the river for irrigation and environmental health.

The infrastructure required to provide this recycled water comprises:

- An Advanced Water Treatment Plant (AWTP) at the St Marys sewage treatment plant (STP) site
- Pumping stations and pipelines which would transfer tertiary treated wastewater from Quakers Hill, Penrith and St Marys STPs to the proposed AWTP at St Marys
- Pumping station and pipeline for the transfer of the concentrate stream from the AWTP, via Quakers Hill STP to the Northern Suburbs Ocean Outfall Sewer (NSOOS) at Vineyard Creek, Dundas
- A pipeline for the transfer of recycled water from the AWTP to the existing outlet into Boundary Creek at Penrith STP, which discharges into the Hawkesbury-Nepean River below Penrith Weir or discharge directly into the Hawkesbury-Nepean River.

2. Existing Noise Environment

2.1 Identification of Sensitive Receivers

The identification of sensitive receivers for the project includes those impacted by noise and vibration during both construction and operation. These sites can therefore be loosely categorised by the STP location where the replacement flows are derived and those along the route of the pipelines.

2.1.1 Penrith

The Penrith STP is accessed by Castlereagh Road which is a major traffic route in the area. To the north, south and west of the existing STP is industrial land use. The nearest receivers are industrial/commercial premises located in Dean Street.

The area to the east of the site is predominantly residential mixed with some open space, sporting grounds and bushland. The nearest residential receivers to the Penrith STP site are located in Panorama Road approximately 900 metres from the STP boundary.

2.1.2 St Marys

The nearest receivers to the St Marys site are residential premises in Triggs Street that are adjacent to the AWTP site boundary. These dwellings are located on Sydney Water land and are owned by Sydney Water. These dwellings are included in the assessment of noise impacts at this stage of the project however, this may change in the future given the refinement of the project footprint and other details.

The nearest privately owned residential dwellings are located on Forrester Road about 1600 metres to the south east of the site. Other commercial buildings are located greater than 50 metres away on Links Road. The existing land use in the area is predominantly industrial with mainly local road traffic. The rear of the St Marys STP backs onto Regional Parkland that has no pre-existing land use.

2.1.3 Quakers Hill

The Quakers Hill AWTP is located on Quakers Road with the nearest residential receivers being located approximately 150 metres to the South of the proposed works in Jasmine Avenue. The existing land use in the area is majority residential with some open parkland to the south east of the site. To the west of the site is Quakers Hill Parkway which is a significant source of road traffic connecting to Richmond Road.

2.1.4 Pipeline

Sensitive receivers along the pipeline route that may potentially be affected by noise during construction of the Replacement Flows Project include:

- Residential dwellings
- Recreational areas
  - Hickeys Park
  - Nepean Rugby Union Oval
  - Andrews Road Baseball Complex
  - Dunheved Golf Course
  - Peter Van Hasselt Park
  - International Peace Park
  - Best Road Park
  - McCoy Park
  - Reynolds Park
  - Belmore Park
  - Old Saleyards Park
  - Fred Robertson Park
- Educational centres
  - Oatlands Primary School
- Hospitals
  - Cumberland Hospital.

These sensitive receivers should be considered in more detail when the construction methodology and program have been completed during the detail design phase.

2.2 Existing Noise Environment

Measurements of the noise environment were undertaken at locations near the STP boundaries and at nearby residential locations to determine the influences of existing noise sources. At the Penrith and Quakers Hill sites an assessment of noise influences was undertaken at separate locations for the STP and the residential receivers. At the St Marys site the nearest residents share a common boundary with the St Marys STP.

A summary of the locations and a description of the noise sources are presented in **Table 1** with the attended monitoring results given in **Table 2**.

Table 1 Monitoring Locations and Description of Noise Sources

STP site	Monitoring Location		Description of noise environment
Penrith	1	STP Site Boundary	At the boundary of the STP the existing noise sources include some road traffic noise. The dominant noise source is from the Crane Enfield Metals Facility in Castlereagh road. Operations from within the STP are largely inaudible against the background noise.
	2	Panorama Avenue (Residential)	Constant industrial noise source of non specific origin from the direction of the STP with occasional "Crash" and "Bang". The majority of the noise generated is believed to come from the Crane Enfield Metals site.
St Marys	3	Triggs Road (Residential) STP Site Boundary	Constant noise from within the STP plant noise and possibly water flows. No other identifiable road traffic or industrial noise sources in the area.
	4	Forrester Road (Residential)	Road traffic noise is dominant source. No other industrial type noise present.
Quakers Hill	5	Jasmine Street (Residential)	Traffic on Quakers Road and Quakers Hill Parkway dominant noise source. Frogs and crickets audible from the drainage channel between the STP and Jasmine Ave. STP not audible from the residences over the background noise levels.

Table 2 Summary of Attended Noise Survey

Location	Time	Noise Level Descriptors - dB(A)			
		L_{A10}	L_{Aeq}	L_{A90}	$L_{A\ Min}$
2	11:11 pm	50	48	46	44
3	10:42 pm	48	47	47	46
5	10:00 pm	51	50	47	45

3. Assessment Criteria

The Replacement Flows Project is required to meet the guidelines for noise and vibration developed by the DEC. These guidelines detail the allowable criteria for airborne noise impacts as well as ground borne vibration for construction and operation of the project infrastructure. **Table 3** summarises the relevant impacts and the guideline used to assess it.

