

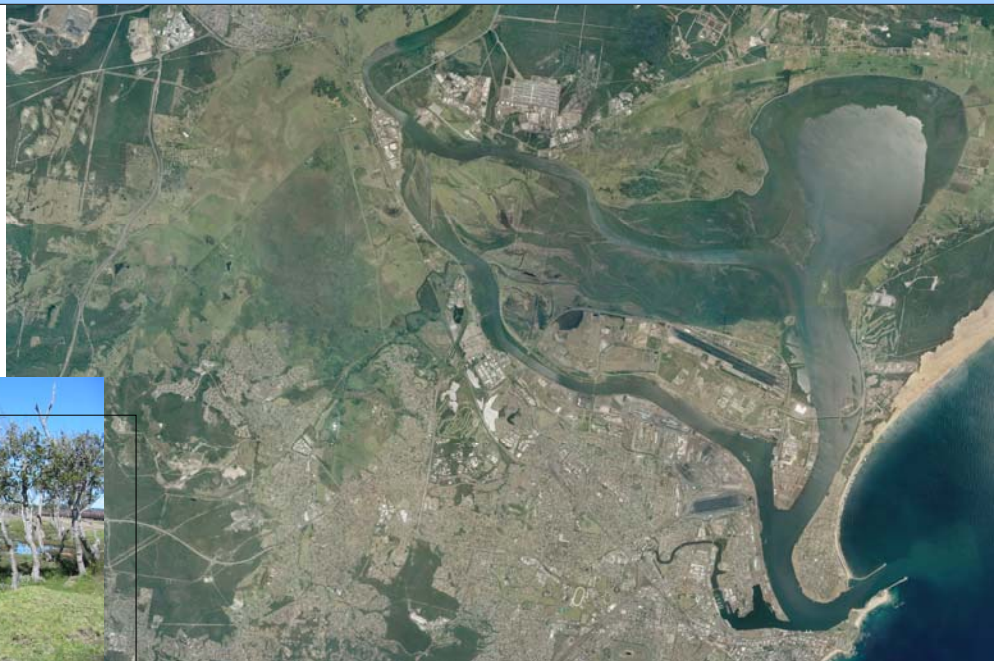
ENVIRONMENTAL IMPACT STATEMENT

ENVIRONMENTAL IMPACT STATEMENT

HEXHAM SWAMP REHABILITATION PROJECT



August 2005



Disclaimer:

This EIS was prepared prior to the commencement of Part 3A of the EP&A Act, in accordance with the legislative regime summarised in Section 2.7 within. The EIS has **not** been amended to reflect the current application of Part 3A of the EP&A Act. Accordingly, the EIS must be read together with the Environmental Assessment (EA) Supplement, to provide an up-to date account of environmental planning considerations in accordance with Part 3A of the Act.

Environmental Impact Statement

Hexham Swamp Rehabilitation Project

Prepared For: Hunter and Central Rivers Catchment Management Authority

Prepared By: WBM Oceanics Australia

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	Client:	Hunter and Central Rivers Catchment Management Authority
	Client Contact:	Sharon Vernon / Brett Peterkin
	Client Reference:	
	Synopsis:	This document is an Environmental Impact Statement for works associated with the rehabilitation of Hexham Swamp. It outlines the existing environment of Hexham Swamp and discussed the predicted impacts of the proposed works, along with measures required to mitigate impacts considered detrimental to the environment.

REVISION/CHECKING HISTORY

REVISION NUMBER	REVISION DESCRIPTION	DATE	CHECKED BY		ISSUED BY	
0	Preliminary draft	December 2002	PEH		PEH	
1	Draft	July 2004	PEH		PEH	
2	Final	April 2005	PEH		PEH	
3	Revised Final	August 2005	PEH		PEH	

DISTRIBUTION

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EXECUTIVE SUMMARY

Hexham Swamp is an internationally recognised wetland, located on the outskirts of Newcastle, NSW (refer **Figure E1**). Hexham Swamp is currently dominated by freshwater wetland vegetation (mostly *Phragmites australis*), however, some 30 years ago, it contained a much more diverse suite of habitats.

The installation and operation of floodgates in the early 1970s as part of the Hunter Valley Flood Mitigation Scheme has significantly reduced tidal inundation within Ironbark Creek and its tributaries throughout Hexham Swamp. Previous saltmarsh and mangrove areas have been replaced by meadow and reed communities, which have subsequently improved opportunities for grazing by cattle and horses.

A decline in estuarine habitat within the swamp is still being observed some 30 years after the construction of the gates. The loss of estuarine habitat has resulted in a corresponding decline in visitation by migratory waders and waterbirds, while the abundance of local fish, prawns and other marine organisms has also been affected by the loss of nursery areas.

The Hexham Swamp Rehabilitation Project aims to restore some of the previous estuarine habitats and their associated values by opening the existing floodgates at the mouth of Ironbark Creek. Opening the gates will reinstate tidal flows to the swamp, resulting in saline inundation of some existing freshwater reed and pasture habitats. Opening of the floodgates during non-flood times was first recommended less than two years after the construction of the gates, when the first signs of habitat degradation began to manifest. Unfortunately significant action was not taken at that time, or in the 30 years since then, and the estuarine wetlands have subsequently degraded to their present condition.

Privately owned lands that will be directly impacted by the Project have been purchased by the Hunter-Central Rivers Catchment Management Authority (HCRCMA). A number of low level earthen bunds are also proposed to restrict saline intrusion onto other private property that has not been purchased by the HCRCMA. These bunds, as well as a series of other ancillary works, are included in the scope of the rehabilitation project and are addressed as part of this Environmental Impact Statement (EIS).

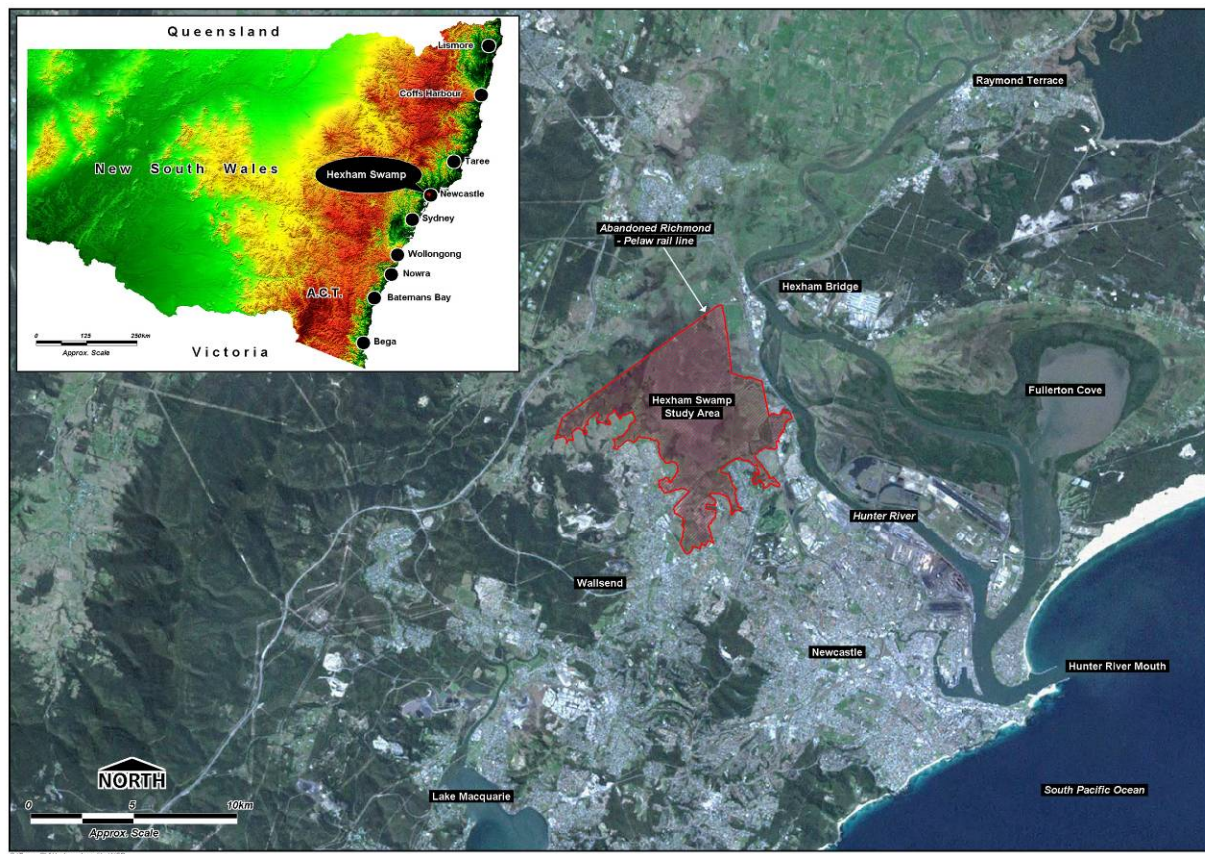


Figure E1 – Hexham Swamp Locality

Under the provisions of the Newcastle Local Environment Plan (LEP) 2003, environmental restoration works are permitted within the Hexham Swamp Project Area zonings without the need for development consent (note the *Project Area* is mostly defined by the 1.5m AHD contour). However, as the majority of the swamp is gazetted under State Environmental Protection Policy (SEPP) 14 – Coastal Wetlands, the Project is deemed Designated Development under the *Environmental Planning and Assessment (EP&A) Act 1979*, and as such, is subject to consent by Newcastle City Council (NCC) and an EIS is required.

The consents and approvals required for this development proposal include:

- Consent by NCC pursuant to SEPP-14;
- Consent to destroy Aboriginal artefacts located in the vicinity of the proposed Marsden St bund, pursuant to the *National Parks and Wildlife Act 1974*;
- Consent to carry out works on public roads, under the *Roads Act 1993*; and
- A flood work approval under the *Water Management Act 2000*.

Given the consents required, the Proposal is integrated development under the EP&A Act.

At present, one of the eight floodgates is open 300 mm, which allows a small tidal variation within Ironbark Creek. The current mean spring tidal range inside Hexham Swamp reduces from 0.44m upstream of the gates to 0.28m near Minmi Road (at the upstream end of the swamp). This is much smaller than the equivalent tidal range of 1.18m in the Hunter River adjacent to the swamp. High spring tides in the swamp currently reach a level of approximately 0.05m AHD near the floodgates, reducing to -0.03m AHD near Minmi Road, while king tides currently reach 0.20m AHD at the gates, reducing to 0.10m AHD at the upstream end of the swamp. Due to the unidirectional operation and design of the floodgates, the mean water level within Hexham Swamp is approximately 0.16 metres lower than the mean water level in the Hunter River (i.e. -0.16m AHD).

Opening of the floodgates will result in a much more dominant tidal regime within Hexham Swamp. Mean spring tides within the swamp are expected to reach a maximum level of 0.54m AHD at the gates, reducing to 0.41m AHD at Minmi Road, while the king tides within the Swamp are expected to reach 0.67m AHD at the gates, reducing to 0.56m at Minmi Road (i.e. an increase of up to almost 0.5m in both cases). The mean water level in the swamp is also predicted to increase, by approximately 0.3m, to a level of

0.15m AHD (which will be about 0.15m higher than the mean level in the adjacent section of the Hunter River).

The change to the tidal hydraulics of Hexham Swamp will have a range of consequences to an array of chemical and biological processes and characteristics. With regard to water quality, the opening of the gates will increase salinity of waters within the swamp. The works will also increase the degree of tidal flushing of the swamp, with greater interaction between the swamp and the adjacent Hunter River. However, the die-off of saline intolerant vegetation may add a new short-term biochemical oxygen demand to the waters of Hexham Swamp and the adjacent Hunter River.

Given the predicted rise in mean water level within Ironbark Creek, the groundwater levels in Hexham Swamp could also be expected to rise. However, the timeframe to recharge the groundwater reserves and increase groundwater tables is likely to be long (in the order of years to decades).

With regard to vegetation, large areas of Phragmites will be periodically inundated by saline water, which will result in the gradual replacement of this species with more salt tolerant saltmarshes and sedges. Mangroves should also re-establish along tributaries and main channel fringes, where tidal inundation will be regular. It is important to note that not all of the freshwater wetlands at Hexham Swamp will be inundated with saltwater. Large areas within the upper reaches of Hexham Swamp will remain freshwater habitat, including several areas of open freshwater (which are important habitats for freshwater waterfowl).

Table E1 presents the areas of current vegetation types (based on mapping by Morrison, 2000) that are predicted to be inundated by king tide and spring tide conditions when all eight (8) floodgates are open. As seen in this table, the majority of inundation will occur within Phragmites swamp, pasture / grasslands, and freshwater swamp complexes.

Table E1 – Vegetation types to be inundated

<i>Habitat</i>	<i>King tide inundation (ha)</i>	<i>Spring tide inundation (ha)</i>
Casuarina woodland	26.8	16.0
Freshwater swamp	102.2	26.1
Mangroves	12.3	5.9
Melaleuca woodland	2.0	0.0
Pasture / grassland	80.1	57.5
Phragmites swamp	526.0	227.9
Saltmarsh	5.0	1.2
Typha	0.5	0.0
Urban / industrial	2.7	1.8
TOTAL	757.5 ha	336.3 ha

If all of the area that is predicted to be inundated by the king tide is returned to estuarine-based habitat (i.e. either mangroves or saltmarsh), then the total area of *Phragmites* swamp would be reduced by 57%, to 392 ha, and the total area of Freshwater swamp would be reduced by 18%, to 473 ha. However, the increased groundwater levels that are expected to accompany the saltwater inundation are likely to be more favoured by freshwater swamp vegetation, at the expense of *Phragmites*. Thus in the long term (as groundwater effects are not expected to manifest for many years or even decades), the extent of *Phragmites* is likely to reduce further, while freshwater swamp habitat is likely to increase in the non-tidal, non-saline sections of the swamp.

Saline intrusion of private lands at Marsden and Alister Streets, Shortland, will be prevented through the construction of a low level tidal-exclusion bund. Exclusion of saltwater from these properties will prevent a change in vegetation, and thus will not significantly affect the manner in which the land is currently utilised.

The change in vegetation within the swamp is likely to have follow-on habitat changes for a range of fauna, including birds, fish and mosquitoes. An increase in the amount of saltmarsh within Hexham Swamp is likely to result in a return of waders and waterbirds that formerly utilised the estuarine wetlands. Increased areas of mangroves and saltmarshes will also benefit fish and other aquatic species through increased nursery habitat. It is reported that prior to the construction of the floodgates, Hexham Swamp was a major nursery for the Hunter River prawns.

The existing freshwater wetlands environment provides habitat to a number of threatened flora and fauna species, including *Zannichellia palustris*. An eight part test has been prepared to determine the impacts of opening the floodgates on these threatened species (refer **Appendix H: Volume 2**).

With regard to mosquitoes, the changed hydrology of Hexham Swamp is likely to impact more on species type rather than actual mosquito numbers. The relative abundance of saltwater mosquito species is predicted to potentially increase, while the numbers of freshwater mosquitoes are predicted to decrease within the Hexham Swamp area. Hexham Swamp is a minor contributor to mosquito numbers in the lower Hunter River estuary, as most mosquitoes breed at Kooragang Island or Tomago Wetlands and travel throughout the area.

Some minor engineering works will be required in addition to the opening of the floodgates to

minimise the impacts of the inundation on private assets and infrastructure around the swamp. These works will include construction of exclusion bunding at Marsden Street and around the Broadcast Australia Limited (BAL) radio towers, raising the level of the private Wallsend airstrip, improving access along Hunter Water pipeline access track, ARTC rail access track, and The Wetlands Centre tracks, and some minor filling of private lands to prevent potential inundation.

Opening of the floodgates will have a net positive long-term economic impact. The loss of revenue associated with reduced land for grazing will be more than offset by the increase in revenue that is expected from commercial and recreational fishing due to improved quality and extent of fish and prawn nursery grounds. Re-establishment of the estuarine wetlands will also increase local tourism, particularly tourism associated with The Wetlands Centre.

The floodgates are proposed to be opened sequentially. Initially, one floodgate will be opened, followed by approximately 3 - 6 months of monitoring. If no major irregularities in the Swamp's response are recorded, then two (2) gates will be opened. Significant overbank inundation is expected from a two gates open condition, and therefore, the timing of this should occur prior to the winter solstice (king) tides, to allow maximum inundation without the threat of substantial mosquito impacts. Approximately 12 months of monitoring should precede any further opening of the gates to ensure that tidal inundation remains within expected extents. Four (4) gates will then be opened, followed by a further 12 months of monitoring before all eight gates are opened. Intensive monitoring will continue for at least 12 months following opening of all eight gates, after which time a lesser amount of monitoring may be considered until new habitats have established and community structures stabilised.

A detailed monitoring program is proposed before, during and after the gate openings. The before-opening monitoring is currently underway, with available results incorporated into this EIS, as appropriate. The monitoring program includes assessment of water quality, benthic macroinvertebrates, fish, vegetation, birds, amphibians and mosquitoes. Most monitoring will be carried out in the field at a range of spatial and temporal frequencies that take into account the natural variability of the wetlands environment. Where necessary, control (reference) monitoring will also be carried out to quantify the extent of impact.

DIRECTOR GENERALS REQUIREMENTS**Department of
Infrastructure, Planning and Natural Resources**

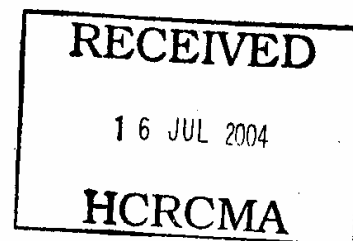
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GPO Box 3927 Sydney NSW 2001
T 02 9762 8000

Our Ref: N98/00140
Your Ref:

Major Development Assessment
Telephone: 9762 8130
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7 July 2004

Ms Sharon Vernon
Hunter-Central Rivers Catchment Management Authority
Private Bag 2010
PATERSON NSW 2421



Dear Ms Vernon

Proposed Hexham Swamp Rehabilitation Project – Newcastle Local Government Area

I refer to your request for Director-General's requirements for the preparation of an Environmental Impact Statement (EIS) for the above development proposal.

Attachment No. 1 outlines the statutory matters that must be included in any EIS under clauses 71 and 72 of the *Environmental Planning and Assessment Regulation 2000* (the Regulation). You should note however, that if the Development Application (DA) to which these requirements relate is not made within two years of the date of this letter, Clause 73(6) of the Regulation requires you to re-consult with the Director-General prior to lodging the application.

Specific requirements

A number of key issues have been identified as being of particular relevance for the EIS to focus upon. Pursuant to clause 73(1) of the Regulation, the Director-General requires that the issues summarised below be addressed in the EIS for the proposed development. These issues have been ranked to generally indicate those matters the Department considers should form major components of the EIS. Ranking is aimed at assisting in the focussed preparation of the EIS and is not necessarily indicative of the actual magnitude of any of the impacts listed.