- **Table 3 Summary of Noise and Vibration Criteria**

Cause of Impact	Guideline	
	Noise	Vibration
Construction	DEC Construction Noise (formerly Chapter 171 ENCM)	**Human Comfort** DEC Vibration Guideline **Building Damage** DIN Standard 4150 or BS6472 Vibration in Buildings
Operational	Industrial Noise Policy	**Human Comfort** DEC Vibration Guideline **Building Damage** DIN Standard 4150 or BS7385 Evaluation and Measurement of Vibration in Buildings

3.1 Construction Noise

For the construction phase of the project, noise objectives documented in the DEC Environmental Noise Control Manual (ENCM, 1994), Chapter 171 Construction Site Noise, are used for assessing the potential impacts. The noise goals are dependent on the existing background noise levels and the expected duration of the works. The conditions of operation (for construction activity) are expressed in terms of L_{A10} noise levels above the nominated background level and are detailed in **Table 4**.

Due to the progressive nature of construction throughout the corridor, the works affecting any one residence are not anticipated to exceed two months in duration with the majority of works at any single location along the pipeline route completed within 4 weeks. The criteria at 1 in **Table 4** should therefore be used as the guiding value for the project unless future information requires this to be modified.

- **Table 4 DEC Construction Criteria Guidelines**

No.	Duration Of Works	DEC L_{A10} Guidelines
1	Construction period of 4 weeks and under	The L_{A10} level measured over a period of not less than 15 minutes when the construction site is in operation must not exceed the background level by more than 20 dB(A).
2	Construction period greater than 4 weeks and not exceeding 26 weeks	The L_{A10} level measured over a period of not less than 15 minutes when the construction site is in operation must not exceed the background level by more than 10 dB(A).
3	Construction period greater than 26 weeks	The EPA does not provide noise control guidelines for construction periods greater than 26 weeks duration, however, it is generally accepted that provided L_{A10} noise levels from the construction area do not exceed a level of 5 dB(A) above background, then adverse (intrusive) noise impacts are not likely to be experienced at nearest sensitive receptor locations.

Restrictions are also placed on the hours of construction to ensure that the acoustic amenity of the closest residences is protected. Hours of operation for construction works and associated road traffic for the project would follow standard construction times listed below. An allowance for negotiated variations to these times with DEC will be necessary where construction works will need to take place at times outside these hours for operational, safety and access reasons.

- Monday to Friday: 7am to 6pm
- Saturday: 8am to 1pm
- No audible construction work to take place on Sundays or public holidays.

The continual movement of construction works associated with the pipeline would help to limit the impacts on properties. From **Table 4** it is expected that the noise goals for construction of the pipeline would be Background (L_{A90}) + 20 dB(A).

3.2 Vibration

The effects of vibration in buildings can be divided into three main categories:

- Where occupants or users of the building are disturbed or inconvenienced
- Those in which the building contents may be affected
- Circumstances in which the integrity of the building or the structure itself may be prejudiced.

The vibrations caused by the construction works are to be assessed against the levels nominated for the Human Comfort Criteria and the Building Damage Criteria (**Table 3**). Residences that are within 30 metres of the closest construction activities should have a building condition survey carried out before and after the works are undertaken to ensure that no damage has occurred as a

result of the construction activities. The following information provides guidance for the assessment of vibration impacts during construction.

3.2.1 Human Comfort

The criterion for maintaining human comfort resulting from continuous and intermittent vibration impacts may be taken from several international as well as local Standards. Many of the vibration Standards for human comfort are recognised and used in Australia and include the British Standard BS 6472 (1984 and 1992), the international Standard ISO 2631.2–1989 and the Australian Standard AS 2670.2–1990.

The British Standard BS 6472 (current and former versions) has guided the DEC's evaluation of vibration since the mid-1980s. The recently released DEC *Environmental noise management - Assessing Vibration: a Technical Guideline* document does not represent a change in DEC policy approach. This guideline presents preferred and maximum vibration values for use in assessing human responses to vibration and provides recommendations for measurement and evaluation techniques. It does not address motion sickness, occupational vibration, blasting vibration effects or vibration-induced damage to buildings or structures.

The frequency range for human response discomfort is taken to be in the range 1-80 Hz although for frequencies above 80 Hz the criteria is the same as 80 Hz. The table below has been taken from the DEC guideline and provides base values for vibration levels for both rms acceleration and peak velocity measurements for nominal frequencies up to 80 Hz. The base values are then modified by values in Table B1.1 (also from the guideline) depending on the type of receiver and the time of day.

The large distance offsets for many of the sensitive receivers from the STP sites means there is little risk to human discomfort levels resulting from operational vibration. A more likely vibration impact to sensitive receivers would be from construction works. As there are a potentially a large number of receivers on the project that may be impacted upon by construction work, a more thorough assessment of vibration impacts would be made during the design and construct phase when construction methodologies and pipeline location are known in greater detail.

Table B1.2 Vibration values for the base curves in Figures B1.1 to B1.4

Frequency Hz	z-axis vibration values		x- & y-axis vibration values	
	rms acceleration m/s^2 (Figure B1.1)	Peak velocity mm/s (Figure B1.3)	rms acceleration m/s^2 (Figure B1.2)	Peak velocity mm/s (Figure B1.4)
1	0.01	2.25	0.00357	0.804
1.3	0.00894	1.61	0.00357	0.643
1.6	0.00791	1.11	0.00357	0.502
2	0.00707	0.796	0.00357	0.402
2.5	0.00632	0.569	0.00446	0.402
3.2	0.00563	0.402	0.00563	0.402
4	0.005	0.281	0.00714	0.402
5	0.005	0.225	0.00893	0.402
6.3	0.005	0.179	0.0113	0.402
8	0.005	0.141	0.0143	0.402
10	0.00625	0.141	0.0179	0.402
13	0.00781	0.141	0.0223	0.402
16	0.01	0.141	0.0286	0.402
20	0.0125	0.141	0.0357	0.402
25	0.0156	0.141	0.0446	0.402
32	0.0197	0.141	0.0563	0.402
40	0.025	0.141	0.0714	0.402
50	0.0313	0.141	0.0893	0.402
63	0.0394	0.141	0.113	0.402
80	0.05	0.141	0.143	0.402