Issues of Key Environmental Planning Importance for EIS Preparation:

- Flora and fauna impacts, particularly the potential impacts on wetland flora and fauna as a result of the proposed change to the Hexham Swamp from a predominately freshwater system to estuarine system. The assessment must clearly assess the benefits of the restoration of the wetland to a more natural system against the likely impacts on the existing freshwater ecological system. The flora and fauna assessment must also assess the potential impacts of the proposal on critical habitats; threatened species, populations or ecological communities, or their habitats;
- Surface and ground water impacts associated with the proposed works. In particular, the management of surface water run-off to prevent the contamination of any nearby waterways, including the SEPP 14 wetland area;
- Soil quality, particularly with regards to the potential disturbance and subsequent management of Acid Sulfate Soils (ASS) or Potential ASS; potential erosion and sedimentation impacts, particularly on the wetland and nearby watercourses; and potential impacts associated with the stabilisation of the site;

- Hydrological, particularly with regards to potential flooding and local drainage regimes including, where relevant, details on any changes and/ or potential impacts on these as a result of the proposal;

Issues of Environmental Planning Importance for EIS Preparation:

- Noise impacts associated with the proposed works on any potential nearby noise receptors. The EIS must assess the predicted noise impact resulting from all noise sources, including road traffic noise. The noise assessment must be undertaken in accordance with the EPA's *Environmental Noise Control Manual*, *Industrial Noise Policy (2000)* and *Environmental Criteria for Road Traffic*;
- Air quality impacts associated with the proposed works, particularly in regards to potential dust impacts on any nearby potential receptors; and
- Heritage impacts associated with the proposed works, particularly with regards to any potential impacts on Aboriginal objects.

Other Important Issues:

- Traffic impacts, particularly the consideration of impacts associated with vehicular movements during construction activities;
- Visual impacts, in relation to the landscaping and minimising visual intrusion of embankments on private receptors;
- An assessment of the proposal against the relevant provisions in the following statutory instruments: *State Environmental Planning Policy No. 14 – Coastal Wetlands* and *Hunter Regional Environmental Plan 1989*, *Newcastle Local Environmental Plan 2003*; and any relevant Development Controls Plans prepared by Newcastle City Council; and
- Consideration of *Hexham Swamp Nature Reserve Plan of Management 1998* prepared by National Parks and Wildlife Service (now part of the Department of Environment and Conservation).

Environmental monitoring and management

- The EIS must indicate how the environmental performance of the proposal would be monitored and managed during construction and operation.

Integrated Development

As the proposal constitutes crown development under section 5A of the *Environmental Planning and Assessment Act 1979* (the Act), integrated development under section 91 of the Act does not apply to the proposal. However, should any approvals be required by another government agency before the proposal could proceed, it is recommended that you consult with these agencies now and take into account any requirements these agencies may have during the preparation of the EIS.

Consultation

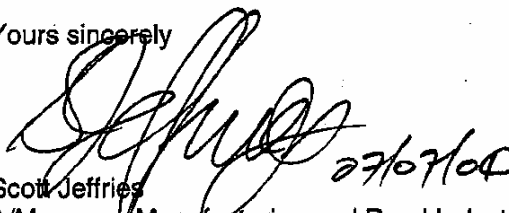
You should consult with the Newcastle City Council, the Department of Environment and Conservation (former National Parks and Wildlife Service), Department of Infrastructure, Planning and Natural Resources (Natural Resources Newcastle regional branch, (Peter Johns, Environmental Review Coordinator, ph 4929 9827)), NSW Fisheries, the relevant Local Aboriginal Land Council (or other similar groups) and any other relevant State and Commonwealth government authorities, service providers and community groups, and take into account any comments these agencies may have in the preparation of the EIS.

Commonwealth Environment Protection and Biodiversity Conservation Act 1999

If your proposal contains any actions that may have significant impact on matters of National Environmental Significance, then it may require additional approvals under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). These approvals are in addition to any approvals required under NSW legislation. If you have any questions about the application of the EPBC Act to this proposal, you should contact the Commonwealth Department of the Environment and Heritage in Canberra (6274 1111 or <http://www.deh.gov.au>).

Please contact Caitlin Bennett on (02) 9762 8130, if you require any further information regarding the Director-General's requirements for the EIS.

Yours sincerely


Scott Jeffries
A/Manager/ Manufacturing and Rural Industries
Major Development Assessment
As Delegate for the Director-General

Note: Matters of National Environmental Significance under the EPBC Act are:

- i. World Heritage properties;
- ii. RAMSAR wetlands;
- iii. threatened species or ecological communities listed in the EPBC Act;
- iv. migratory species listed in the EPBC Act;
- v. the environment in a Commonwealth marine area; and
- vi. nuclear actions.

ATTACHMENT NO. 1

**STATUTORY REQUIREMENTS FOR THE PREPARATION
OF AN ENVIRONMENTAL IMPACT STATEMENT UNDER PART 4 OF
THE ENVIRONMENTAL PLANNING AND ASSESSMENT ACT 1979**

In accordance with the *Environmental Planning and Assessment Act 1979* (the Act), an environmental impact statement (EIS) must meet the following requirements.

Content of EIS

Pursuant to Schedule 2 and clause 72 of the *Environmental Planning and Assessment Regulation 2000* (the Regulation), an EIS must include:

1. A summary of the environmental impact statement.
2. A statement of the objectives of the development or activity.
3. An analysis of any feasible alternatives to the carrying out of the development or activity, having regard to its objectives, including the consequences of not carrying out the development or activity.
4. An analysis of the development or activity, including:
 - (a) a full description of the development or activity; and
 - (b) a general description of the environment likely to be affected by the development or activity, together with a detailed description of those aspects of the environment that are likely to be significantly affected; and
 - (c) the likely impact on the environment of the development or activity, and
 - (d) a full description of the measures proposed to mitigate any adverse effects of the development or activity on the environment, and
 - (e) a list of any approvals that must be obtained under any Act or law before the development or activity may be lawfully carried out.
5. A compilation, (in a single section of the environmental impact statement) of the measures referred to in item 4(d).
6. The reasons justifying the carrying out of the development or activity in the manner proposed, having regard to biophysical, economic and social considerations, including the following principles of ecologically sustainable development:
 - (a) The precautionary principle - namely, that if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

In the application of the precautionary principle, public and private decisions should be guided by:

 - (i) careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment, and
 - (ii) an assessment of the risk-weighted consequences of various options,
- (b) Inter-generational equity - namely, that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations,
- (c) Conservation of biological diversity and ecological integrity, namely, that conservation of biological diversity and ecological integrity should be a fundamental consideration,
- (d) Improved valuation, pricing and incentive mechanisms, namely, that environmental factors should be included in the valuation of assets and services, such as:
 - (i) polluter pays, that is, those who generate pollution and waste should bear the cost of containment, avoidance or abatement,
 - (ii) the users of goods and services should pay prices based on the full life cycle of costs of providing goods and services, including the use of natural resources and assets and the ultimate disposal of any waste,
 - (iii) environmental goals, having been established, should be pursued in the most cost effective way, by establishing incentive structures, including market mechanisms, that enable those best placed to maximise benefits or minimise costs to develop their own solutions and responses to environmental problems.

An environmental impact statement referred to in Section 78A(8) of the Act shall be prepared in written form. The prescribed form to accompany the environmental impact statement must comply with the requirements of clause 71 of the Regulation and be signed by the person who has prepared it.

Procedures for public exhibition of the EIS are set down in clauses 77 to 81 of the Regulation.

Attention is also drawn to clause 283 of the Regulation regarding false or misleading statements in EISs.

Note

If the development application to which the EIS relates is not made within 2 years from the date of issue of the Director-General's requirements, under clause 73(6) of the Regulation the proponent is required to re-consult with the Director-General.

- ✧ -

Table A provided below outlines how this EIS has considered the issues raised in the Director General's Requirements, and details relevant Section numbers where further information regarding the issues can be found.

Table A Director-General Requirements Check-List

Issues	Consideration given	Relevant EIS Section
<u>Issues of Key Environmental Planning Importance</u>		
Flora and fauna impacts	Significant changes to the flora and fauna of Hexham Swamp can be expected due to changes in wetland hydraulics, salinity and fauna passage	Existing conditions see Sections 3.7, 3.8, and 3.9 Impacts see Sections 4.4, 4.6 and 4.9.
Surface and groundwater impacts	Significant changes to surface water inundation can be expected, while a net elevation in groundwater will also result	Existing conditions see Sections 3.3 & 3.5.1.3 Impacts see Sections 4.1 and 4.3.2.
Soil quality, particularly with regard to Acid Sulfate Soil (ASS), erosion and stabilisation	Soil characteristics will not be significantly affected. No disturbance of existing soils are proposed, thus ASS should not be of concern	Existing conditions see Sections 3.5 and 3.6. Impacts see Section 4.3.
Hydrological impacts, particularly with regards to potential flooding and local drainage regimes	Impacts of proposal on existing flooding conditions would be minor, while tidal flushing and drainage of the swamp will improve dramatically	Existing conditions see Section 3.3. Impacts see Section 4.1.
<u>Issues of Environmental Planning Importance</u>		
Noise impacts	Localised, short-term noise impacts may be experienced during the construction of the Marsden Street and BAL bunds, and minor raising of the Wallsend Airstrip	Existing conditions see Section 3.10. Impacts see Section 4.10.
Air quality impacts	No significant impacts on air quality are expected	Impacts see Section 4.11.
Heritage impacts, including Aboriginal objects	No significant impacts on the heritage aspects of Hexham Swamp, including the Aboriginal heritage, with the exception of an identified artefact site along proposed Marsden Street bund alignment	Existing conditions see Section 3.15. Impacts see Section 4.14.3.

Issues	Consideration given	Relevant EIS Section
<u>Other Important Issues</u>		
Traffic impacts	No significant impacts on local traffic around Hexham Swamp are expected	Impacts see Section 4.12.
Visual impacts	The proposal is likely to provide positive benefits to the visual amenity by increasing diversity and open water to the landscape	Existing conditions see Section 3.12. Impacts see Section 4.13.
Statutory Instruments, including SEPP-14, Hunter REP, Newcastle LEP and relevant DCPs	Due consideration has been given to all Environmental Planning Instruments	See Sections 1.3, 2.7 and 4.14.1.
Hexham Swamp Nature Reserve Plan of Management	Due consideration has been given the aims and objectives of the Plan of Management	See Sections 2.7.5.3 and 4.14.2.
<u>Consultation</u>	Consultation has been carried out with community, relevant stakeholders and private landholders in and around Hexham Swamp	See Section 2.8.1 for details and responses
<u>Commonwealth EPBC Act 1999</u>	Referral has been made to the Commonwealth Department of Environment and Heritage	See Section 2.7.5.1 and Appendix B: Volume 2 for details

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1 INTRODUCTION

1.1 The Need for Wetland Rehabilitation at Hexham Swamp

Hexham Swamp is located approximately 10km northwest of Newcastle CBD and consists of an area of some 1,946 hectares of freshwater and estuarine wetlands on the lower floodplain of the Hunter River. The swamp comprises the majority of the lower catchment area of Ironbark Creek, which is the largest tidal creek in the Hunter River Estuary. A small area in the north-eastern corner of the swamp drains into Purgatory Creek. The general Hexham Swamp locality is shown in Figure 1.1.

The swamp is presently dominated by freshwater wetlands, with small areas of estuarine wetlands confined to the riparian zones along the lower reaches of Ironbark Creek and its tributaries. The proportion occupied by estuarine wetlands has decreased considerably in the last 30 years predominantly due to the restriction of tidal exchange caused by construction of one way operating floodgates at the mouths of Ironbark Creek and Purgatory Creek.

The installation and operation of the floodgates has reduced tidal inundation and hence flooding within Hexham Swamp, and has enabled cattle and horse grazing to expand. However, as large areas of mangroves and saltmarsh have been replaced by meadow and reed communities (as a result of changes in hydrology and salinity), the area of nursery habitat for fish, prawns and other marine organisms has consequently been reduced. In addition, the number of waterbirds and migratory wader bird species has decreased markedly (ICTCMC 1996). Weeds and pest species such as alligator weed, pampas grass, water hyacinth, feral pigs, and foxes have increased.

Reduced tidal exchange has also resulted in oxidation of acid sulfate soils, lowering pH levels in several tributaries and raising soluble iron levels in the local waterways (ICTCMC 1996).

In order to address problems such as those described above, the Ironbark Creek Total Catchment Management Committee released its Total Catchment Management Strategy in 1996 (ICTCMC 1996). This Strategy contained a list of recommendations divided into three Priority Classes. Among the highest priority recommendations were:

“Improve tidal flows to reinstate and sustain healthy mangroves along the banks of Ironbark Creek, [and its tributaries] Fishery Creek and Shelley Creek”;

“Develop and implement appropriate floodgate and other management procedures, following proper evaluation, continue to exclude Hunter River flooding to the extent of the existing structures but allow rehabilitation of the Hexham Swamp estuarine ecosystem in the long term”.

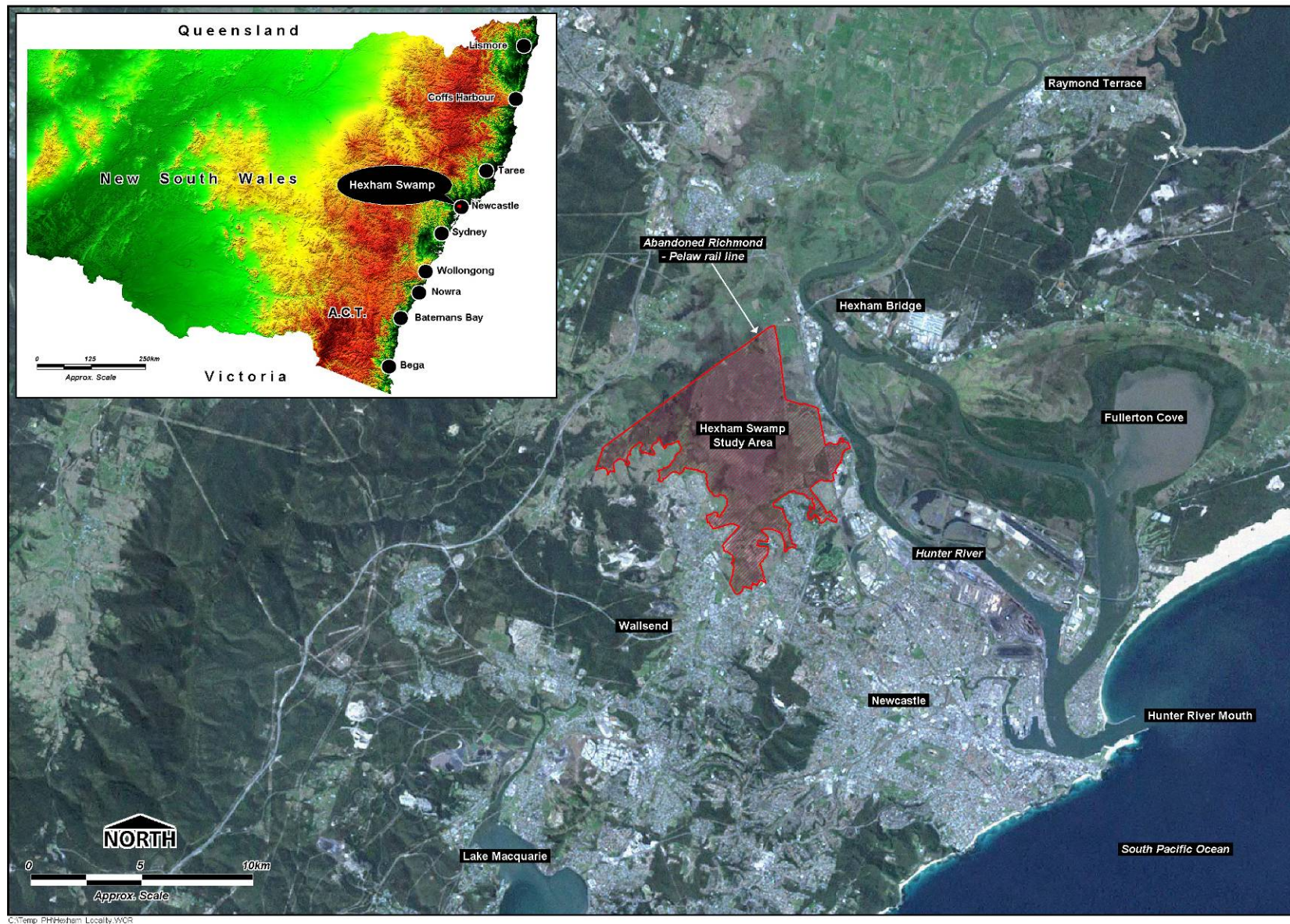


Figure 1.1 Hexham Swamp Locality Map

In response to these recommendations, a data compilation study (Pacrim 1998) was commissioned by the Hunter Catchment Management Trust (now the Hunter-Central Rivers Catchment Management Authority) to address the following:

- Confirm adequacy of the existing tidal inundation models;
- Determine the effects of tidal inundation on existing freshwater ecosystems;
- Determine the ecologically suitable tidal inundation level to determine a requirement for land acquisition;
- Deliver the requirements of native flora and fauna especially in relation to the movement of marine species through the Ironbark Creek floodgates.

In addition to the compilation of data, Pacrim (1998) also provided a list of issues and a brief for the preparation of an Environmental Impact Statement (EIS). The present EIS is based on this brief and on the findings of Pacrim (1998).

1.2 Objectives

Table 1.1 outlines the objectives for the Hexham Swamp Rehabilitation Project (in an approximate priority order), which are based on the objectives of the Hexham Swamp Plan of Management (HCRCMA, 2003 – refer **Appendix L: Volume 2**).