Source DEC Assessing Vibration: a Technical Guideline

Table B1.1 Multiplying factors used to specify satisfactory magnitudes of building vibration with respect to human response

Place	Time	Multiplying factors	
		Continuous vibration	Impulsive vibration
Critical working areas (e.g. hospital operating theatres, precision laboratories)	day night	1 1	1 1
Residences	day night	2–4 1.4	60–90 20
Offices	day night	4 4	128 128
Workshops	day night	8 8	128 128

Source: BS 6472–1992

Source DEC Assessing Vibration: a Technical Guideline

3.2.2 Criteria for Building Structures

Vibration from construction activities with regard to building damage would be controlled by compliance with the German standard *DIN 4150: Part 3 – 1999 Effects of Vibration on Structures* or the British Standard *BS 7385:Part1-1993 Evaluation and Measurement for Vibration in Buildings*. The DIN guideline provides more conservative values for vibration levels that may potentially cause building damage and specifically identifies heritage structures as having a more stringent criterion. For ease of use on the project the DIN standard will be adopted as the appropriate criterion for building damage. If however, these criteria cannot be met within practical limitations, reference to the British Standard may be necessary. Peak particle velocity (mm/s) measured at the foundation of the building are summarised in **Table 5**. It may be seen from **Table 5** that like the human comfort criteria, these values are also frequency dependent and are specific for particular categories of structure.

- **Table 5 Guideline Values of Vibration Velocity, for Evaluating the Effects of Short Term Vibration DIN 4150**

Line	Type of Structure	Guideline Values for Velocity, vi , in mm/s			
		Vibration at the Foundation at a Frequency of			Vibration at Horizontal Plane of Highest Floor at all Frequencies
		1 Hz to10 Hz	10 Hz to50 Hz	50 Hz to100 Hz*	
1	Buildings used for commercial purposes, industrial buildings and buildings of similar design	20	20 to 40	40 to 50	40
2	Dwellings and buildings of similar design and/or use	5	5 to 15	15 to 20	15
3	Structures that, because of their sensitivity to vibration, do not correspond to those listed in lines 1 and 2 and are of great intrinsic value (eg buildings that are under a preservation order)	3	8 to 10	8 to 10	8
* For frequencies above 100Hz, at least the values specified in this column shall be applied					

3.2.3 Regenerated Noise

Levels of vibration can be transmitted into the ground by some construction operations. These vibration levels can cause a low-frequency rumbling sound to be generated within rooms of a building. This sound is termed “regenerated noise”. Regenerated noise cannot occur outside a building envelope. There is no specific DEC policy for regenerated noise criteria. However, recommendations for internal noise levels in AS2107-2000 *Acoustics – Recommended design sound levels and reverberation times for building interiors* for residential sleeping areas (negligible transportation) indicate that LAeq 25 dB(A) is appropriate for night time noise levels. Based on

the conditions of other major infrastructure projects, a slightly higher target objective of LAeq 35 dB(A) for residential premises would most likely be appropriate for the shorter duration construction activities, where night time works would take place.

3.3 Operational Noise

The EPA, now the DEC, released the NSW Industrial Noise Policy (INP) in January 2000. This document provides the framework and process for deriving project specific noise limits for impact assessments. The INP is designed to determine an acceptable level of impact expected at a community level and where the INP criteria are met no adverse noise impacts would be reasonably expected at the closest sensitive receivers.

The INP requires that the noise from a development under assessment comply with the lower of the amenity or intrusive noise criteria. The intrusive criterion is determined by the difference between the industrial noise under assessment being no more than 5 dB(A) above the Rating Background Level (RBL). The RBL is the tenth percentile of the background noise environment evaluated in the absence of industrial noise from the development in question. This is usually assessed prior to the commencement of operations.

The amenity criterion is based on the zoning of the residences likely to be affected by noise, the general land use near the receiver location and the extent of the existing industrial noise in the area. Where there is an existing influence of industrial noise, the INP implements modifying factors to the criteria to account for cumulative noise impacts in order to minimise background creep and control the long term noise environment.

In general to categorise the range in the background noise levels, one week of ambient noise monitoring must be undertaken. The DEC categorises one 24-hour monitoring period into the following three assessment periods:

- Day – 7:00 am to 6:00 pm
- Evening – 6:00 pm to 10:00 pm
- Night – 10:00 pm to 7:00 am.

For this project the nearest sensitive receivers are located up to 900 plus metres away for some of the STP sites. In an urban environment there are many local noise sources that may affect the noise environment at the project site as well as residential locations. The background levels at the different locations may be substantially different given the large distances involved and therefore not appropriate for the setting of project criteria.

With respect to these issues attended noise measurements have been used to establish measured values for the noise environment near the STP and the residential areas separately. A modified noise criteria based on the attended background noise monitoring has been used to determine the project Intrusiveness Criteria.

3.3.1 Intrusive Noise Criteria

From the INP the definition of a non-intrusive noise source is when:

- the LAeq, 15 minute level does not exceed the RBL by more than 5 dB(A) for each of the day, evening and night-time periods
- the subject noise does not contain tonal, impulsive, or other modifying factors as detailed in Chapter 4 of the INP.

3.3.2 Amenity Noise Criteria

The amenity criteria apply to the L_{Aeq} Level determined for the period of assessment of day, evening or night. The noise amenity classification for the area surrounding the STPs is "Urban" and "Urban/Industrial" based on the description for this type of location in the Industrial Noise Policy. The INP recommends that for a residence located in a rural area, an acceptable amenity criteria would be an L_{Aeq} of 60, 55 and 45 dB(A) for day, evening and night periods respectively.