Table 1.1 Objective and Targets for HSRP

	Objective	Target
	<u>Nature Conservation</u>	
1	To increase habitat diversity by restoring estuarine habitats within the project area	➤ Estuarine Habitat diversity increased through increases in tidal inundation to a minimum of 600ha by 2010
2	Improve habitat for estuarine fauna (waterbirds, migratory birds) and aquatic fauna (fish, amphibians, crustaceans, and invertebrates)	➤ Increase biodiversity of estuarine and aquatic flora and fauna above baseline levels by 2010
3	Encourage the integration of the Hexham Swamp Rehabilitation Project into a regional protected natural area network	➤ Resolve the long-term management of the Hexham Project area in conjunction with the Kooragang Wetland Rehabilitation Project area, The Wetlands Centre and other areas
4	Control of weeds and pests	➤ Implementation of weed and feral animal control programs within two years of land acquisition ➤ Mosquito breeding monitored, in association with Kooragang Wetland Rehabilitation Project and Newcastle City Council, to measure the effect of increased tidal inundation on mosquito numbers

	Objective	Target
5	Improve quality levels of water exported from Hexham Swamp	➤ Nutrients reduced from baseline levels ➤ Dissolved oxygen increased from baseline levels ➤ Pollutants, suspended solids, bio-chemical oxygen demand (BOD) and faecal coliform decreased from baseline levels
6	Increase flushing of small tributaries that have become stagnant and restore creek beds	➤ Creeks open to tidal flushing by 2010
7	Encourage research into the optimal management of the Swamp	➤ Develop a research and monitoring program
	<u>Other Objectives</u>	
8	To ensure that the floodgates close during Hunter River floods	➤ Floodgates managed to ensure Hunter River floods up to 1.8m AHD are excluded
9	Infrastructure access maintained in consultation with utilities	➤ Maintain access for the servicing of existing infrastructure
10	Enhance opportunities for passive recreation and nature appreciation	➤ Involve stakeholders, including the community, in the development of an access plan for recreational purposes
11	Encourage the use of Hexham Swamp for educational purposes	➤ Passive activities, such as canoe tours from The Wetlands Centre, maintained ➤ Open days, information days held at least three times per annum, at different venues around Hexham Swamp ➤ Identify and develop a plan for education opportunities, complimentary to the recreational access plan, that could be offered through existing organisations ➤ Managed education programs that build awareness of the HSRP objectives

1.3 Legislative Basis and Scope of the EIS

1.3.1 Legislative Basis and Purpose

The Hexham Swamp Rehabilitation Project is designated development under *State Environmental Planning Policy No 14 - Coastal Wetlands* (SEPP 14) for which an Environmental Impact Statement (EIS) is required under the *Environmental Planning and Assessment Act 1979* (EP&A Act) (see Section 2.7.2.1).

The main objectives of this EIS are:

- To provide the public and government with an overview of the proposal and associated environmental impacts;
- To provide details of the commitments made in relation to the proposal;
- To provide an opportunity for interested parties and stakeholders to make comment during the public review period; and
- To enable the project to proceed following the assessment of environmental impacts and development of an effective implementation/management plan.

1.3.2 Director General Requirements

This EIS has been prepared in accordance with the provisions of the *Environmental Planning and Assessment Act 1979* and the *Environmental Planning and Assessment Regulations 2000*. To comply with this Act and Regulations, the requirements of the Director-General of the Department of Infrastructure, Planning and Natural Resources (DIPNR) were sought.

The Director-General's Requirements (refer section following the *Executive Summary* and also **Appendix A: Volume 2**) outline a number of specific issues that need to be addressed in the EIS. The requirements also indicate that consultation should be carried out with Newcastle City Council, various state and commonwealth government agencies, the relevant Local Aboriginal Lands Council and other stakeholders (eg service providers) and community groups.

In accordance with the Director-General's requirements, consultations have been sought from various government authorities and stakeholders. Consultation with stakeholders and the general community is discussed further in Section 2.7.5.6. Consultation with government authorities and stakeholders has also been facilitated through the Ironbark Creek Total Catchment Management Committee, who nominated the project within their Total Catchment Management Strategy (ICTCMC, 1996) and has been actively involved in the project since its inception.

The Director-General's requirements also highlight the possible need to obtain commonwealth approvals under the *Environment Protection and Biodiversity Conservation Act 1999*, in addition to approvals under NSW legislation. Consultation with the Commonwealth Department of Environment and Heritage (DEH) has been carried out, with the referral letter and DEH response also provided in **Appendix B: Volume 2** of this document.

1.3.3 Ecologically Sustainable Development

Clause 72 of the EP&A Regulation requires the contents of an EIS to include the matters set out in Schedule 2 to the EP&A Regulation. Schedule 2 to the EP&A Regulation requires, amongst other things, that an EIS must include "the reasons justifying the carrying out of the development or activity in the manner proposed, having regard to biophysical, economic and social considerations, including the ... principles of ecologically sustainable development".

This EIS has been prepared with regard to biophysical, economic, and social considerations and the principles of ecologically sustainable development (ESD). Put simply, ESD is development that aims to meet the needs of today, while conserving our ecosystems for the benefit of future generations.

Schedule 2 of the EP&A Regulation describes the principles of ESD as follows:

- “The precautionary principle - namely, that if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation”;
- “Inter-generational equity - namely, that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations”;
- “Conservation of biological diversity and ecological diversity”; and
- “Improved valuation and pricing of environmental resources”.

By following the principles of ESD, the likelihood of serious environmental impacts arising from economic activities should be reduced. The principles of ESD are described further in **Appendix C: Volume 2** of this document, while consistency of the Project with the ESD principles, is discussed in Section 5.2.

1.4 The NSW Wetlands Management Policy

In 1996, the NSW Government issued its Wetlands Management Policy (DLWC 1996) as one of the component policies of the State Rivers and Estuaries Policy. “The goal of the NSW Wetland Management Policy is the ecologically sustainable use, management and conservation of wetlands in NSW for the benefit of present and future generations” (DLWC 1996, p17). Among the nine principles which were adopted for the sustainable management of wetlands, there are several of direct relevance to the present project, including:

- Principle 2: To encourage land use and management practices that maintain or rehabilitate wetland habitats and processes;
- Principle 6: Natural wetlands should not be destroyed, but when social or economic imperatives require it, the rehabilitation or construction of a wetland should be required;
- Principle 7: Degraded wetlands and their habitats and processes will be actively rehabilitated as far as practical; and
- Principle 8: Wetlands of regional or national significance will be conserved.

The present project espouses to these principles.

1.5 Issues to Address

Apart from the positive objectives of the project, as outlined in Section 1.2, there are a number of potential negative impacts associated with the proposal that need to be managed. These issues include:

- Increased tidal exchange would increase the area inundated on a regular basis, thus restricting the area available for cattle and horse grazing;
- Hydrological impacts on some privately and publicly owned properties;
- Increased tidal inundation would cause a decrease in the area presently covered by freshwater wetlands. This could potentially affect flora and fauna species utilising those areas, including species listed under the *Threatened Species Conservation Act 1995*;
- In regards to the previous issue, the proposal may result in altered environmental conditions within the Hexham Swamp Nature Reserve. Given that the Nature Reserve was gazetted principally for its freshwater values for freshwater waterfowl, the proposal should not detrimentally affect the overall value of the Nature Reserve. Nonetheless, the Hexham Swamp Nature Reserve Plan of Management recommends the opening of the floodgates to help fulfil international obligations to restore habitat for migratory birds and waterfowl (refer Section 2.7.5.3).

These issues are addressed in detail in this EIS. Mitigation measures designed to counteract or minimise these impacts are described throughout Section 4 and summarised Section 6 of this document.

1.6 Structure of this Environmental Impact Statement

The EIS has been structured to consider all matters pursuant to Clauses 51 and 84 of the EP&A Regulation. The EIS addresses the potential environmental impacts that may result from modifying the operation of the floodgates at the mouth of Ironbark Creek. Such impacts may include those on the biophysical environment (biota, soils, surface and ground water quality, hydrology) and those on the socio-economic environment (Aboriginal and European heritage, economics, visual amenity, noise). Measures that would mitigate the adverse environmental impacts are also described.

The following format has been adopted for the EIS:

- A **summary** of the major points of the EIS has been provided at the beginning of the report, including a copy of the Director General's Requirements for the Project, and a summary of how these requirements have been considered by the EIS;
- **Section 1** provides a background to the proposal, describes the objectives of the proposal, and the legislative framework for the EIS;
- **Section 2** provides a full description of the proposal, along with the statutory requirements that need to be met prior to implementing the proposal, and a summation of the stakeholder and community consultation conducted;
- **Section 3** describes the existing environment likely to be affected by the proposal;
- **Section 4** describes the impacts on the existing environment associated with the proposal, along with a full description of the measures proposed to mitigate any adverse effects of the proposal;

- **Section 5** presents an analysis of alternatives to the proposal (including the do-nothing alternative) and justification for the proposal, along with evidence demonstrating compliance with ESD principles;
- **Section 6** presents a compilation of the mitigation measures required to minimise environmental impact; and
- **Section 7** outlines the requirements of the Director General's Requirements, and cross-checks these requirements with relevant Sections of the document. Section 7 also provides a list of all approvals required before the proposal can be implemented.

Supplementary information is provided in Appendices, which are provided in a second volume (**Volume 2**) to this document.

2 THE PROPOSAL

2.1 Overview of the Proposal

The Hexham Swamp Rehabilitation Project proposal involves the opening of one-way floodgates located at the downstream end of Ironbark Creek, during non-flood times. Opening of these floodgates will reintroduce tidal waters into the Swamp and inundate low lying lands with saline water, promoting the re-establishment of former estuarine wetland habitat.

Opening of the floodgates will be accompanied by a series of minor engineering works aimed at minimising the impact of tidal inundation on privately owned properties around the fringe of the swamp. These structural works will include:

- Bunding to exclude tidal inundation;
- Raising of access roads and tracks;
- Minor fill of some private lands; and
- One way tidalgates on drainage lines.

2.2 Existing Floodgates and their Operation

Levee banks were constructed along the edge of the Hunter River and floodgates were installed near the mouth of Ironbark Creek during 1970-71 in order to mitigate the effects of floods in the Hexham Swamp area by the exclusion of small and medium floods (DPW 1972; Lawson and Treloar 1995). The following information on the operation of the floodgates is largely quoted from Lawson and Treloar (1995).

The floodgates consist of eight 2.13 x 2.13 m box culverts (invert level of -1.0m AHD) each with a heavy, hinged flap gate on the Hunter River side (refer Figure 2.1). The top-hinged floodgates allow flow to pass through the culverts out of the swamp. When water levels rise on the swamp side of the gates to a level higher than the water level in the Hunter River, the hydrostatic pressure associated with the water level difference across the gates forces the gates open and water flows out of the swamp. If the Hunter River water level is higher than the swamp water level, the hydrostatic pressure forces the gates closed and seals the culverts, preventing flow from entering Hexham Swamp from the Hunter River.

Each individual gate may be raised incrementally, which opens a gap at the base of the flap that then permits free flow between the river and the swamp. Presently, one of the gates is raised two notches - a height of approximately 0.30 m. Prior to July 2001, this gate was raised by only one notch - a height of approximately 0.15m. This relatively small opening significantly attenuates the tidal flow entering and exiting the swamp.

Under low flow conditions, when the system is dominated by semi-diurnal tides, the present gate configuration allows more rapid outflow from the swamp than inflow. Outflow can occur through all of the gates whilst inflow can only occur under the one partially lifted gate. Under these low flow conditions, the mean water level in the swamp is less than the mean water level in the Hunter River by approximately 0.15 metres (refer Section 3.3.3.3).



Figure 2.1 Existing Ironbark Creek Floodgates

During flood conditions, if Hunter River flood levels are higher than those in Hexham Swamp, then flow from the swamp to the River is prevented. Floodwaters from the Hunter River will overtop the levee system when flood levels are above about 1.8m – 2.1m AHD. This equates to a flood within the Hunter River system with an average recurrence interval (ARI) of approximately 5 - 10 years (DPW 1972).

The primary effects that have resulted from the construction and present operation of one-way floodgates and adjacent levee banks at the mouth of Ironbark Creek are:

- A lowering of the water table behind the gates to below mean water;
- The restriction of saline waters entering the swamp area;
- Significantly reduced tidal flushing of the swamp, leading to stagnation of some areas behind the floodgates;
- Restricting the passage of mobile aquatic fauna between the river and the swamp; and
- Blocking the passage of debris from the swamp.

2.3 Rationale for Modifying the Operation of the Floodgates

While the floodgates were originally intended to remain lowered or closed at all times (Lawson and Treloar 1995), it was suggested as early as 1972 (almost immediately after the construction of the floodgates) to modify the operation of the floodgates to allow normal tidal exchange in times other than floods (DPW 1972). The reason for this was to maintain the ecosystem values that were

prevalent before the installation of the floodgates, which were showing the first signs of degradation (DPW 1972). Unfortunately no action was taken apart from raising one gate by one notch (ie 0.15 metres).

Modifications to the floodgate operation was reiterated in the Ironbark Creek Total Catchment Management Strategy (ICTCMC 1996), in response to steadily worsening ecological conditions. Lawson and Treloar (1995) note that “if the TCM Committee decides to recommend that the floodgates be opened to allow some level of tidal ventilation of the swamp, then the floodgates should be managed to maintain the present benefits to urban areas for floods above the level of 1.6 m AHD. This management should include fitting the gates with a water level sensor system or some other means of sensing when the water level in the Hunter River exceeds a critical level, thereby causing the floodgates to fall into place in their full flood protection configuration. This will protect the lands behind the Hunter River levee system to the present level of flood protection and will not allow extreme ocean events to penetrate into the swamp”.

Future management of the Ironbark Creek floodgates will be the joint responsibility of the HCRCMA (being a registered floodgate controller), and the Department of Infrastructure, Planning and Natural Resources (DIPNR). Management of the floodgates during times of flooding in the Hunter River will be undertaken by DIPNR in accordance with their Flood Procedures Manual (DLWC, 2000). This document defines the plans and procedures that need to be followed during floods in the Lower Hunter Valley.

With respect to the Ironbark Creek floodgates, the Manual indicates that the floodgates are to be closed following receipt of the first flood warning (i.e. ‘flood alert’) from the Bureau of Meteorology of the SES. In the event that the relevant DIPNR staff cannot be contacted, arrangements have been made with Newcastle City Council, for its Local Emergency Management Officer (LEMO) to close the gates. Following the flood, DIPNR will reinstate the gates to the same conditions prior to the flood warning. DIPNR is also responsible for carrying out an annual inspection and floodgate closure exercise (usually during the first week of December).

Management of the floodgates during non-flood times will be undertaken by the HCRCMA, in accordance with the information presented in this EIS. Manipulation of the floodgates by HCRCMA will involve staged opening of the gates, as well as periodic closure (or partial closure) of one or more gates at select times of large tides (king tides and possibly larger spring tides). Management of the gates will allow tidal inundation in the swamp to be controlled, thus limiting the potential impacts on flooding and mosquito breeding.

The proposal involves modification to the operational management of the floodgates only. There are no additional construction activities proposed at the floodgates.

2.4 Strategy for Staged Opening of the Gates

It is proposed to open the floodgates in a stepwise and pragmatic manner. This will involve opening the gates sequentially, followed by adequate periods of monitoring to determine and assess impacts associated with the hydrological changes.

Initially, it is proposed to fully open one gate only. The tidal inundation resulting from one gate open has been predicted to have limited overbank extents (refer Section 4.1.2), and as such, is unlikely to

cause significant vegetation and habitat change. Therefore, the main purpose of opening just one gate initially will be to ensure that resulting water levels are within the limits of model predictions, and thus provide confidence to the numerical model for more substantial floodgate opening regimes. A *minimum* post-gate opening monitoring period of 3 months would be required to allow the swamp to ‘pump-up’ to its new hydrologically stable conditions.

There are a number of considerations with regard to the timing of the gate openings. Based on recommendations relating to the threatened aquatic vegetation species *Zannichellia palustris*, the timing of the opening of the first gate should coincide with the development of *Z. palustris* propagules, which is in spring / early summer. The increased tidal flows in the waterway would have a greater potential to disperse the propagules into other sections of the swamp, and thus minimise the impact of change to existing habitat areas (see Section 6.4.2 for details). With respect to the abundance of the existing Phragmites stands, gate openings should occur during winter, when the standing crop of Phragmites is at a minimum. Opening of the gates during winter is also recommended from a mosquito management perspective, so that the extents of inundation can be fully assessed without the threat of major mosquito population changes.

Opening of one gate is not likely to result in significant overbank inundation within the swamp (refer Section 4.1.2.3), meaning that issues associated with vegetation and mosquitoes would be minimal. The issue associated with *Zannichellia*, however, is only related to the opening of the first gate, with increased tidal waters essentially staying within the confines of existing channels and waterways. Therefore, the first floodgate will be opened in late spring / early summer. All subsequent floodgate openings will occur during winter.

As the first gate is to be opened in spring / early summer, active floodgate management will be required during the first summer solstice tide. Management is required to limit the ingress of the king tide, and hence limit the extent of floodplain inundation (which would not be flushed by subsequent tides and thus would form stagnant saltwater ponds ideal for mosquito breeding). With only one floodgate open, however, the extents of floodplain inundation are likely to be relatively small (refer Section 4.1.2.3). Nonetheless, active management of the single open gate will provide a good opportunity to ‘fine tune’ the proposed floodgate operation strategy for subsequent stages when more gates are open.

If it is determined that the extents of tidal inundation with one gate open are appropriate and consistent with predictions, then a second gate will be open (i.e. two gates open in total). Substantial overbank inundation of Hexham Swamp is expected with two gates fully open (refer Section 4.1.2.3), particularly during king tide conditions. Significant changes to vegetation and habitat within Hexham Swamp should start to occur under this hydrologic regime. To maximise the impact of the opening, it should be timed to immediately precede a solstice (king) tide. From a vegetation and mosquito management perspective, opening should occur immediately prior to the winter solstice tides. A period of at least 12 months would be required for monitoring to allow for stabilisation of the hydrological regime and to determine early trends in vegetation change.

The third stage in the gate opening process will involve opening four gates (in total). As for the two gates stage, it is proposed that the additional gates are opened immediately prior to the winter solstice, to maximise the immediate inundation extents achieved. A further 12 months of monitoring will be carried out prior to the final stage, which involves opening all eight floodgates. Detailed monitoring should follow the gate modifications for a period of at least 12 months. If after 12 months it is

determined that environmental changes are occurring as predicted, monitoring intensity could be reduced, but still continuing until new vegetation communities and habitats have fully established and fauna assemblages have stabilised.

If monitoring finds that inundation extents under the eight gates open scenario exceed the predicted impacts, and encroach onto lands that were not targeted for saline intrusion, then one or more gates can be closed sequentially until the extents of inundation match those expressed in this EIS.

From an ecological perspective, the rate of change in hydrological conditions would be minimised, to reduce the length of time that the environment is in a state of flux. However, from an adaptive management and precautionary perspective, an adequate amount of monitoring is required before progressing to the next stage to ensure that the changes are not going to exceed the changes expected and documented within this EIS.

The proposed timeframe for gate openings is therefore:

- Nov / Dec 2006: Open one gate
- June 2007: Open two gates
- June 2008: Open four gates
- June 2009 Open eight gates

The above timeframe can be achieved providing that approval for the project can be obtained before mid 2006, and that construction of all ancillary works (including bunds etc) can be carried out prior to November 2006 (i.e. within a timeframe of about 4 months if approval is not granted until mid 2006).

2.5 Other Works Included in the Proposal

While the proposed inundation of the swamp will mostly occur within the Hexham Swamp Nature Reserve, there will be some effects beyond the Nature Reserve that may influence the usage of fringing private residential lands, or access tracks through low-lying operational lands.

A series of *Other Works* are proposed to minimise the impact on stakeholders and private property owners. The Other Works include:

- 700m long low-level bund protecting private properties located in Marsden, Alister and Mawson Streets, Shortland;
- Perimeter bund around radio towers owned by Broadcast Australia Limited adjacent to the floodgates;
- Low-level bunds in front of flood culverts under the historic Richmond-Pelaw railway line along the western boundary of the swamp;
- Raising the unsealed runway and taxiways at Wallsend airstrip;
- Raising low sections and generally improving the condition of the Hunter Water Corporation pipeline access road and other infrastructure access roads;
- Raising of access tracks and associated drainage at The Wetlands Centre;
- Raising of isolated sections of the ARTC rail access track, as necessary;

- Minor fill on private residential lands directly adjacent to Ironbark Creek, and at Watts' property in Maryland;
- One-way tidalgates on a number of formal drainage lines; and
- Removal of informal causeway across Muckeye Creek.

2.5.1 Marsden Street Bund

The Marsden Street bund is to be located adjacent to Ironbark Creek, north of Hunter Water's Shortland Wastewater Treatment Works (refer Figure 2.2). The bund is designed to prevent inundation of tidal waters onto privately owned properties located along Marsden, Mawson and Alister Streets, Shortland.

The bund will be high enough to prevent saltwater from the creek entering the private lands, but low enough not to significantly affect the flood behaviour of the local area. The design crest level of the bund is proposed to be 0.6m AHD, with the average height of the bund being about 0.5 metres. As the soils within the swamp are susceptible to settlement, it is proposed to over-fill the bund by a further 150mm (subject to further consideration during detailed design of the structure). A minimum of two banks of one-way culverts will be constructed within the bund to allow drainage of the land behind the bund. Excavation / sediment removal will not occur in the natural creeklines, however, minor vegetation could be removed to improve hydraulic efficiency and encourage natural surface flows to be directed through the culverts.

The bund will be approximately 3 metres wide at the crest and have side slopes of approximately 1(v):4(h), meaning the average base width will be about 7 metres. Approximately 3,500m³ of imported clean fill will be required to construct the bund. A longitudinal profile of the bund alignment is shown in Figure 2.3, which illustrates the proposed height of the bund compared to the existing ground levels, while typical sections through the bund are presented in Figure 2.4.

The bund will be vegetated, except for the crest, which will be trafficable to allow for maintenance of the structure and the culverts. Further details regarding the bund (eg, materials specification, compaction limits etc) will be developed during detailed design.

The bund is located primarily on land owned by Hunter Water Corporation, however, the northern end of the bund will tie into higher ground on land that is being purchased by HCRMA from Morris. Construction access and principal maintenance access will be via the southern Hunter Water end of the structure. A small number of trees may need to be cleared during the construction process. These would be isolated trees only, with no significant reduction in habitat or fragmentation of vegetation communities. The bund will be located almost entirely within SEPP-14 land.

Preliminary design and set-out details for the Marsden Street bund are provided in **Appendix O: Volume 2**.

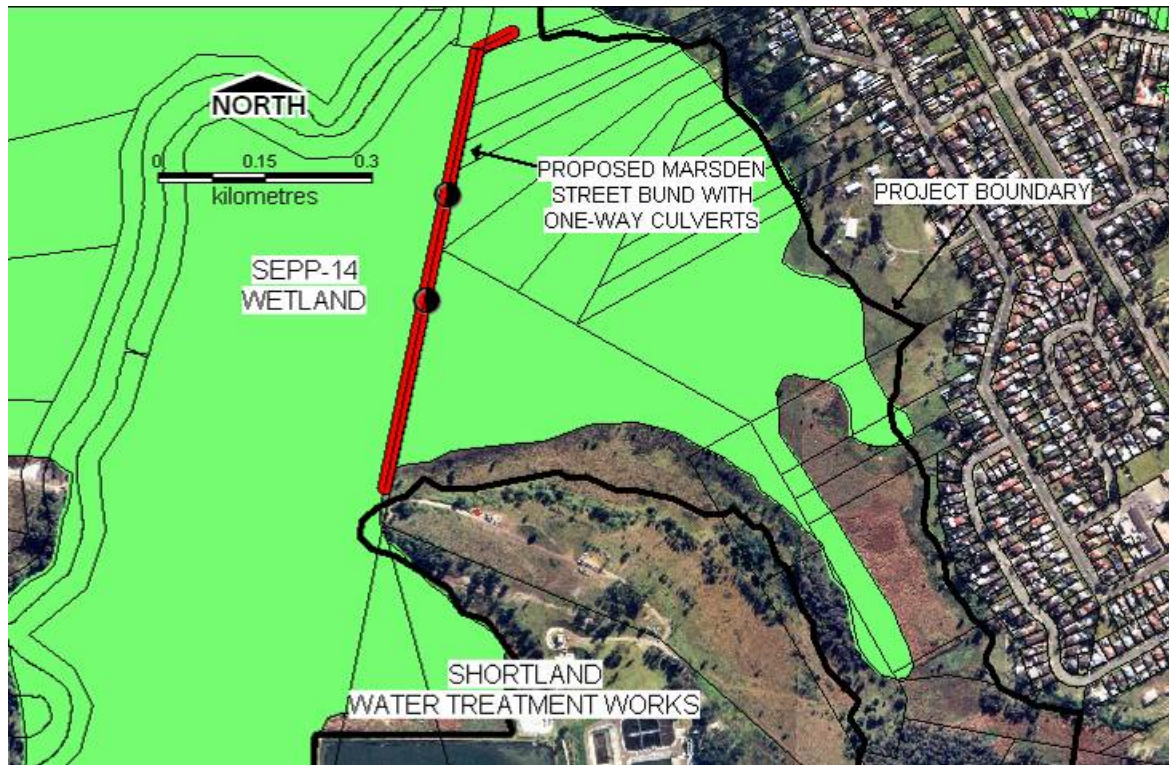


Figure 2.2 Proposed Marsden Street Bund

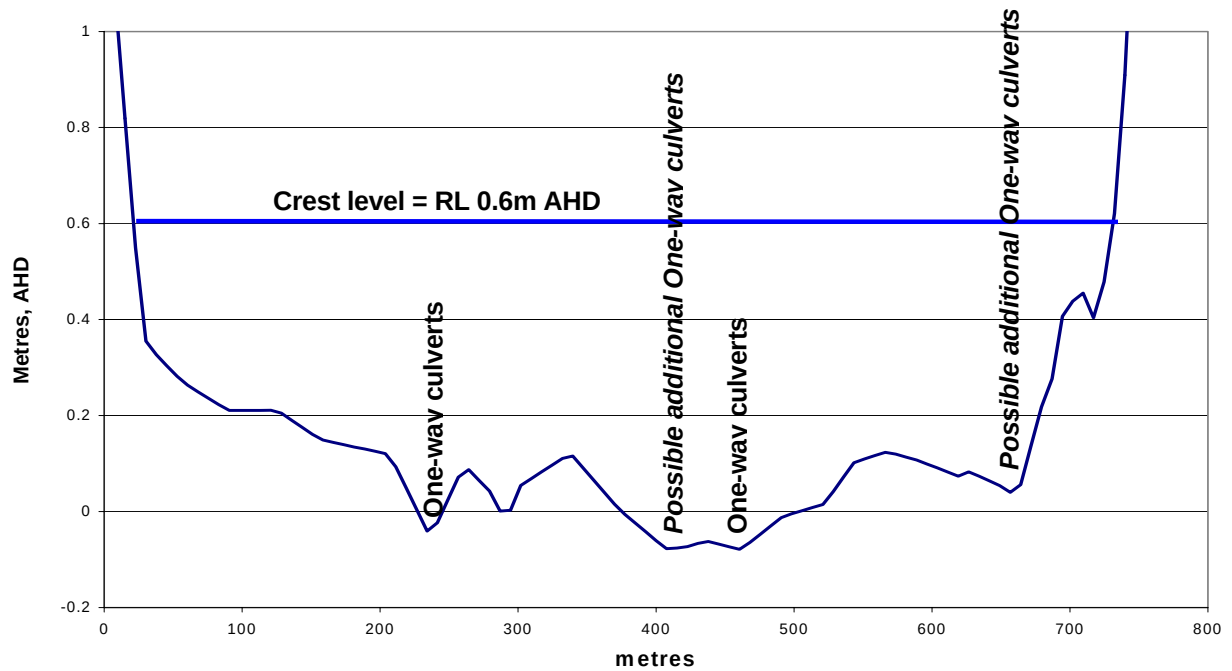


Figure 2.3 Longitudinal Profile of Marsden Street Bund

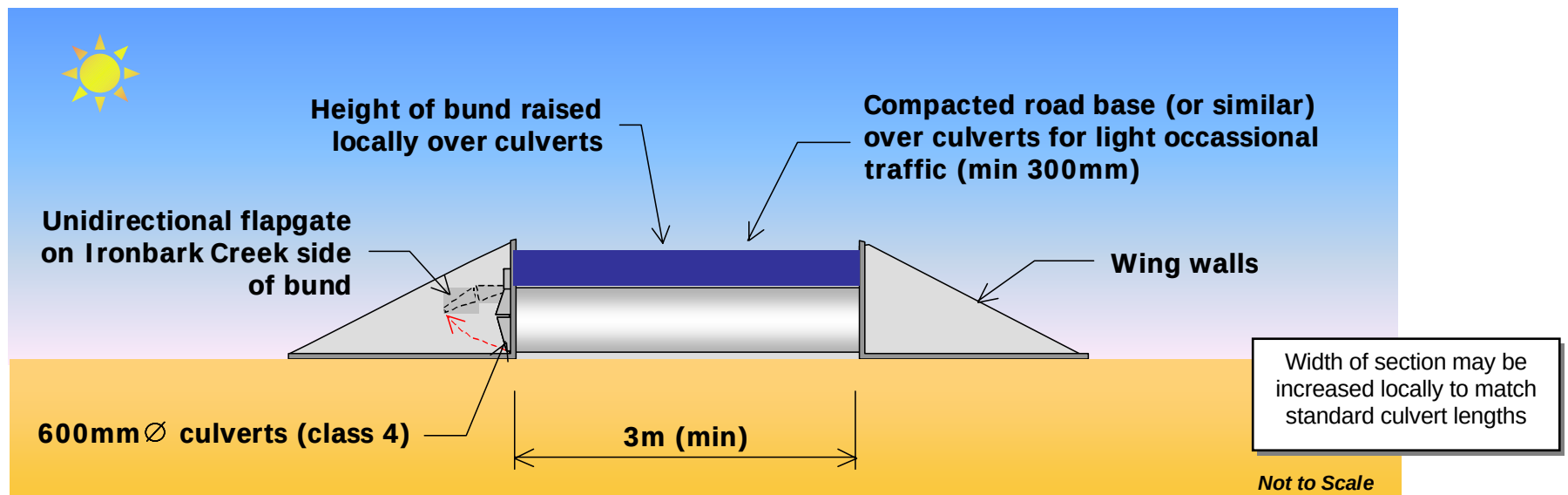
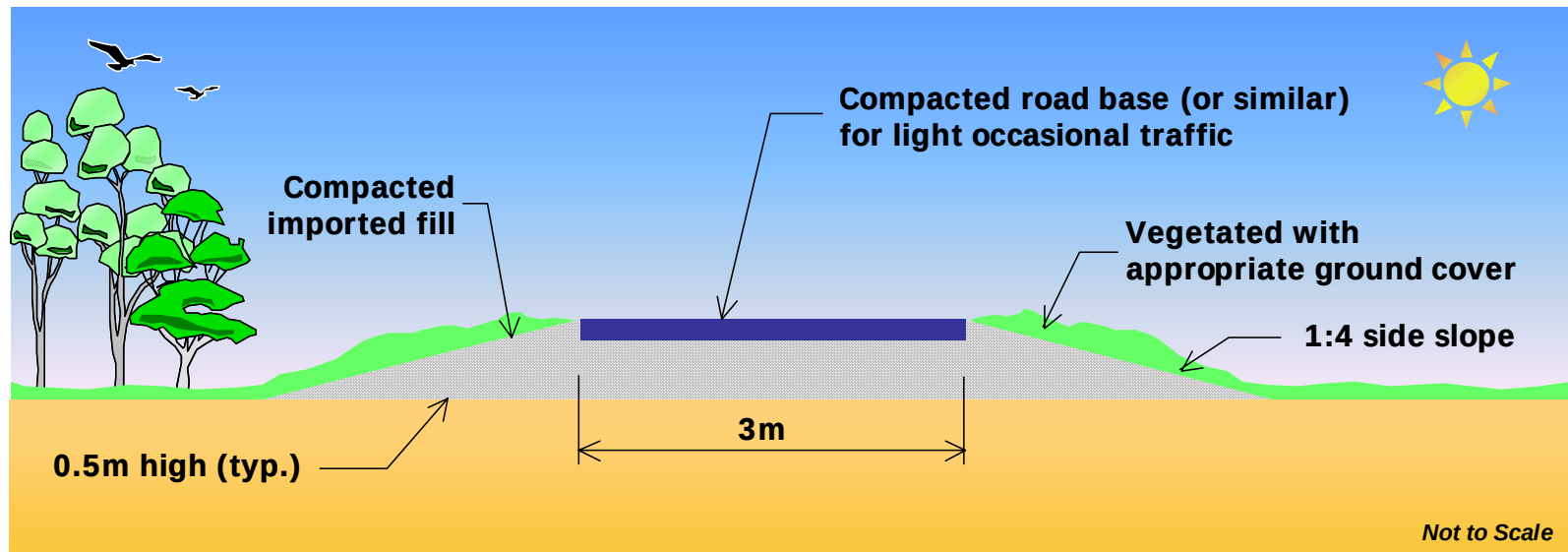


Figure 2.4 Typical sections through the Marsden Street bund and culverts

2.5.2 Broadcast Australia Limited Bund

A 230 metre long low level bund is proposed around the Broadcast Australia Limited (BAL) radio masts located immediately adjacent to the floodgates at the downstream end of Ironbark Creek (refer Figure 2.5). The bund will prevent saltwater inundation of land at the base of the tower structures. It is recognised, however, that the land currently contains residual salts within the soil structure, which support small patches of saltmarsh, particularly in areas of ponded water.

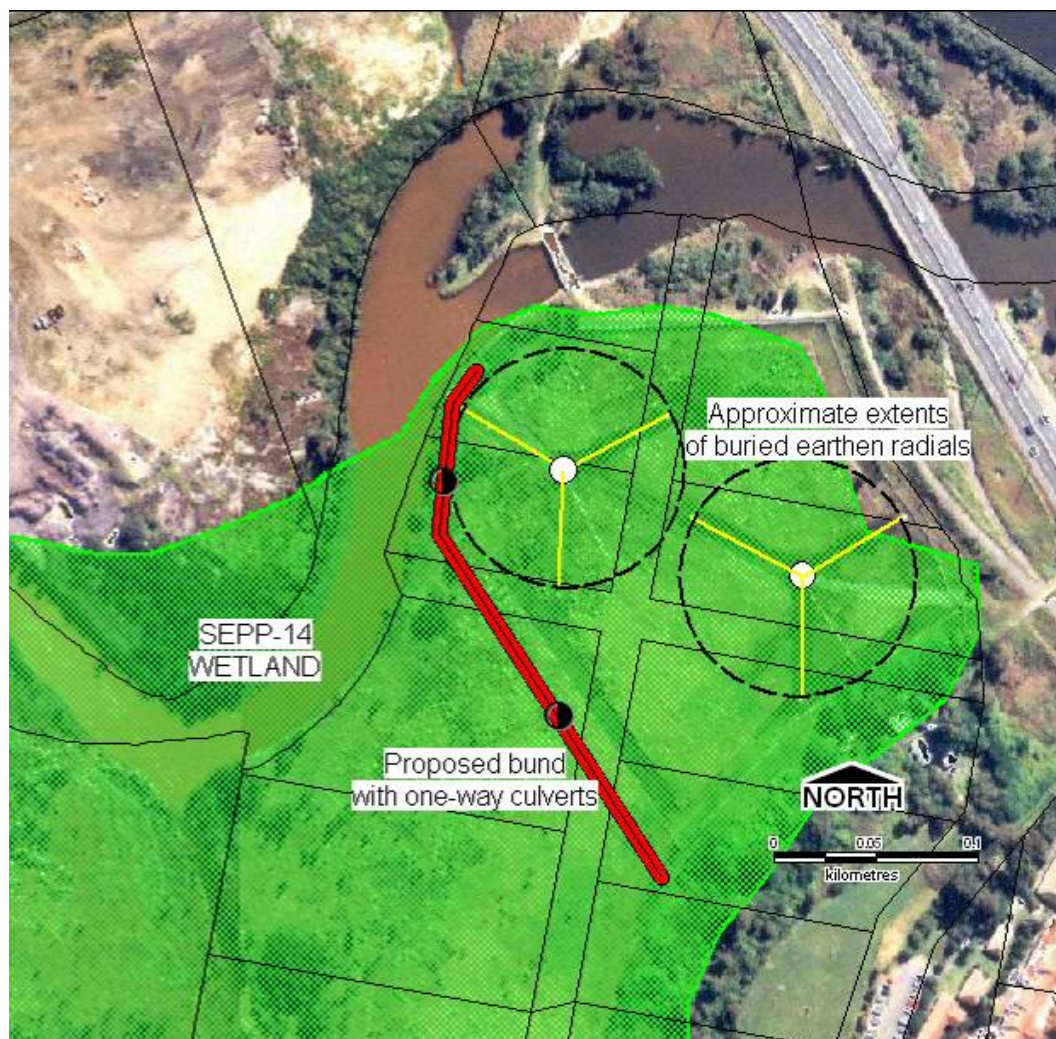


Figure 2.5 Proposed BAL Bund

The land beneath the radio masts contains buried earthen cables used to assist radio transmissions. The location of the bund will be positioned to minimise interference with the earth radials around the towers. Investigations by THL Australia (2005), on behalf of the HCRCMA, have identified the locations and condition of the earth radials. The THL (2005) investigation found that the effective length of the earth radials is 53 metres, although the cables themselves can extend to a distance of 63 metres (i.e. the bund can be placed over the last 10 metres of cable without compromising its

conductance or integrity). Therefore, the inward limit of the bund has been positioned greater than 53 metres from the towers. A guy anchor block is also located in the vicinity of the proposed bund, however, there is sufficient room to locate the bund between the anchor block and the edge of Ironbark Creek, provided that the side slope of the bund is steepened (to 1(v) in 2(h)) on the creek side of the bund in the immediate vicinity of the anchor block.

Construction of the bund will also involve removal and reconstruction of the man-proof perimeter fence for a length of approximately 60 metres. The fence would be reconstructed on the inside edge of the bund.