3.3.3 Cumulative Noise Impacts

The INP aims to control cumulative noise impacts resulting from the combined effects of a proposed project and existing industrial noise sources by modifying the amenity criteria depending on the level of existing impact. Where there is an existing industrial noise influence, the amenity criteria in Table 2.1 of the INP (shown in **Table 6**) are decreased in accordance with the appropriate values in Table 2.2 of the INP (shown in **Table 7**).

- **Table 6 Extract of Table 2.1 DEC Amenity criteria (EPA 2000)**

Type of receiver	Indicative noise amenity area	Time of day	Recommended L_{Aeq} noise level, dB(A)	
			Acceptable noise level (ANL)	Recommended maximum
Residence	Rural	Day	50	55
		Evening	45	50
		Night	40	45
	Suburban	Day	55	60
		Evening	45	50
		Night	40	45

			Recommended L_{Aeq} noise level, dB(A)	
	Urban	Day	60	65
		Evening	50	55
		Night	45	50
	Urban/industrial interface – for existing situations only	Day	65	70
		Evening	55	60
		Night	50	55

- **Table 7 Modification to ANL to Account for Existing Level of Industrial Noise (EPA 2000)**

Total existing L_{Aeq} noise level from industrial sources, dB(A).	Maximum L_{Aeq} noise level for noise from new sources alone, dB(A)
≥ ANL plus 2	If existing noise level is *likely* to decrease in future: ANL minus 10 If existing noise level is *unlikely* to decrease in future: existing noise level minus 10.
ANL plus 1	ANL minus 8
ANL	ANL minus 8
ANL minus 1	ANL minus 6
ANL minus 2	ANL minus 4
ANL minus 3	ANL minus 3
ANL minus 4	ANL minus 2
ANL minus 5	ANL minus 2
ANL minus 6	ANL minus 1
<ANL minus 6	ANL

At the nearest residence, the modified amenity criterion for night time operations for each of the zones around each STP is shown in **Table 8**. These goals have been adjusted based on the observations at site and measurements summarised in **Table 2**.

- **Table 8 Modified Night Time Amenity Noise Criterion by Site**

Location	Industrial noise audible?	L_{Aeq} Measured	Indicative noise amenity area	Amenity criterion (night time)	Modified amenity criterion (night time)
Penrith	Yes	48	Urban	45 dB(A) $_{Period}$	35 dB(A) $_{Period}$
St Marys	Yes	47	Urban/Industrial	50 dB(A) $_{Period}$	47 dB(A) $_{Period}$
Quakers Hill	No	50	Urban	45 dB(A) $_{Period}$	45 dB(A) $_{Period}$

3.4 Project Specific Noise Goals

Project specific noise goals for noise and vibration sensitive receivers for various operational scenarios are ideally set against the most stringent assessment criterion. The L_{Aeq} noise level resulting from the proposed works during the night time period is assumed to be the most stringent at the nearest affected residence.

Although unattended noise monitoring has not been undertaken for the project to establish the RBL for the night time period, the assessment has been made based on a site visit to the various STPs during the early part of the night time period. This level of assessment is considered appropriate, considering the pre-existing noise environment surrounding the STPs and the low level risk of impact associated with the proposed works. At Penrith and St Marys the extent of proposed works and the distances to the nearest privately owned receivers means that there is an extremely low level of risk for noise or vibration resulting from the project.

This is however qualified by the fact that at the St Marys STP, site of the proposed AWTP, the nearest residences are adjacent to the STP site in Trigg Street. The strip of land currently used for residential purposes is owned by Sydney Water and has been identified as being potentially necessary for the project footprint. The noise assessment has included the residences in Trigg Street as the nearest receivers however this may change in the future.

At Penrith and St Marys the project specific noise goals are designed to account for the cumulative noise impacts are conservatively estimated to be L_{Aeq} 47 $dB(A)_{period}$ and 35 $dB(A)_{period}$ respectively where the L_{Aeq} value is taken over the night time (8 hr) period (**Table 7**). These values are derived from the application of the modified **amenity criteria** calculated in **Table 8**, based on the influence of industrial noise on the existing environment.

At Quakers Hill the night time hours are controlled by road traffic noise and therefore the application of amenity criterion to the project in this case is not valid. Based on an estimate of the background noise level in the vicinity of the Quakers Hill STP during the early hours of the morning, background noise levels may reduce to L_{A90} 35 dB(A) producing an intrusive noise criterion for the project of L_{Aeq} 40dB(A) $_{15\ Min}$ at the nearest residential boundary. This estimate of an intrusive noise goal is conservative and favours the residential locations to the south of the site. **Table 9** presents a summary of the project noise goals for each of the sites.

Table 9 Summary of Project Noise Goals by Site

STP site	Location of Assessment	Noise criterion L_{Aeq}
Penrith	Panorama Avenue	35 dB(A) $_{8hr\ (night)}$
St Marys	Triggs Road	47 dB(A) $_{8hr\ (night)}$
Quakers Hill	Jasmine Street	40 dB(A) $_{15\ Minute}$

4. Operational Noise Assessment

4.1 Proposed Works

A description of the equipment, which may be used in the proposed works for each of the sites, has been given below. The equipment types and sizes are nominal at this stage but represent typical units for the required duty specified for the project. Noise levels for each of the larger pieces of equipment have been estimated based on the size and quantities required. These estimated noise levels have then been applied to the SoundPLAN noise model and were used to predicted the level of noise at the nearest residential receivers.

4.1.1 Penrith

At the Penrith site, the proposed additional infrastructure includes a balance tank and pump, to pump the effluent to the AWTP at St Marys. The purpose of the balance tank is to even out diurnal flows in the sewerage stream to provide a continuous flow to the AWTP. The balance tank is likely to be constructed from reinforced concrete with a submersible pump to provide the required head and flow rates. The estimated motor size for this pumping duty is 2 x 160 kW. As the pumps would be submersible there are not expected to be any noise emissions from these units.