The crest level of the bund is proposed to be 0.8m AHD, which will exclude tides (including king tides) from the land surrounding the towers. Similar to the Marsden Street bund, it is proposed to over-fill the bund by a further 150mm (subject to further consideration during detailed design of the structure) to compensate for possible settlement after construction.

One-way culverts will be located at the low points along the bund alignment to allow drainage of the land behind the bund. A longitudinal profile of the bund alignment is presented in Figure 2.6. This figure shows that the bund will have a typical height of about 0.4 metres. Similar to the Marsden Street bund, it will be about 3 metres wide at the crest and trafficable for maintenance purposes (refer Figure 2.4 for typical sections of bund). Side-slopes of the bund will be no steeper than 1(v):4(h) to allow easy maintenance, except adjacent to the creek in the immediate vicinity of the guy wire anchor block. The bund will be located outside the perimeter fencing to facilitate maintenance and access.

Preliminary design and set-out details for the BAL bund are provided in **Appendix O: Volume 2**.

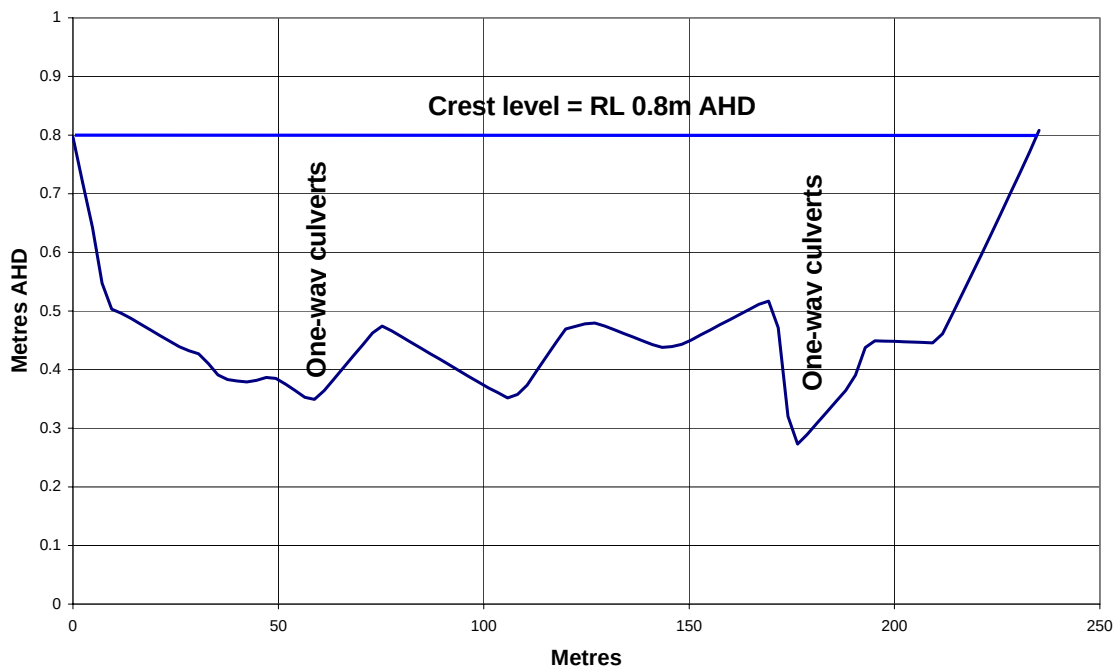


Figure 2.6 Longitudinal Profile of BAL Bund

Most of the land on which the bund is to be constructed is being purchased by the HCRCMA from Broadcast Australia Limited. For the sections of land that will not be purchased from BAL, an easement will provide legal rights for access and maintenance of the bund. The land is also entirely within a designated SEPP-14 area (refer Figure 2.5).

Approximately 1,100m³ of clean imported material will be required to construct the bund. Further details regarding the bund (eg, materials specification, compaction limits etc) will be developed during detailed design.

2.5.3 Bunds at culverts under Richmond-Pelaw railway line

A number of culverts / small span bridges are located along the historic Richmond-Pelaw rail line, which defines the western boundary of the project (refer Figure 2.7). These structures provide hydraulic connectivity between Hexham Swamp and the low-lying privately owned floodplain lands to the west and north-west of the study area (refer Figure 2.8).



Figure 2.7 Typical culverts under Richmond-Pelaw Rail line

It is proposed to construct low-level bunds on the Hexham Swamp Nature Reserve side of these culverts to prevent saline tidal waters flowing through the culverts and into the private grazing lands on the western side of the rail embankment. The bunds would be located entirely within the rail corridor (on land owned by Rio Tinto) and not within the Hexham Swamp Nature Reserve.

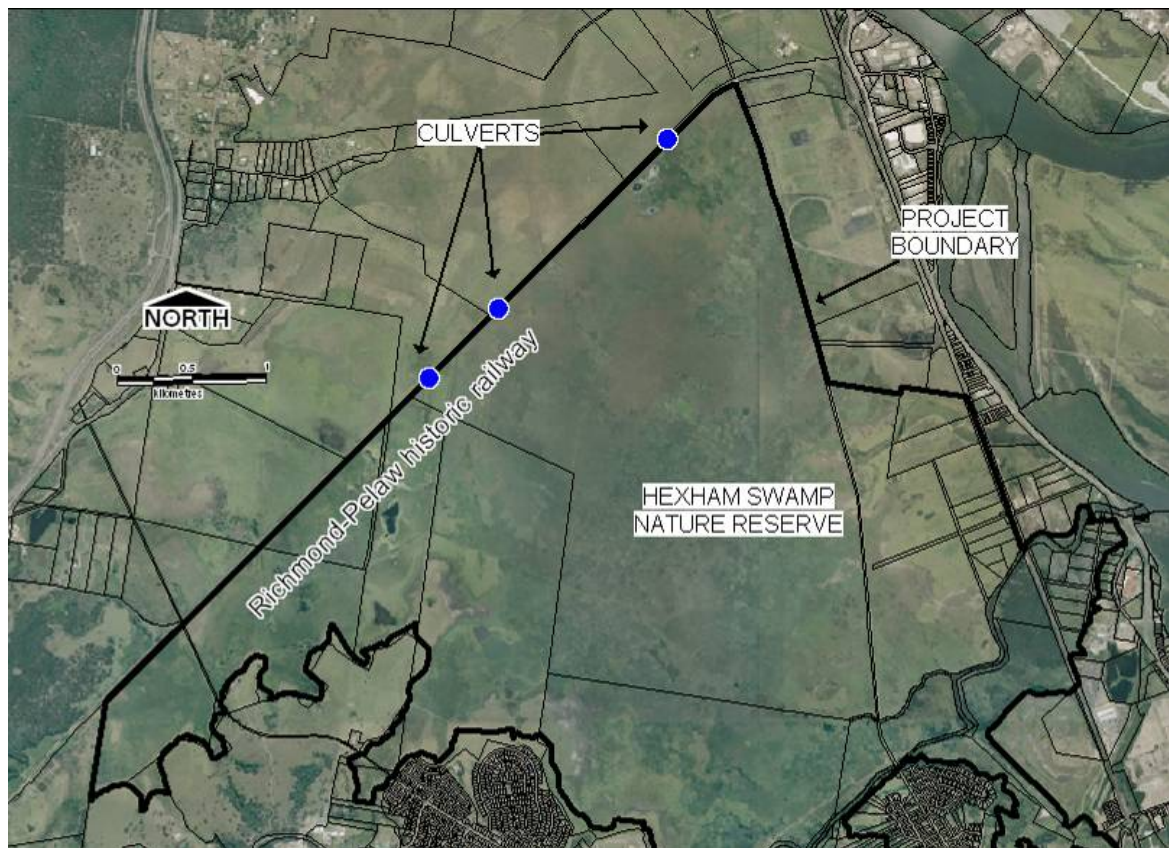


Figure 2.8 Locations of Culverts along Historic Richmond-Pelaw Rail Line

The bunds would be high enough to prevent overtopping of tidal waters (during king tide conditions) from the Nature Reserve, but would be low enough not to significantly affect the conveyance of flood flows through the openings during significant Hunter River floods. Given that the maximum king tide levels in this part of the swamp would not exceed 0.5m AHD, it is expected that the crest elevation of the bunds would be a maximum of 0.5 to 0.6m AHD, which is only about 0.2 to 0.4 metres higher than the adjacent ground level in the swamp. The structure of the bunds would be similar to that proposed for Marsden Street (refer Figure 2.4), except that the crest width would be reduced to 1 metre or so given that access along the crest of the bunds will not be required (refer Figure 2.9). During detail design, further consideration would also be given to the structural integrity and performance of the bunds associated with high velocity over-flows associated with significant Hunter River floods (which may require more formal structural stability and/or a gentler side slope on the western side of the bunds). There are no culverts proposed within the bunds under the Richmond-Pelaw rail line.

It is expected that these bunds would not be constructed at the outset of the Project, but rather, as a long term adaptive contingency measure once the full extend of tidal inundation is realised when the gates are progressively opened. Based on predicted tidal inundation extents (see Section 4.1.2.3), the bunds would need to be constructed prior to opening of two or more floodgates (see Section 2.6).

Construction would involve using clean, fully imported material. Less than 50m³ of material would be required to construct all three bunds under the rail line.

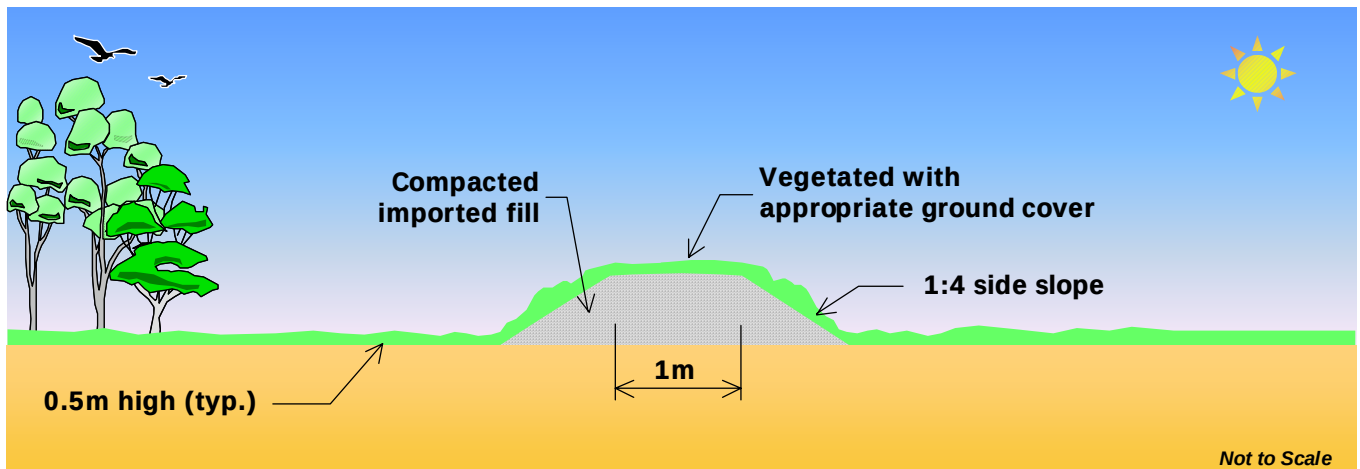


Figure 2.9 Typical section through low level bunds under Richmond-Pelaw rail line

2.5.4 Wallsend Airstrip

The Wallsend Airstrip is a privately owned runway and hanger facility, located on land adjacent to the upper tidal reaches of Ironbark Creek (refer Figure 2.10). It is proposed to partially raise the runway as part of the Hexham Swamp Rehabilitation Project. The existing runway surface (Figure 2.11) will be removed and stockpiled, allowing for raising of the base material by clean fill. The northern end of the runway is to be raised by 200 – 250mm, tapering to zero mid way along the runway. The existing surface material would then be re-layed over the runway, supplemented by additional coarse aggregate as required, to achieve a 100mm minimum thickness. Approximately 3,150m³ of material will be required to partially raise and resurface the runway. It is expected that the material could be sourced locally.

The runway will be raised to offset potential impacts to these surfaces associated with a potential increase in groundwater as a result of the opening of the Ironbark Creek floodgates.

The proposed airstrip works are located outside the Hexham Swamp SEPP-14 area (refer Figure 2.10), but are still within Newcastle Zone 7(b) Environmental Protection. Whilst aerodromes are a prohibited activity in such zonings, Wallsair retain existing use rights over the operation, with the airstrip being in continuous use since its establishment in the 1960s, and have gained development consent for other aerodrome improvement works in recent years.

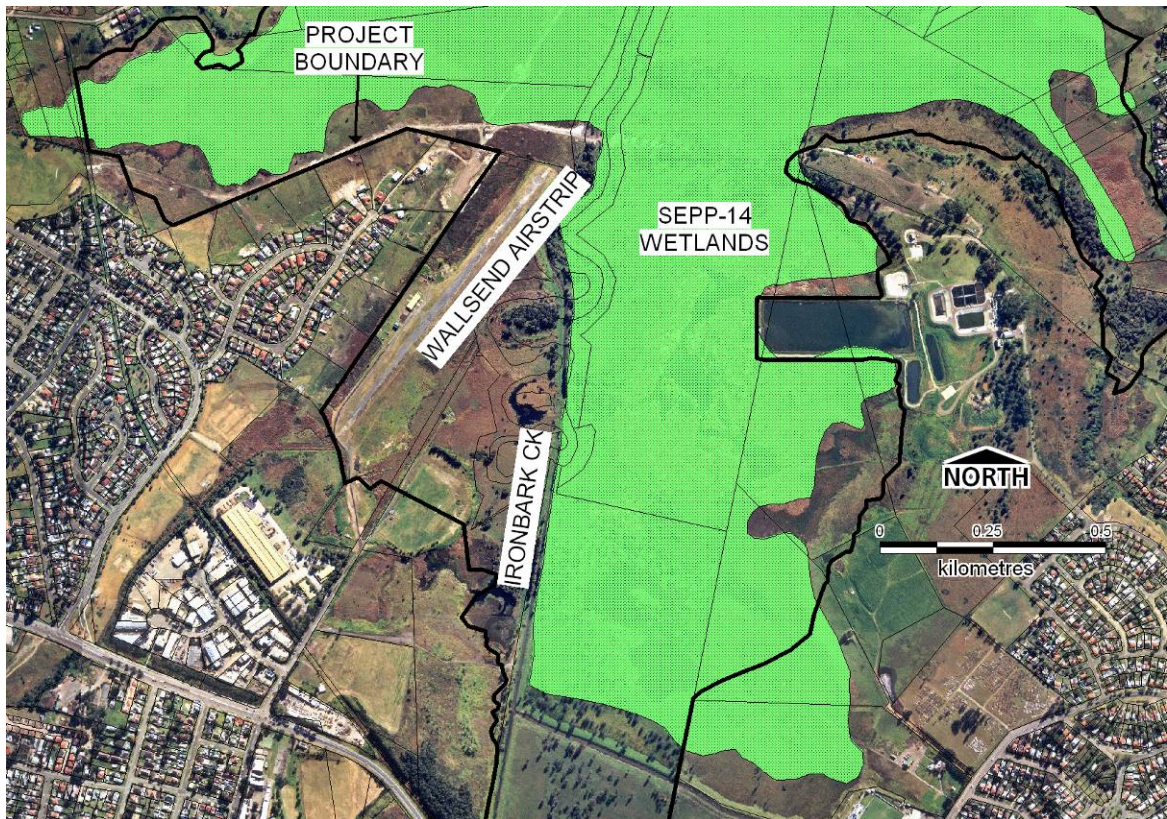


Figure 2.10 Wallsend Airstrip



Figure 2.11 Existing Condition of Wallsend Airstrip

2.5.5 Hunter Water Pipeline Access Track

The access track that runs adjacent to, and services, the main Chichester Water Main through Hexham Swamp (refer Figure 2.12) is approximately 0.5 metres higher than the adjacent ground level in the swamp, with a typical level of about 0.7 to 1.0m AHD. However, some sections of the track have become degraded and are lower than this typical level (refer Figure 2.13).

It is proposed to 'top up' these low sections of the Hunter Water access track as part of the Hexham Swamp Rehabilitation Project using compacted road base, gravel or other similar granular materials. The works will be carried out on an as-needed basis, and as such, the actual volume of material required will not be known until works are being carried out. It is expected that less than 100m³ of material would be required to top-up the low sections of track. It is not proposed to install additional culverts, however, if necessary, existing culverts may need replacement or structural repairs as part of the proposed track improvement works. The need for replacement of existing culverts would be assessed during the track filling works. It is possible that up to three or four sets of culverts may need to be replaced or repaired.

The main purpose of the works is to maintain access for maintenance of the pipeline when the low lying areas adjacent to the pipeline are re-inundated with tidal waters once the floodgates are opened permanently.

Hunter Water Corporation has a long term plan to replace the existing above-ground water pipeline that runs through Hexham Swamp. However, the timeframe of this replacement is such that it will not affect the track upgrading works required as part of this proposal.

The land on which the access track is located is owned by Hunter Water Corporation. The land is also within a designated SEPP-14 area.

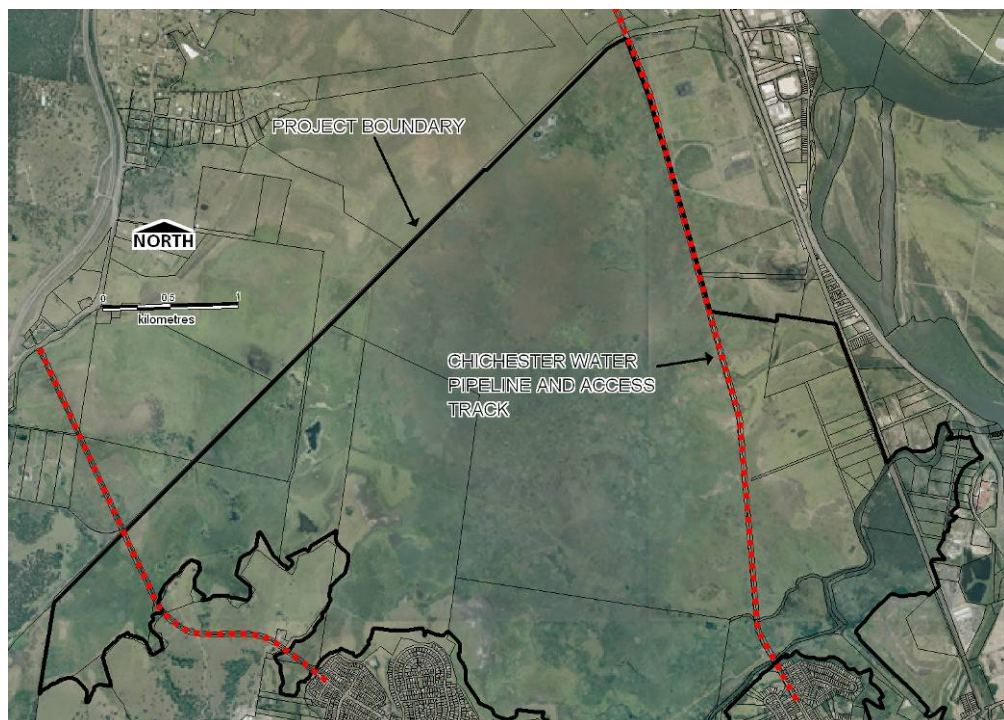


Figure 2.12 Location of Hunter Water Pipeline and Access Track



Figure 2.13 Typical access along Hunter Water pipeline with culverts that may need to be replaced (subject to individual assessments during works activities)

2.5.6 The Wetlands Centre and Transgrid Access Tracks

Several access tracks are located within The Wetlands Centre (TWC), providing access to difference locations and facilities throughout the property, as well as services located on TWC land (eg power transmission lines, water quality monitoring) (refer Figure 2.14). It is proposed to fill the lower lying sections of these access tracks as part of the Hexham Swamp Rehabilitation Project, so than access (particularly for adjacent infrastructure, eg power transmission lines) is maintained once the floodgates are opened.