4.1.2 St Marys

The St Marys site has several sources of noise that may potentially cause an impact at nearby residential receivers. The main items of noise emission are:

- The effluent feed pumps (HP) 5 off 225kW at 108 dB(A) SWL and effluent feed pumps (LP) 2 off 140kW at 103 dB(A) SWL. These units are to be housed in the main equipment building
- Transfer pumps (return flow to Penrith) 2 x 250kW at 104 dB(A) SWL
- Concentrate Transfer Pumps 2 x 65kW at 91 dB(A) SWL
- Balance tank 2 x 160 kW these are submersible pumps and therefore no audible noise emissions
- Electrical substation (unknown transformer duty but would be a source of low frequency emissions).

4.1.3 Quakers Hill

At the Quakers Hill site, the proposed additional infrastructure includes a balance tank and pump, to pump the effluent to the AWTP at St Marys and an additional pump station to pump the concentrate received from the AWTP. As with the Penrith site the balance tank is likely to be constructed from reinforced concrete with a submersible pump to provide the required head and flow rates. These units would be sized similarly to the Penrith pumps and once again no noise emissions are expected from these units.

The concentrate pumps are expected to be located above ground in a specially designed pump house of brick and mortar construction. The combined Sound Power Level for these units is estimated to be 91dB(A). The pump house enclosure would be lined with sound absorbing materials to reduce the reverberant levels within the building and any ventilation to the outside would be through acoustically treated louvers.

4.2 Noise Predictions and Assessment

The noise level predictions at each of the sites have been undertaken using SoundPLAN modelling software implementing the Concawe algorithm. The data used in the model include topographical information, estimates of equipment size, and the location and construction of plant and buildings based on preliminary project information. The proposed project details may be refined at some point in the future, at which time a revised assessment may be required depending on the extent of any changes. For assessment purposes it has been assumed that any buildings that contain equipment are generally brick or other masonry construction unless otherwise noted.

4.2.1 Penrith

The works undertaken for the balance tank would implement a submersible pump. At this location audible noise emissions are not predicted from the proposed works. Therefore no additional increase to the existing noise environment at the nearest sensitive receivers is expected as a result of the proposal at this location.

4.2.2 St Marys

The predicted noise level resulting from the AWTP at the St Marys site would exceed the Modified Amenity Criteria at the nearest residential locations in Trigg Street by approximately 6 dB(A). These levels are based on the construction of the main AWTP building being fabricated from sheet steel with the HP and LP feed pumps enclosed in a masonry enclosure.

There is the potential to reduce this predicted noise level by several dB(A) at the nearby residences, using a more substantial construction for the main building, as well as the judicious positioning of equipment within the building where for example, equipment is evenly spaced throughout the building and not grouped together at one end. External pumps and other noise sources would also require attenuation so as not to increase the overall noise emissions from the pump station. Noise impacts are expected at this location but potentially may be mitigated to achieve the criterion for the residents in Triggs Road. If the residential land in Trigg Road is resumed, the nearest residential sites would be located approximately 1600 metres away and therefore no audible impacts would be expected.

4.2.3 Quakers Hill

The predicted noise emissions from the Quakers Hill site include the balance tank, which would implement a submersible pump and the Concentrate Transfer Pumps. The Balance tank pumps are expected to be inaudible and the Concentrate Transfer Pumps are assumed to be in a pump house of masonry construction.

At the nearest receiver locations in Jasmine Street audible noise resulting from the proposal are predicted to be less than 30 dB(A). This level would be lower than the existing background noise levels during even the quietest periods of the night and therefore no additional increase to the existing noise environment at the nearest sensitive receivers is expected as a result of the proposal at this location.

4.3 Operational mitigation measures

The initial assessment of the proposed project works indicates that operational criteria can be met at all STP sites including the proposed site of the AWTP at St Marys. At the Penrith and Quakers Hill sites there are currently no recommendations for additional noise mitigation treatments. At St Marys the AWTP would operate within a building structure, located on the existing St Marys STP site. The design and layout of the building would be appropriate for the control of noise emissions, in accordance with the INP, at the nearest residential receivers.

Periodic maintenance and inspections would typically not result in significant noise generation and would be managed through Sydney Water's standard management procedures.

5. Construction Noise and Vibration Assessment

Project construction and in particular the laying of the pipelines and related infrastructure is likely to impact on the acoustic environment of nearby sensitive receivers. Currently there is insufficient information to fully assess construction noise along the pipeline routes. This level of detail would follow the provision of a work program and a work method statement from a construction contractor. In order to provide preliminary information on construction noise for the project, an initial review of construction activities has been undertaken.

5.1 Potential Construction Impacts

Equipment likely to cause noise and vibration impacts at sensitive receivers include:

- excavator operations and earthmoving equipment
- boring rigs
- pipe jacking or similar methods
- vibratory rollers
- truck movements

The construction activities will be continually moving along the proposed project route and is unlikely to be adjacent to any residence for a period of more than a few weeks. From **Table 4** it was determined that the project construction noise goals would be Background + 20 dB(A) based on the progressive nature of the works. Night-work may be required in some locations to minimise disruption of local and through traffic for construction of the pipelines where the pipeline route crosses major roads or intersections.

There is the potential for vibration impacts on properties under which directional drilling would take place. To a lesser extent vibration may impact on properties alongside the pipeline route particular within the densely populated areas along the proposed concentrate pipeline. The potential vibration impacts include contents and cosmetic or structural damage. At the STP sites the potential for vibration impacts resulting from either construction or operational activities to the nearest residential locations is non-existent.

5.1.1 Mitigation Measures

Monitoring would be undertaken during the initial stages of construction to assess compliance with the ENCM goals. Where noise would be audible at residential properties construction would be limited to standard working hours. Work would not be undertaken on Sundays and public holidays

unless inaudible at the nearest residences. Any night works would need to be carefully assessed prior to commencement to ensure intrusive noise impacts are controlled at any sensitive receivers.

Appropriate noise management measures would be implemented by the appointed Contractor to minimise construction noise impacts. Construction activities would be undertaken in accordance with Australian Standard *AS 2436-1981 Guide to Noise Control on Construction, Maintenance and Demolition Sites* and a management plan would be prepared for construction noise to include the following:

- selection of equipment to minimise noise levels
- maintenance of equipment in good working order (including mufflers, enclosures and bearings) to ensure unnecessary noise emissions are eliminated
- use of residential class mufflers and where applicable engine shrouds (acoustic lining)
- appropriate use of plant and equipment including adoption of 'reasonable' working practices with no extended periods of 'revving' , idling, or 'warming up' within close proximity to residential receivers. Any excessively loud activities would be scheduled during periods of the day when high ambient noise levels are apparent
- all equipment to be used on site would need to demonstrate compliance with noise levels recommended within AS2436-1981.

It would be the responsibility of the contractor to implement appropriate management practices to ensure that noise and vibration levels would aim to comply with the project specific noise goals during installation of the pipeline. The impacts on sensitive receivers in each location would be considered and amelioration measures adopted on an 'as-needs' basis.

Residents in the vicinity of the pipeline route and STP sites will be advised prior to the commencement of construction activities. Contact details would be provided as well as an outline of the construction activities, duration and timing of the works. A log of complaints would be maintained and a complaints management procedure would be formulated and adhered to.

Where vibration may cause impacts to property or residents construction activities would be managed in accordance with the British Standard 7385:Part1-1993 *Evaluation and Measurement for Vibration in Buildings* and for historic buildings, which have a higher sensitivity to vibration, the more conservative guidelines within the German Standard DIN 4150:Part3 – 1986 would be adhered to.

Where the potential for vibration impacts are identified, such as close to a building, a pre-construction structural survey would be conducted and monitoring undertaken through construction to confirm that levels remain below the appropriate guidelines.

6. Conclusion

The potential for noise and vibration impacts resulting from the operations of the proposed replacement flows project have been assessed based on initial project information and in general accordance with the DEC Industrial Noise Policy. The likely impacts arising from the project have been found to be minimal at the Penrith and Quakers hill sites due to the extent of the works proposed and the distance to that separates the Sewerage Treatment Plants and the receivers. Based on the current project details, no additional mitigation would be recommended for these sites.

At St Marys there is the potential for an exceedance of the noise goal at the nearby residential receivers in Triggs Road. The land in Triggs Road is owned by Sydney Water. Any exceedances at this location are expected to be mitigated through design and noise attenuation measures. The next nearest receivers are located some 1600 metres away and no associated noise impacts from the AWTP would be expected at that location.

The potential for noise generation during the construction of the pipeline has been identified however there is insufficient information to fully assess the impacts at this time. Appropriate construction noise mitigation would be identified when the there is more detail of the proposed construction methodology and work program available.

Appendix G

Environmental risk assessment



Appendix G – Environmental Risk Analysis

1.0 Environmental Risk Analysis

As required by the Director General's Requirements a risk assessment, based on Australian Standard/NZS 4360 Risk Management and Environmental Risk Management – Principles and Process 2000, was undertaken. The results of the qualitative risk assessment used to assess the risks during construction and operation are provided in **Table 1** and **Table 2** below.

The method used for the Environmental Risk Analysis encompasses the following key steps:

- Establish the context for the risk analysis process
- Identify environmental risks
- Analyse risks

Each of these steps is discussed further below.

1.1 Establish the context for the risk analysis process

The environmental risk analysis undertaken for the Project considered risks to the natural environment, members of the public and heritage items. The 'Project' was considered to be the processes and activities described in Chapter 3 of the main text, categorised into the two phases below:

- Construction Phase
    - Activities include: clearing, excavating, drilling, boring, backfilling trenches, revegetation etc.
- Operation Phase
    - Activities include: diversion of tertiary treated effluent to the AWTP, discharge of highly treated recycled water to the Nepean River at Penrith and discharge of concentrate to the NSOOS.

1.2 Identify environmental risks

Environmental risks for the Project have been identified through a multi-disiplinary approach involving; professional opinion, review of legislative requirements, consultation with relevant government agencies and other key stakeholders.

The process followed involved identification of a component of the surrounding environment that may be impacted by the Project, identification of activities from the two phases described above that may affect the environment component and identification of potential environmental impacts for each environmental component, as a result of the proposed activities.

1.3 Analyse risks

Each environmental risk was assessed using a five level qualitative ranking of consequence versus likelihood as outlined in **Table 3** below. The risks were analysed by combining possible consequences and their likelihood, in the context of existing measures to control the risk.

The residual environmental risk following implementation of mitigation measures for all environmental aspects investigated in Chapter 8 is considered to be low.