Filling would involve placement of compacted granular material over the existing track surface to a depth suitable to exclude inundation (likely to be less than 0.3 metres). It may be necessary to provide small pipe culverts under the access roads if the landward side of the track is to remain free-draining.

It is recommended that only the lowest parts of the tracks be filled initially. Other sections of the track that may be affected should be filled once a better appreciation of inundation levels is obtained through the proposed staged opening process of the gates.

The access track adjacent to the Transgrid power lines between The Wetlands Centre and Wallsair private airstrip is higher than expected tidal inundation levels. Therefore, it is not anticipated that this part of the power lines access track will need to be raised. If inundation of this section of track occurs as a result of the works, then filling will be carried out, as described above.

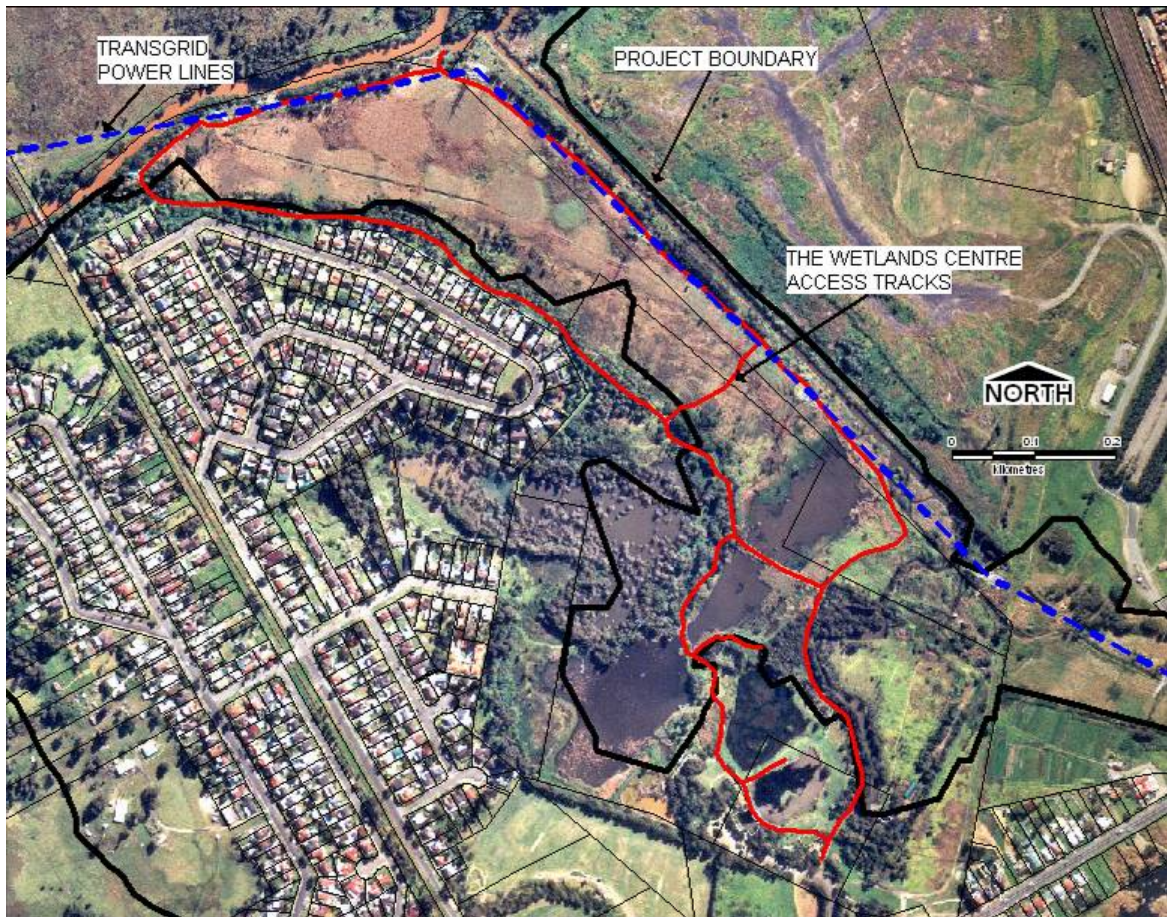


Figure 2.14 Access Tracks within The Wetlands Centre, Shortland

2.5.7 ARTC Rail Access Track

An access track servicing the main northern rail line is located immediately adjacent to the rail line on the down side (southern side) between the Ironbark Creek bridge and Sandgate (refer Figure 2.15). Localised low areas in the track (i.e. less than RL 1.0m AHD) would be 'topped up' using free draining granular aggregate. The scale of these works would be similar to the filling of low-lying section of the access track adjacent to Hunter Water Corporation's Chichester pipeline (refer Section 2.5.5).

The location and quantity of fill would be determined on-site, and following a more detailed ground survey of access track levels. Considerable works are proposed in this section of the rail line as part of the ARTC Sandgate Fly-over project. It is expected that material and equipment required to top-up the track, as necessary, could be obtained during the implementation of the Fly-over project (concurrent timing pending).

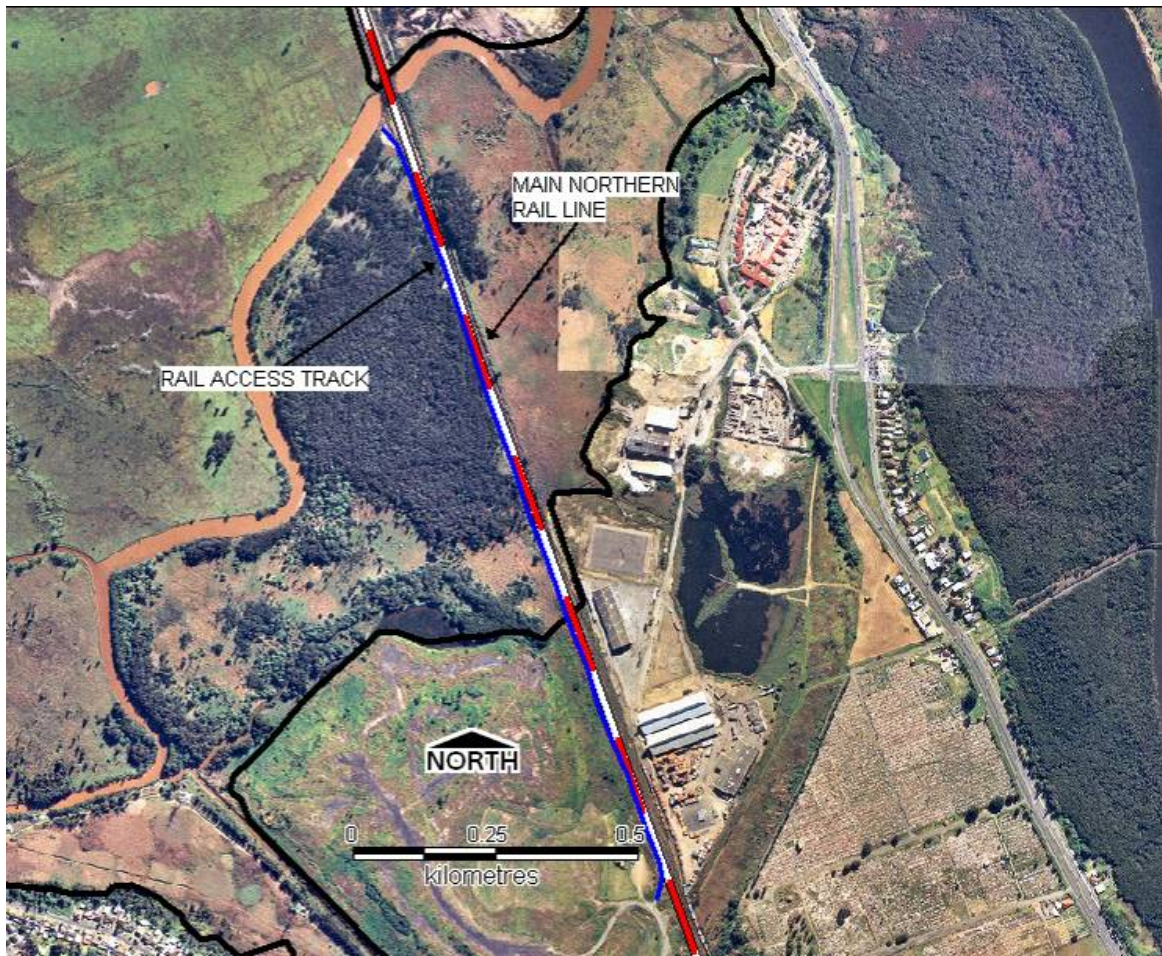


Figure 2.15 ARTC Rail Access Track

2.5.8 Minor Fill on Private Properties at end of Marsden Street

Minor filling of privately owned riparian lands is proposed for three properties at the end of Marsden Street, owned by Cook, Dombkins and Puliueva (Lot20 DP16703; LtB DP350274; LtA DP350274). The area to be filled lies immediately adjacent to Ironbark Creek, covering an area of less than 0.4 hectares (220m long by 15m wide) (refer Figure 2.16). It has a current ground level of between 0.25m and 1.0m AHD. It is proposed to raise the ground level of this land to an elevation of approximately 0.8m – 1.0m AHD using a fill volume of approximately 1000m³ (or about 1800 tonnes). A slope no steeper than 1(v):6(h) would be used to grade the fill into the existing creek bank. This bank would be heavily vegetated to prevent erosion during floods. Minor filling would also occur on land at either end of the private properties to help transition the ground contours and hence creek flows during times of flood.

The purpose of the filling is to prevent tidal inundation of these private lands associated with altered tidal conditions in the adjacent Ironbark Creek. The lands are currently used for grazing and private recreation. Filling is required to ensure that these landuses can be maintained. Revegetation of the fill would also be carried out through plantings and/or hydro-mulching, as well as reconstruction of all affected boundary fences. Within property Lot20 DP16703 (Cook - owner), existing infrastructure

associated with a groundwater bore would also be elevated, as necessary, to match the proposed ground levels following filling of this land. Existing infrastructure includes a concrete pad, electric pump and galvanised iron shed.

The filling will be carried out partly within the designated SEPP-14 area, and would need to be completed prior to opening of the floodgates to ensure no saline tidal inundation of these private lands.

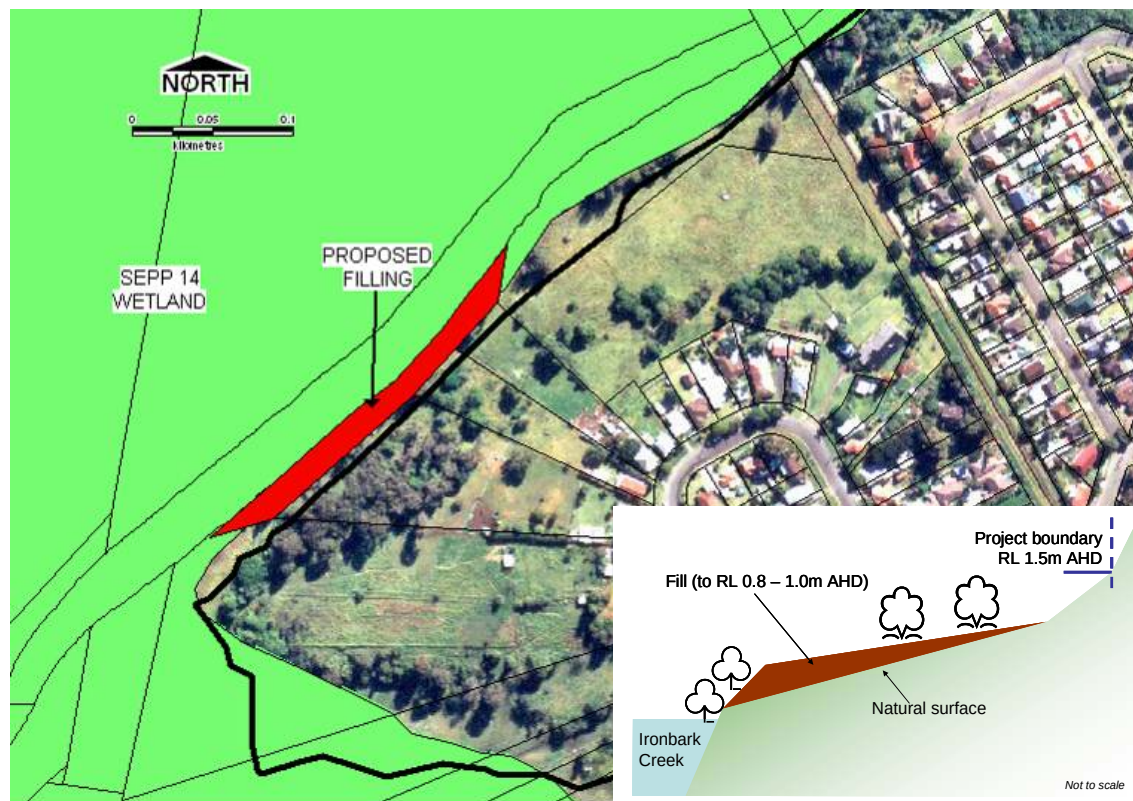


Figure 2.16 Location of Proposed Filling of Private Lands at Marsden Street

2.5.9 Minor Fill at Watts

An area of low-lying land within the Project Area owned by Watts (Lt28 DP864756) will be filled with clean imported fill (refer Figure 2.17). The area to be filled covers approximately 1500m², and varies in ground elevation between about 0.3 and 0.8m AHD. Average depth of fill would be about 0.3 metres, giving a total volume of fill of approximately 450m³ (or about 800 tonnes). The final ground level would be approximately 0.8m AHD. The purpose of the works is to prevent saline surface water from inundating the privately owned property, and potentially altering the existing ground cover vegetation.

The land at present is covered in freshwater marsh vegetation, and provides limited economic benefit to the landowner. It is proposed to hydroseed the land with pasture grasses following spreading and compaction of the fill material.

As shown in Figure 2.17, the filling of this low lying land will be carried out entirely within the SEPP-14 boundary.

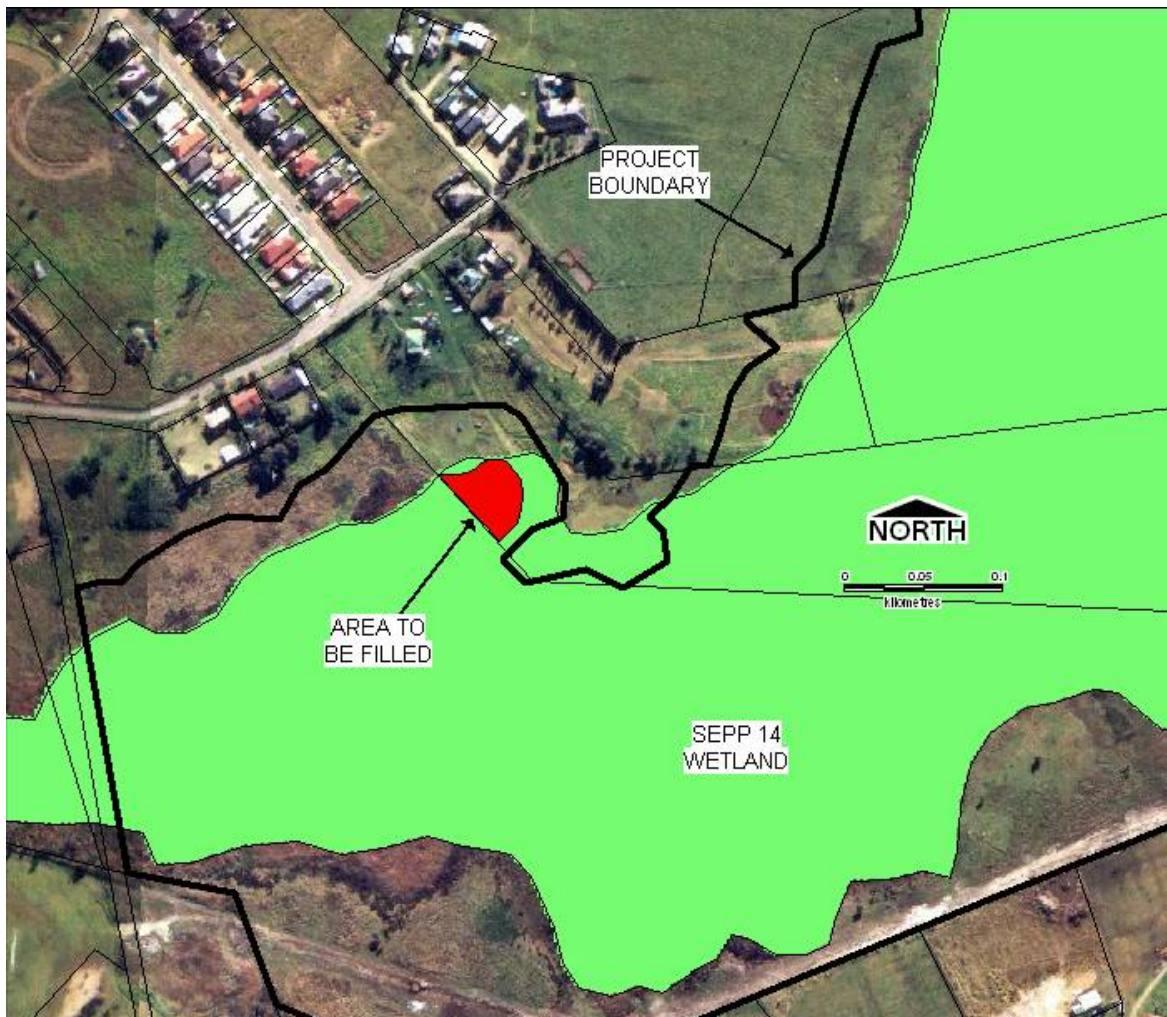


Figure 2.17 Area to be filled on Watts' property

2.5.10 One-Way Tidalgates

There are a number of informal drains and illegally constructed culverts that discharge drainage waters directly into Ironbark Creek or its tributaries. Where necessary, it is proposed to install one-way flap gates on the ends of these culverts to prevent saline intrusion into the drainage network behind (refer Figure 2.18). In the case of the 2HD ponds, important freshwater habitat is located behind the structure, so it is important that saline waters are excluded from this area once the gates are opened.

Flapgates have been proposed for formal drainage channels adjacent to Ironbark and Dark Creeks, at the upstream end of the study area, as well as at the downstream end of the 2HD ponds. An example of a typical flap gate that would be used for these applications is shown in Figure 2.19.



Figure 2.18 Locations of Proposed Tidal flap gates



Figure 2.19 Example of typical flapgates proposed for Hexham Swamp drains
(source: www.humes.com.au)

2.5.11 Removal of Informal Causeway Across Muckeye Creek

An informal gravel causeway has been built across Muckeye Creek to allow maintenance of the surrounding privately owned property. This causeway is proposed to be removed to improve tidal flushing within the creek (although given that the creek is heavily silted, removal of the causeway is unlikely to improve tidal exchange in the creek significantly). As such, the removal of the informal causeway in Muckeye Creek is not a high priority activity.

Removal of the causeway will be carried out as part of future management works of the greater Hexham Swamp area. Until then, the causeway may need to be retained to provide access to areas adjacent to Muckeye Creek that are being purchased by the HCRCMA from BAL, particularly as this area is identified as one of the first areas likely to be inundated when the gates are opened (refer Section 4.1.2).

2.6 Relative timing for implementation of works and staging of gate opening

Some of the works described in the previous Section will need to be carried out prior to opening of the first gate, while other works will be carried out on an as-necessary basis, once the full extents of the inundation are realised. Outlined below is a summary of the relative timing of the ancillary works compared to the staged process for opening of the gates.

Table 2.1 Timing of Works relative to gate opening strategy

Timing	Works Required	Section No.
Prior to one gate open	Marsden Street bund	Section 2.5.1
	BAL bund	Section 2.5.2
	Minor fill on private properties at end of Marsden Street	Section 2.5.8
	One-way tidal gates	Section 2.5.10
	Minor fill at Watts	Section 2.5.9
	Wallsend airstrip	Section 2.5.4
Prior to two gates open	The Wetlands Centre Access Tracks	Section 2.5.6
	Hunter Water Pipeline Access Track	Section 2.5.5
	ARTC Rail Access Track	Section 2.5.7
	Bunds at culverts under Richmond-Pelaw railway line	Section 2.5.3
As necessary	Removal of Informal Causeway across Muckeye Creek	Section 2.5.11

2.7 Legislative Considerations for the Proposal

Hexham Swamp and the surrounding land are subject to a variety of Environmental Planning Instruments and Policies. The specific provisions of these instruments and policies, and their relevance to the proposal to open the Ironbark Creek floodgates, are outlined below.

2.7.1 The Environmental Planning and Assessment Act 1979 (EP&A Act)

The Hunter and Central Rivers Catchment Management Authority, the proponent of the proposal, is a statutory authority. Clause 226(1) of the EP&A Regulation defines a public authority as the crown for the purposes of s 116C of the EP&A Act. Accordingly, Part 5A of the EP&A Act applies to this development application.

Section 116C of the EP&A Act provides that a consent authority, in respect of a development application made by or on behalf of the Crown, must not:

- (a) refuse its consent to the application, except with the written approval of the Minister; or
- (b) impose a condition of its consent, except with the written approval of the Minister or the applicant.

The proposal is designated development under the EP&A Act for which an environmental impact statement is required (see Section 2.7.2.1). The proposal is also integrated development under the EP&A Act (see Sections 2.7.5.2, 2.7.5.7, and 2.7.5.8).

2.7.2 State Environmental Planning Policies

2.7.2.1 State Environmental Planning Policy No 14 - Coastal Wetlands (SEPP 14)

State Environmental Planning Policy No 14 - Coastal Wetlands (SEPP 14) aims to preserve and protect coastal wetlands in NSW. It is recognised that coastal wetlands serve statewide environmental and economic interests. The policy applies to wetlands in the State identified as needing protection by the Department of Infrastructure, Planning and Natural Resources. The majority of the land within the area covered by the proposal and most of the ancillary engineering works associated with this proposal are located within land to which SEPP 14 applies. Figure 2.20 shows wetland No. 840 mapped under SEPP 14.

The proposal will result in the death of some of the present vegetation and will also involve the construction of some bunds and minor filling within the SEPP-14 boundary. Clause 7 of SEPP 14 has the effect that clearing, draining, filling or constructing a levee (bund) on land to which SEPP 14 applies is designated development for the purposes of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) for which:

- (1) the consent of the Council of the City of Newcastle; and
- (2) the concurrence of the Director of the Department of Environment and Conservation;

is required unless these activities are carried out as restoration works. SEPP 14 defines restoration works as works “that are carried out to restore or enhance the natural values of coastal wetlands in order to rectify a breach of” SEPP 14. As the proposal is not being carried out to restore a breach of SEPP 14 the works associated with the proposal are not restoration works and thus is designated development under the EP&A Act. The EP&A Act provides that an EIS is required for designated development. Thus an EIS is required for the proposal.

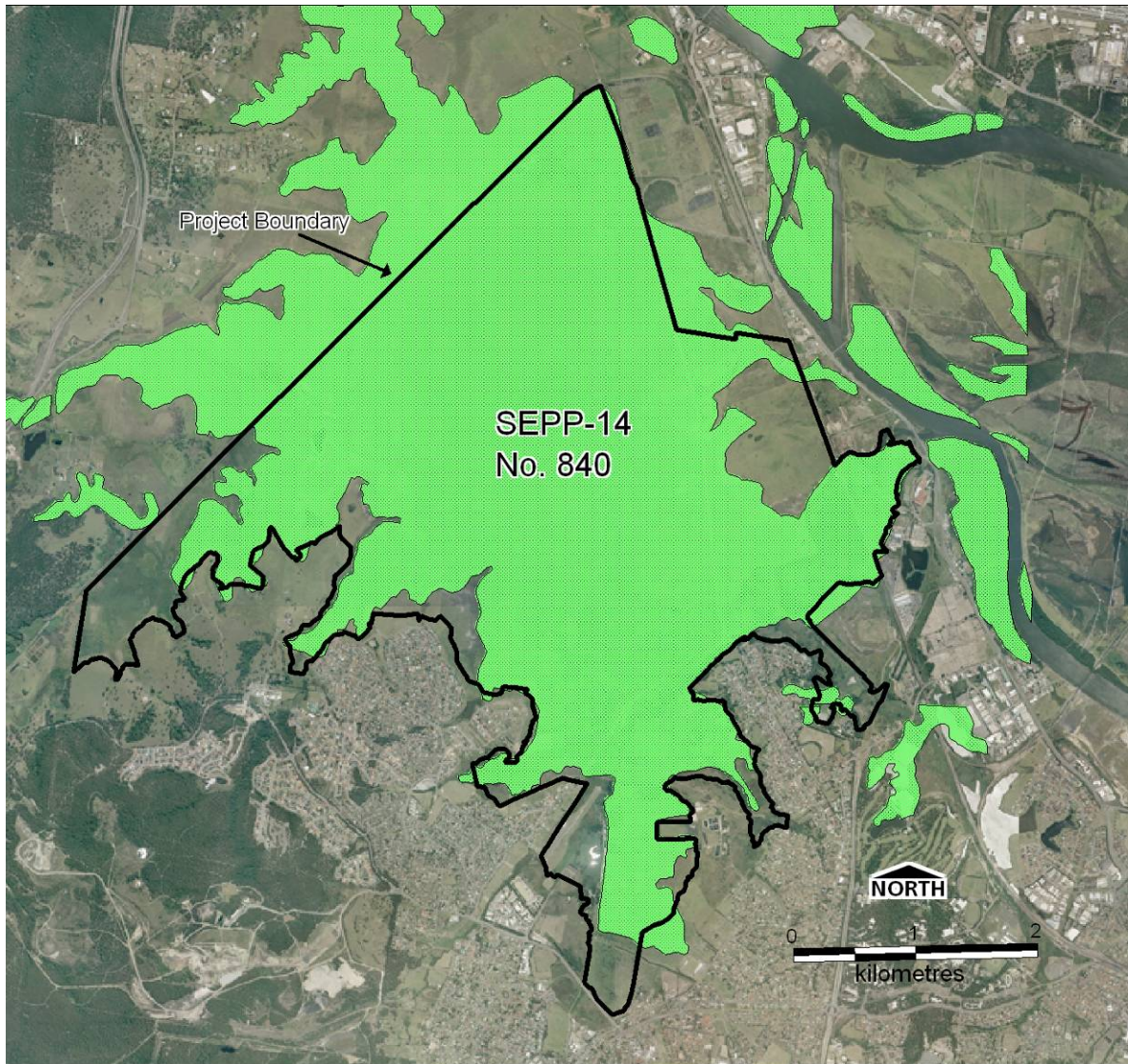


Figure 2.20 SEPP-14 No. 840 at Hexham Swamp

Clause 7(2) of SEPP 14 requires the Director of the Department of Environment and Conservation, in determining whether to grant concurrence to the proposal pursuant to clause 7(1) of SEPP 14 to consider:

- the environmental effects of the proposal, including the effect of the proposal on:
 - ◊ the growth of native plant communities;

- ◇ the survival of native wildlife populations;
- ◇ the provision and quality of habitats for both indigenous and migratory species;
- ◇ the surface and groundwater characteristics of the site on which the development is proposed to be carried out and of the surrounding area, including salinity and water quality;
- whether adequate safeguards and rehabilitation measures have been, or will be, made to protect the environment;
- whether carrying out the development would be consistent with the aim of SEPP 14;
- the objectives and major goals of the "National Conservation Strategy for Australia" in so far as they relate to wetlands and the conservation of "living resources" generally;
- whether consideration has been given to establish whether any feasible alternatives exist to the carrying out of the proposed development, and if so, the reasons given for choosing the proposed development;
- any representations made by the Director General of the Department of Environment and Conservation in relation to the development application;
- any wetlands surrounding the land to which the development application relates and appropriateness of imposing conditions requiring the carrying out of works to preserve or enhance the value of those surrounding wetlands.

2.7.2.2 State Environmental Planning Policy No -71 Coastal Protection (SEPP 71)

SEPP 71 applies to land the whole or any part of which is within the coastal zone as defined in the policy. SEPP 71 defines the "coastal zone" by reference to the definition contained in the *Coastal Protection Act 1979 (NSW)*. The *Coastal Protection Act 1979* provides that the "coastal zone" includes the area of land shown on the maps outlining the coastal zone. Specific maps defining the Coastal Zone within the Newcastle Local Government Area have been prepared, but these have not yet been approved by the Minister for Infrastructure, Planning and Natural Resources. Therefore SEPP 71 does not apply to this proposal.

2.7.3 Regional Environmental Plans

1.5.3.1 Hunter Regional Environmental Plan 1989

The *Hunter Regional Environmental Plan 1989* (HREP) aims to:

- promote the balanced development of the region, the improvement of its urban and rural environments and the orderly and economic development and optimum use of its land and other resources, consistent with conservation of natural and man made features and so as to meet the needs and aspirations of the community;
- co-ordinate activities related to development in the region so there is optimum social and economic benefit to the community; and
- continue a regional planning process that will serve as a framework for identifying priorities for further investigations to be carried out by the Department and other agencies.

Clause 7 of the HREP requires a consent authority to consider the content of the background report and the objectives, policies and principles contained in the HREP, which are relevant to the matter in determining to grant consent to a development application made under any environmental planning instrument.

The HREP lists a number of policies for the control of development that are relevant to the decision of a consent authority to grant consent to a development application. The following policies are of potential relevance to the proposal:

- Before granting consent to a development application for development (other than commercial farming) on land identified as prime crop or pasture land councils should take account of the views of officers of the Department of Agriculture and Fisheries on the effect of the development on the productive potential of the land and on the productive use and potential of adjoining lands (cl 27).
- Clearing, draining, filling, construction of a levee or other development on any wetland shown on the map (other than any wetland under the control of the National Parks and Wildlife Service or the Forestry Commission) shall not be carried out without the consent of the council, and the council should not grant such consent until it has taken into consideration:
 - (a) the environmental effects of such development on the natural ecosystem plant life, water quality and wildlife population of the wetland and on any migratory species using the wetland;
 - (b) whether adequate safeguards and rehabilitation measures are proposed to protect the environment;
 - (c) the objectives and goals of the “ National Conservation Strategy for Australia ” in so far as they relate to wetlands;
 - (d) whether consideration has been given to any feasible alternative to the proposed development; and
 - (e) comments received as a result of any advertising of proposals and advice from relevant public authorities (cl 62).
- A consent authority, in considering proposals for development on land within 100 metres of the ocean or any substantial waterway should consider:
 - (a) whether there is sufficient foreshore open space accessible and open to the public in the vicinity of the proposed development;
 - (b) the likely impact of the proposed development on the amenity of the waterway;
 - (c) the principles of any foreshore management plan applying to the area; and
 - (d) any alternative use for which a waterfront site is essential (cl 66).

1.5.3.2 Hunter Regional Environmental Plan 1989 (Heritage)

The *Hunter Regional Environmental Plan 1989 (Heritage)* does not apply to land within the City of Newcastle local government area. As the land within the project boundary is entirely within the City of Newcastle local government area this plan does not apply to the land within the project area.

2.7.4 Newcastle Local Environment Plan 2003

The recently gazetted Newcastle Local Environment Plan 2003 (NLEP) replaces the previous Newcastle Local Environment Plan 1987. The NLEP provides strategic direction for future development within the Newcastle Local Government Area (LGA).

2.7.4.1 Land Zoning Provisions

The Project Area lies within a number of different zonings as defined by the NLEP 2003 (refer Figure 2.21). Applicable zonings and their areas within the Hexham Swamp Project Area are listed in Table 2.2.

Table 2.2 Hexham Swamp Landuse Zonings

<i>Zoning Description</i>	<i>Area in Project Area (ha)</i>
4(b) Port and Industry	1.1
5(a) Special Uses	86.5
6(a) Open Space and Recreation	3.1
7(a) Conservation	0.8
7(b) Environmental Protection	947.5
7(c) Environmental Investigation	1.0
8(a) National Parks	905.8
TOTAL	1946

As can be seen in Table 2.2 and Figure 2.21, the vast majority of the project area (95%) is located within either 7(b) or 8(a) zoned land. Most of the remaining land is zoned 5(a) for Hunter Water uses (Shortland WWTW).

Works associated with the Hexham Swamp Rehabilitation Project are considered to be “Environmental Protection Works” under the NELP. The NLEP defines “Environmental Protection Works” to mean “any work associated with the rehabilitation of land towards its natural state or any work to protect land from environmental degradation, and includes bush regeneration works, wetland protection works, erosion rehabilitation works, erosion protection works, dune restoration works, dune protection works and the like.”

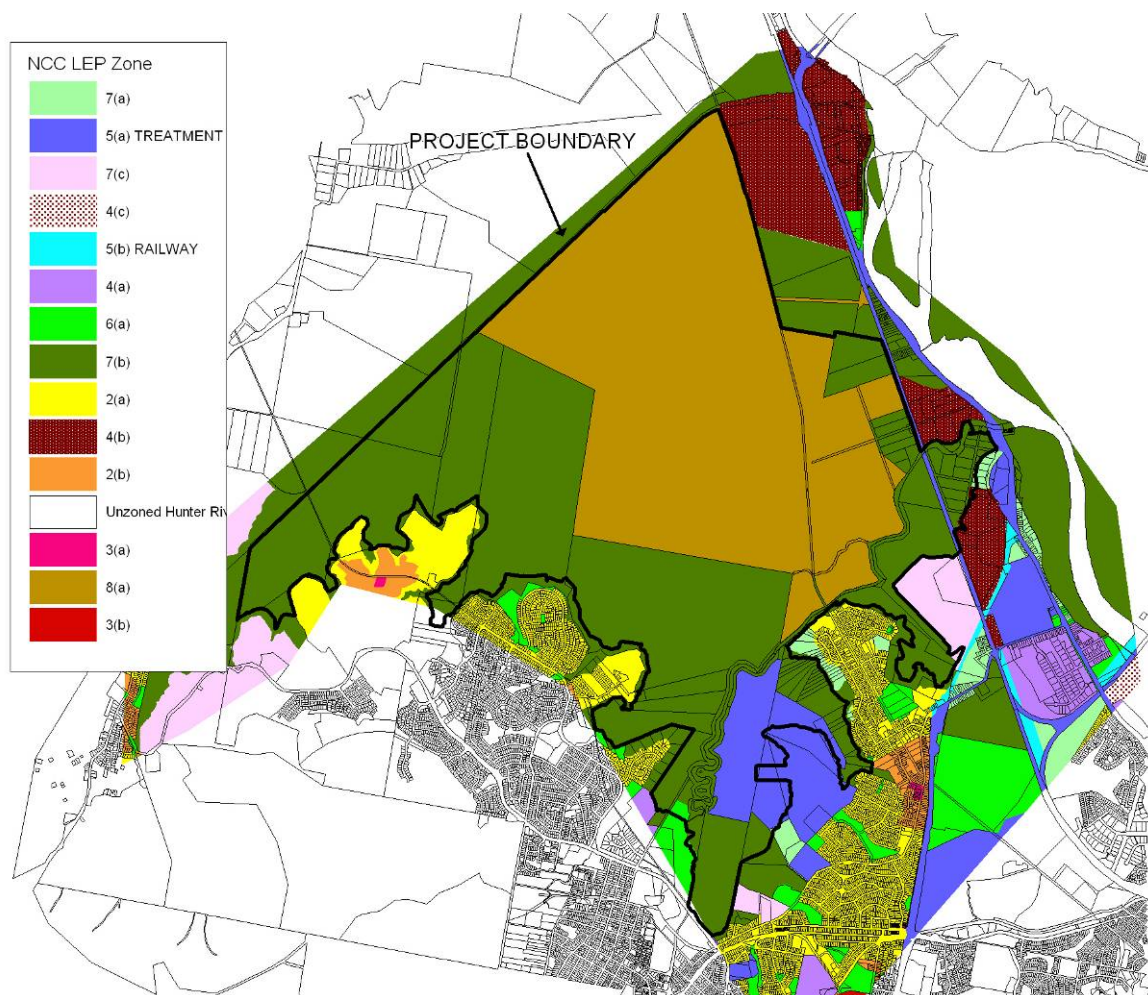


Figure 2.21 Newcastle LEP 2003 Zonings for Hexham Swamp

Clause 13(e) of the NLEP provides that “Environmental Protection Works” do not require consent under the NLEP except as otherwise provided by NLEP. The zoning table contained at cl 16 of the NLEP provides that consent is not required for “Environmental Protection Works” for each of the applicable zones set out in Table 2.2 other than zone 8(a) National Parks. The zoning table contained at cl 16 of the NLEP provides that “any development authorised by or under the *National Parks and Wildlife Act 1974* (NPW Act) and any development incidental or ancillary to such development is permitted without consent” and no other development is permissible within the zone. Details of the NPW Act, and relevant development associated with the Act, are discussed in Section 2.7.5.2.