Table 2 Risk assessment construction phase

Subject	Potential risk	Mitigation measures to be implemented	Risk assessment			Residual risk
			Co	L	R	
Flora and fauna						
Fauna	Injury or death of fauna, in particular emu, kangaroos, reptiles and amphibians in the Regional Park areas.	Fallen logs and felled timber retained on site. Trenches would be dug with shallow sloping ends to allow natural fauna escape and should be inspected each morning and checked for captured fauna. Any fauna captured should be removed and released into adjacent natural habitat.	4	D	Low	**LOW**
Flora	Loss of Ecologically Endangered Communities (EECs), riparian vegetation, remnant trees and fauna habitat.	Minimise construction area and fence off areas of vegetation to be retained. Boring beneath creeks or in areas of dense vegetation.	5	D	Low	
Flora and fauna	Damage/ disturbance/ loss of wildlife habitats.	Locate construction compounds, access tracks, stockpiles, storage areas on cleared sites away from watercourses. Revegetate with endemic species and monitor revegetation success.	4	D	Low	
Flora	Introduction or spread of noxious weeds.	Implement management procedures to prevent spread of noxious weeds.	4	E	Low	
Waste						
Liquid waste	Liquids from the dewatering process impacting on the local environment.	Dewatering to be managed in accordance with the requirements of the POEO Act.	4	D	Low	**LOW**

Subject	Potential risk	Mitigation measures to be implemented	Risk assessment			Residual risk
			Co	L	R	
Solid waste	Solid waste production resulting in high costs and premature filling of local landfill sites.	Waste to be managed in accordance with the *Waste Avoidance and Resource Recovery Act 2001* and Spoil reuse opportunities to be investigated.	5	C	Low	
	Organic wastes.	Vegetation clearance to be kept to a minimum. Composting options to be investigated.	5	C	Low	
	Packaging waste.	Preferential purchase of materials with minimal packaging/higher recycled content.	5	C	Low	
	Disposal of disused construction materials.	Accurate ordering and careful handling to minimise breakage/wastage.	5	C	Low	
Hazardous waste	Inappropriate handling and disposal of asbestos containing materials.	Asbestos containing materials to be handled and disposed of by a suitably licensed contractor and disposed of in accordance with DEC guidelines.	4	E	Low	**LOW**
Noise						
Noise	Disturbance to neighbouring residences, commercial areas and users of recreational facilities.	Construction activities to be undertaken in accordance with AS2346-1981. Employing noise mitigation measures.	5	C	Low	**LOW**
	Sleep disturbance through night works.	Limiting timing and duration of construction and avoidance of night work.	5	D	Low	
Vibration	Damage to specific buildings and heritage listed structures.	Construction activities to be managed in accordance with guidelines. Where the potential for vibration impacts have been identified, an assessment of the likelihood of damage would be carried out. If it is considered that damage is possible, a pre-construction dilapidation survey would be conducted on potentially affected properties and monitoring undertaken through construction to confirm any potential impacts.	5	E	Low	**LOW**

Subject	Potential risk	Mitigation measures to be implemented	Risk assessment			Residual risk
			Co	L	R	
Contamination						
Contaminated land	Potential for runoff from contaminated spoil at STP sites and from pipeline routes	Managed in accordance relevant guidelines. Appropriate transport and disposal of waste/contaminated materials/asbestos.	4	D	Low	**LOW**
		Contamination identified during construction to be further investigated and managed.	5	D	Low	
Accidental releases	Spillage of potentially polluting liquids/materials during construction	Appropriate handling and storage of construction materials and liquids and spill kits available.	4	E	Low	**LOW**
Water pollution	Erosion and sedimentation/dewatering.	Controls implemented in accordance with Managing Urban Stormwater Guidelines (Landcom 2005).	5	C	Low	**LOW**
	Water pollution due to dewatering of excavations.	Containment and treatment of liquids resulting from dewatering in line with provisions of the POEO Act and *Managing Urban Stormwater* guidelines (Landcom 2005)	4	E	Low	
	Infiltration of contaminated groundwater.	Contaminated water to be removed and disposed of to appropriate waste management facility.	4	E	Low	
Hazardous materials						
Storage of class 3 flammable liquids	Potential for fire or explosion risk associated with fuels required for construction vehicles, chainsaws etc.	Storage of fuels on or around the site to be avoided. Vehicles and equipment to be refuelled off site where possible.	4	E	Low	**LOW**
Heritage						
Aboriginal heritage	Potential impacts on PADs and rock flakes identified as isolated finds or artefact scatters along pipeline routes.	Avoidance of PADs and aboriginal artefacts through boring. Ongoing consultation.	5	D	Low	**LOW**
	Identification of Aboriginal heritage items during construction.	Construction to cease and advice sought from Archaeologist.	5	C	Low	

Subject	Potential risk	Mitigation measures to be implemented	Risk assessment			Residual risk
			Co	L	R	
European heritage	Impact on AMUs	For the two AMUs, monitoring by appropriately qualified archaeologist during construction.	5	C	Low	**LOW**
	Impact on Parramatta gaol	Alternative route chosen or boring to be undertaken beneath the gaol and monitoring conducted.	4	D	Low	
	Discovery of European heritage items during construction.	Construction to cease and advice sought from Archaeologist.	4	E	Low	
Land use						
Property	Acquisition/disruption/ access restrictions.	Consultation with affected property owners prior to works commencing. Maintain access to private properties.	4	D	Low	**LOW**
Services and utilities	Potential damage to underground services during construction.	All services to be located prior to works. Notification of service providers of proposed works.	4	E	Low	**LOW**
	Potential disruption to rail services associated with rail crossings.	Ongoing consultation with RailCorp to determine construction requirements for railway crossing.	4	E	Low	
Land use	Change of land use.	Rehabilitation of the land to former use on completion.	4	D	Low	**LOW**
Property	Potential disruption/damage due to leakage.	Infrastructure to be managed in accordance with Sydney Water's standard management procedures.	5	E	Low	**LOW**
	Property damage due to settlement.	Development of measures to mitigate settlement impacts in the event that they are identified.	4	E	Low	
Visual						
Visual amenity	Disturbance to residents	Avoidance of residences and short construction period. With immediate rehabilitation. Screening of STP and work depots.	4	D	Low	**LOW**
Visual amenity	Disruption to users of fields and reserves	Construction works limited on weekends and outside of normal work hours and short construction period. Storage of major construction equipment away from open areas.	4	D	Low	

Subject	Potential risk	Mitigation measures to be implemented	Risk assessment			Residual risk
			Co	L	R	
Air quality						
Dust	Dust from construction impacting on local residences/properties.	Appropriate dust control measures would be implemented.	4	D	Low	**LOW**
Vehicle emissions	Release of particulates and greenhouse gases	Maintenance of vehicles and construction equipment.	5	C	Low	**LOW**
Traffic						
General traffic management	Road closures and traffic diversions	Consultation with RTA, local government and public transport service providers and local residents and limitation of construction period and undertaken night works	5	C	Low	**LOW**
Major roads	Significant traffic disruption and intersection delays.	For pipeline crossings of major roads and major intersections underground boring techniques would be used to minimise any damage or disruption to roads.	5	C	Low	**LOW**

Co = consequence, L = Likelihood, R = Risk

Likelihood - C = might occur at some time, D = not likely to occur, E = may occur in exceptional circumstances

Consequence – 1-5 from severe (1) to negligible (5)

Table 3 Risk assessment operation phase

Subject	Potential risk	Mitigation measures	Risk assessment			Residual risk
			Co	L	R	
Flora and fauna						
Flora & fauna	Vegetation loss and soil erosion.	Revegetation where vegetation removal has occurred.	4	D	Low	**LOW**
	Spread of noxious weeds on maintenance vehicles.	Prevent the spread of weeds in accordance with the *Noxious Weeds Act 1993* and Sydney Water's standard management systems and practices.	4	E	Low	
Waste						
Aqueous waste	Waste produced during periodic cleaning and maintenance will require disposal.	Management and maintenance to be undertaken in a manner that ensures wastes production is minimised.	4	D	Low	**LOW**
Solid waste	Inappropriate disposal of chemical containers and spent reverse osmosis membranes.	Maintenance to be undertaken in a manner that ensures wastes production is minimised and waste produced is disposed of to licensed facilities.	4	D	Low	**LOW**
Noise						
Operational noise	Potential noise impacts from the AWTP site and pumping stations	AWTP enclosed in a building designed to ensure the operation meets the noise criteria outlined in the *NSW Industrial Noise Policy* (NSW EPA 2000). Enclosure of pumping stations.	4	D	Low	**LOW**
	Maintenance vehicles and workers.	To be managed in accordance with Sydney Water's standard management systems and practices.	5	E	Low	
Water pollution						
Water pollution	Spillage, leakage, accidental release of liquids during operation.	Facilities to be managed and maintained in accordance with Sydney Water's standard management systems and practices.	4	E	Low	**LOW**

Subject	Potential risk	Mitigation measures	Risk assessment			Residual risk
			Co	L	R	
Hazardous materials						
Class 8 Handling	Potential for spillage during delivery, unloading or use and potential for direct contact with workers and assets.	Workforce trained in appropriate handling procedures, unloading only within designated bunded areas. Drainage to sewer/sump and spill kit maintained on site.	4	D	Low	**LOW**
Class 8 Storage	Potential for direct contact in event of spillage.	Storage of materials in accordance with AS1940 in bunded facilities and appropriate drainage.	4	E	Low	**LOW**
Land use						
Land use	Land use change.	The infrastructure would be managed in accordance with Sydney Water's standard management procedures.	4	E	Low	**LOW**
Property	Potential disruption/damage due to leakage.	Infrastructure to be managed in accordance with Sydney Water's standard management systems and practices.	4	E	Low	**LOW**
	Property damage due to settlement.	Development of measures to mitigate settlement impacts in the event that they are identified.	4	E	Low	
Visual						
Visual amenity	View to STP sites.	Vegetation screening along boundaries where views of new infrastructure are available to sensitive receptors	5	E	Low	**LOW**
Air quality						
Odour	Odour from concentrate storage pond.	To be managed in accordance with Sydney Water's standard management systems and practices.	5	E	Low	**LOW**
Vehicle emissions	Release of particulates and greenhouse gases	Maintenance vehicles to be properly maintained.	5	E	Low	**LOW**
Dust	Vehicular traffic and maintenance activities	To be managed in accordance with Sydney Water's standard management systems and practices.	5	E	Low	**LOW**

Subject	Potential risk	Mitigation measures	Risk assessment			Residual risk
			Co	L	R	
Traffic						
Deliveries	Disruption to local traffic movements	Deliveries to be timed to minimise impacts on local traffic and managed in accordance with Sydney Water's standard management systems and practices.	4	E	Low	**LOW**
Maintenance vehicles	Disruption to local traffic movements/ access restrictions.	Maintenance to be undertaken in accordance with Sydney Water's standard management systems and practices.	5	E	Low	**LOW**

Co = consequence, L = Likelihood, R = Risk

Likelihood - C = might occur at some time, D = not likely to occur, E = may occur in exceptional circumstances

Consequence – 1-5 from severe (1) to negligible (5)

Table 1 - Risk Matrix

			Step 1 – Determine the Consequence				
			5	4	3	2	1
		People	First Aid Injury	Medical treatment required	Lost time injury	Permanent disability or extensive injuries	Fatality
		Environment	Limited impact to minimal area	Reversible, short-medium term impact to local area	Reversible medium term local impact	Medium to long term widespread impact	Long term, widespread impacts
		Community	Workforce concern	Local community concern	Regional concern	National concern	International concern
		Assets	Minor damage to plant or system	Damages impact on budget and program	Significant damage to plant or system	Extensive damage to plant or system	Virtual complete loss of plant or system
Step 2 – Determine the Likelihood	A	Common or frequent occurrence	High	High	Extreme	Extreme	Extreme
	B	Will probably occur in most circumstances	Moderate	High	High	Extreme	Extreme
	C	Might occur at some time	Low	Moderate	High	Extreme	Extreme
	D	Not likely to occur	Low	Low	Moderate	High	Extreme
	E	May only occur in exceptional circumstances	Low	Low	Moderate	High	High



Printed on recycled paper.

SWC November 2006
SW113 10/06