The objectives of each of the relevant zones as set out in cl 16 of the NLEP are set out in Table 2.3.

Table 2.3 Landuse Zone Objectives

Zone	Objectives
4(b) Port and Industry	(a) To accommodate port, industrial, maritime industrial, and bulk storage activities which by their nature or the scale of their operations require separation from residential areas and other sensitive land uses. (b) To require that development of land within 750 metres from the high-water mark of the shores of the Port of Newcastle, capable of docking ocean-going vessels, is used for purposes that: (i) require a waterfront location that provides direct access to deep water; or (ii) depend upon water-borne transport of raw materials or finished products; or (iii) have a functional relationship that necessitates proximity to the activities described above. (c) To facilitate sustainable development through the application of industrial ecology. (d) To provide for other development which will not significantly detract from the operation of large scale industries or port-related activities, that is primarily intended to provide services to persons employed in such industries and activities.
5(a) Special Uses	(a) To accommodate major transport networks and facilities. (b) To accommodate large scale facilities and services, together with ancillary activities. (c) To accommodate large scale community establishments, together with ancillary activities. (d) To require development to be integrated and reasonably consistent in scale and character with surrounding natural, rural or urban environments.
6(a) Open Space and Recreation	(a) To accommodate leisure, recreation and sports facilities in parks, gardens, plazas and other open spaces, for the general use of the community, where consistent with an adopted plan of management under the <i>Local Government Act 1993</i> or the <i>Crown Lands Act 1989</i>. (b) To provide for the conservation of urban bushland where associated with parks and other open spaces. (c) To accommodate other facilities for the benefit of the community that are compatible and consistent with the heritage and character of the open space and with the character and amenity of the neighbourhood.
7(a) Conservation	(a) To provide for the conservation of the rural and bushland character of the land that forms the scenic edge of and the gateway to urban Newcastle. (b) To provide for the conservation, enhancement and protection of environmentally sensitive land, such as

Zone	Objectives
	remnant bushland, in both urban and rural localities.
7(b) Environmental Protection	(a) To provide for the conservation, enhancement and protection of environmentally sensitive land, particularly wetlands. (b) To allow limited development where it is unlikely to have a significant detrimental effect on the growth of natural communities, the survival of native wildlife populations, the provision and quality of habitats for indigenous and migratory species and the surface and ground water characteristics of the site. (c) To provide for the management of the majority of the Hunter River flood plain by restricting the type and scale of development to that compatible with the anticipated risk to life and property.
7(c) Environmental Investigation	(a) To provide for the development of land for purposes which will not, or will be unlikely to, prejudice its possible future development for urban purposes or its environmental conservation. (b) To conserve the rural or bushland character, and the biodiversity values or other conservation values, of the land.
8(a) National Parks	To provide for the management and appropriate development of land, which is reserved or dedicated under the <i>National Parks and Wildlife Act 1974</i> .

2.7.4.2 Acid Sulphate Soils

The Potential Acid Sulfate Soil Planning Map for Hexham Swamp, as provided by Newcastle City Council, is provided in Figure 2.22. This map shows that the vast majority of the Hexham Swamp project area has an Acid Sulfate Soil classification of 2 although some of the land within the project area has Acid Sulfate Soil classification of 1 and 3.

Clause 25(2) of the NLEP provides that:

A person shall not, without the consent of the consent authority, carry out works on land to which this plan applies, being Class 1, 2, 3, 4, or 5 land as indicated on the "Potential Acid Sulphate Soils Planning Map", being works specified for the respective class of land in the following Table, except as otherwise provided by this clause:

Class of land	Works to which this clause applies
1	Any works.
2	Works below the ground surface. Works by which the water table is likely to be lowered.
3	Works more than 1 metre below the natural ground level. Works by which the water table is likely to be lowered beyond

	<i>1 metre below natural ground surface.</i>
4	<i>Works more than 2 metres below the natural ground level. Works by which the water table is likely to be lowered more than 2 metres below natural ground surface.</i>
5	<i>Works within 500 metres of adjacent Class 1, 2, 3, or 4 land which are likely to lower the water table more than 1 metre on that adjacent Class 1, 2, 3, or 4 land.</i>

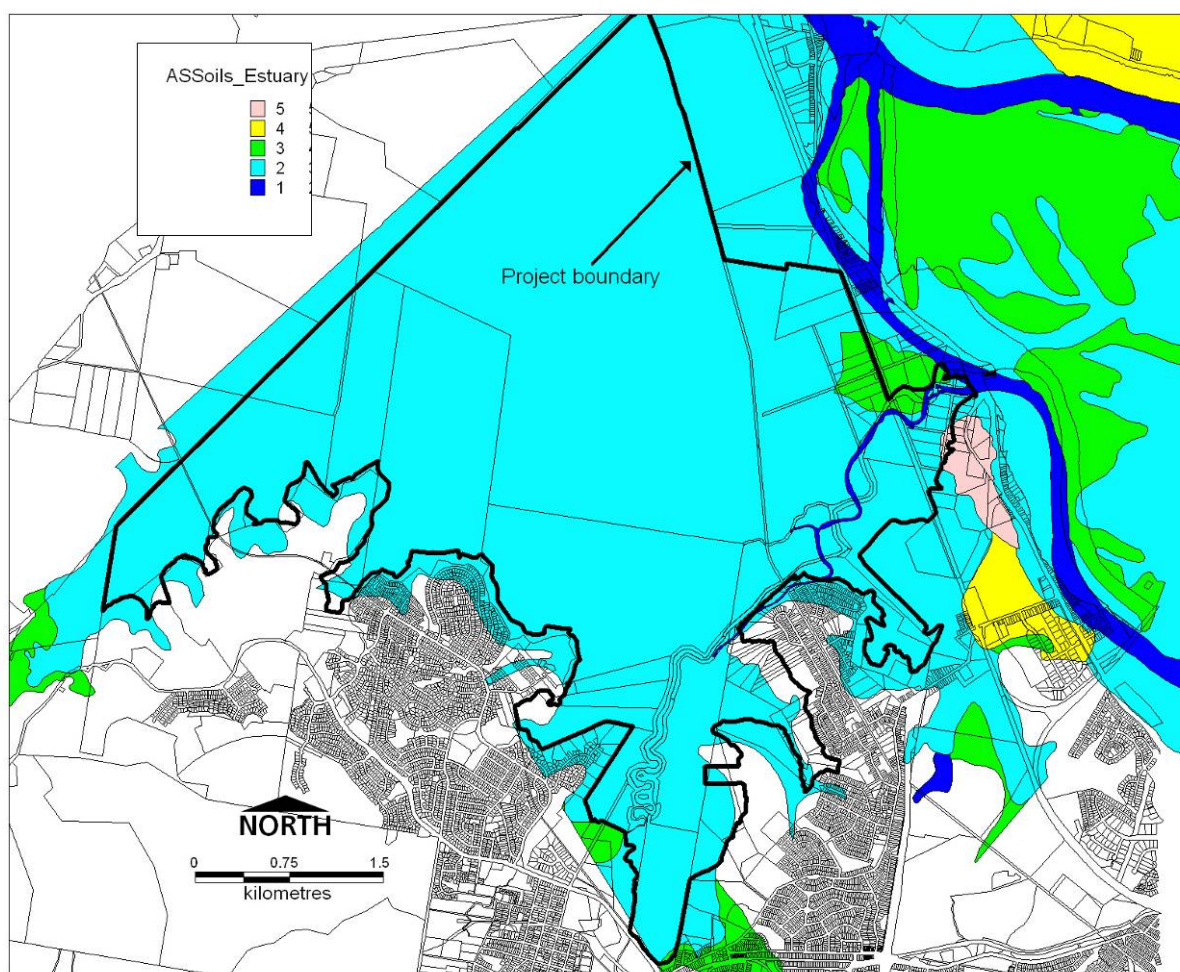


Figure 2.22 Acid Sulfate Soils Classification in the Hexham Swamp area

Clause 25(1) of the NLEP provides that, for the purpose of cl 25 of the NLEP:

"works" means any disturbance of more than one tonne of soils, the construction or maintenance of drains, extractive industries, dredging, the construction of artificial water

bodies (including canals, dams and detention basins), the construction of footings or erection of foundations, flood works, or any other works that are likely to lower the water-table.

“Flood works” are defined in cl 37 of the NLEP to have the same meaning as under the *Water Management Act 2000*. The *Water Management Act 2000* defines a “flood work” to mean:

“a work (such as a barrage, causeway, cutting or embankment):

- (a) that is situated:*
 - (i) in or in the vicinity of a river, estuary or lake, or*
 - (ii) within a floodplain, and*
- (b) that is of such a size or configuration that, regardless of the purpose for which it is constructed or used, it is likely to have an effect on:*
 - (i) the flow of water to or from a river, estuary or lake; or*
 - (ii) the distribution or flow of floodwater in times of flood;*

and includes all associated pipes, valves and equipment, but does not include any work declared by the regulations not to be a flood works.”

Under the definition of “works” and “flood works” contained in the LEP, the proposed construction of saltwater exclusion bunds at Marsden Street and around the BAL towers would constitute ‘flood works’ under cl 25 of the NLEP. These works will all occur on that part of the land which has an Acid Sulfate Soil classification of 2. Accordingly, consent would only be required under cl 25(2) of the NLEP if these works occurred below the grounds surface or were likely to result in the lowering of the groundwater table. Construction of the earthworks proposed as part of the Hexham Swamp Rehabilitation Project will involve importation of all materials, and thus will not require any excavation, dredging or other works below the ground surface. Further, as indicated in Section 4.3.2, the Project will not result in a lowering of groundwater levels, but rather is likely to produce an increase in the groundwater table (particularly in areas adjacent to open waterways). This is likely to reduce the acid sulfate soil risks of the swamp, and help mitigate any existing acid sulfate soil problems.

Given the above, it is considered that consent for the proposed works is not required pursuant to cl 25(2) of the Newcastle LEP.

2.7.4.3 Bush Fire Prone Land

Clause 26 of the NLEP provides that:

The consent authority shall not grant consent to development on bush fire prone land unless the consent authority is satisfied with the measures proposed to be taken with respect to the development to protect persons, property and the environment from danger that may arise from a bush fire.

“Bush fire prone land” is defined under the EP&A Act to mean land recorded for the time being as bush fire prone land on a bush fire prone land map for the area. The EP&A Act defines “bush fire prone land map” to mean a map for the area certified as referred to in section 146 (2). The land within the area covered by the proposal is identified as “Bushfire Vegetation Category 1” on a bush fire prone land map.

2.7.5 Other Policies, Instruments and Approvals

2.7.5.1 *Environmental Protection and Biodiversity Conservation Act 1999*

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides for the protection of matters of national environmental significance, including:

- World Heritage Properties;
- National Heritage Places;
- Wetlands of International Importance;
- Listed Threatened Species and Ecological Communities;
- Listed Migratory Species; and
- Commonwealth Marine Areas.

If an activity has the potential to impact on one or more matters of national environmental significance, an assessment process in accordance with the EPBC Act and Guidelines (Environment Australia 2000) is required. If the assessment concludes that a significant impact is likely, then the activity will be deemed a controlled action and approval for the activity is required from the Commonwealth Department of Environment and Heritage via a detailed referral process, including public exhibition.

The Hexham Swamp study area lies adjacent to the Shortland Wetlands, and in close proximity to the Kooragang Nature Reserve, both of which are part of the internationally important Ramsar wetland known as the Hunter Estuary Wetlands Ramsar site. The Hunter Estuary Wetlands are listed on the Register of the National Estate. Also, the study area provides habitat for 8 threatened species, 20 migratory species and 20 marine protected species, as listed in the EPBC Act 1999.

A referral has been made to the Minister for Environment and Heritage. This referral, along with additional information provided, and the response received from the Minister, are provided in **Appendix B: Volume 2**. The Minister's response, dated 25 November 2003, indicates that the Department of Environment and Heritage (DEH) decided that the Proposal is not a controlled action in relation to Listed Threatened Species and Ecological Communities provided that the Proposal is undertaken as follows:

- Monitoring of water levels and salinity will occur in the vicinity of the '2HD swamp' during the staged opening of the flood gates to determine the likelihood of inundation affecting salinity within the swamp.
- In the event that modelling indicates a credible risk to the hydrology or water quality of the 2HD swamp during king tide or other extreme tidal events (eg combined high tide and storm surge), such that the swamp's habitat and breeding values for the listed vulnerable Green and Golden Bell Frog may be adversely affected, flood gates will be installed within the channel draining from the 2HD swamp to Hexham Swamp to ensure that saline intrusion does not occur.
- Frog populations within the 2HD swamp will be monitored during the three year inundation project to ensure that management regimes, including manipulation of tidal regimes, do not adversely affect frog populations.

Subsequent to the referral of the proposal to the Minister, the Hunter Estuary Wetlands were listed on the register of the National Estate. The Authority approached DEH by email on 23 March 2005 seeking confirmation that:

- (1) the proposal does not have to be re-referred to the Minister in light of the listing of the Hunter Estuary Wetlands on the register of the National Estate and minor amendments made to the project boundary; and
- (2) the Minister's response, dated 25 November 2003, was intended to indicate that the Proposal is not controlled action in relation to protected wetlands.

On 23 March 2003 the DEH confirmed that:

- (1) neither the listing of the Hunter Estuary Wetlands on the register of the National Estate and amendments made to the project boundary "have any implications in terms of the likely significance of the referred action on matters protected under the EPBC Act" and confirmed that "the original decision stands".
- (2) "the decision maker found that there is not likely to be a significant impact on the ecological character of a Ramsar Wetland."

Correspondence from DEH outlining the above is also included in **Appendix B: Volume 2**.

2.7.5.2 NSW National Parks and Wildlife Act 1974

The *National Parks and Wildlife Act 1974* (NPW Act) provides for the protection of Aboriginal sites and designated conservation areas and the flora and fauna that inhabit them. The Act aims to conserve habitats, ecosystems, biological diversity, significant landforms and natural landscapes.

Under s 90 of the NPW Act, it is an offence to damage or destroy Aboriginal sites without a licence, permit or other authority from the Director-General of the Department of Environment and Conservation (formerly the Director-General of the National Parks and Wildlife Service). As discussed further in Section 3.15.4, the proposed Marsden Street bund will be located over a small Aboriginal archaeological site containing scattered stone fragments.

Land zoned 8(a) within the Project Area has been declared the Hexham Swamp Nature Reserve, and is owned and managed by the Department of Environment and Conservation in accordance with the requirements of the NPW Act.

Pursuant to s 30J of the NPW Act, the purpose of a Nature Reserve is to identify, protect and conserve areas containing outstanding, unique or representative ecosystems, species, communities or natural phenomena so as to enable those areas to be managed in accordance with the following principles:

- the conservation of biodiversity, the maintenance of ecosystem function, the protection of geological and geomorphological features and natural phenomena;
- the conservation of places, objects, features and landscapes of cultural value;
- the promotion of public appreciation, enjoyment and understanding of the nature reserve's natural and cultural values; and

- provision for appropriate research and monitoring.

A Plan of Management for the Hexham Swamp Nature Reserve and the Kooragang Nature Reserve has been prepared by DEC (NPWS, 1998) (refer Section 2.7.5.3).

2.7.5.3 Hexham Swamp Nature Reserve Plan of Management

The Hexham Swamp Nature Reserve was dedicated in 1990. A Plan of Management for the Nature Reserve was subsequently prepared in accordance with Section 72 of the NPW Act 1974 and adopted in 1998 by the Minister for the Environment (NPWS, 1998). The Plan of Management is also consistent with the management guidelines for wetlands listed in Resolution C.5.7 and Recommendation C.5.3 as adopted by the Ramsar Convention.

The Hexham Swamp Plan of Management defines the scheme of operations for future management of the area defined by the Nature Reserve. No operations are permitted within the Nature Reserve except in accordance with the Plan.

Hexham Swamp is the largest freshwater swamp on the north coast of NSW. However, alterations to the hydrology of the swamp in the early 1970s have promoted these freshwater habitats at the expense of a more diverse suite of wetland types, including many estuarine wetlands.

In managing the Nature Reserve, the DEC has an obligation to international treaties to restore and/or enhance the habitat for migratory birds and waterfowl. To achieve this, the Plan of Management requires:

- Modification of the hydrology within the Swamp, which has been artificially regulated since the early 1970s;
- Rehabilitate degraded vegetation communities, particularly the estuarine mangrove and saltmarsh communities, which have been displaced by the common reed *Phragmites*.

The Plan of Management acknowledges that to rehabilitate the habitats of the Nature Reserve, existing landuse rights on nearby private properties may need to be modified, or protected through the construction or structural works, such as levees / bunds and floodgates.

Various policies are presented in the Plan of Management to achieve its overall objectives, including the manipulation of the floodgates to allow saltwater back into the lower area of the swamp, which will promote reestablishment of mangroves and saltmarshes, and increase habitat diversity within the swamp. The extent of common reed (*Phragmites australis*), which has taken over large areas of the Nature Reserve, will also be reduced.

2.7.5.4 National Trust of Australia (New South Wales) Act 1990

The National Trust of NSW is a non-statutory body committed to the conservation of the natural and built environment. The Trust maintains a Register of Significant Heritage Items and lists them as either Classified or Recommended. The following National Trust Items are near or within the Study area:

- Hunter River Estuary Landscape Conservation Area: including the remaining natural areas in the estuary of the Hunter River, which form a viable and diverse ecological unit still largely in an

undisturbed state and embracing Kooragang Island, Fullerton Cove and Hexham Swamp - Classified.

- Sandgate Cemetery - Classified

There are no statutory obligations of the applicant to include information or to notify the National Trust of the proposal. The National Trust may, however, provide submissions to the consent authority with regard to the application and its implications to items classified or recorded by the Trust.

2.7.5.5 *The Heritage Act 1977*

Section 57(1) of the *Heritage Act 1977* prohibits the carrying out of certain works likely to impact on a place, building, work, relic, moveable object, precinct, or land which is the subject of an interim heritage order or which is listed on the State Heritage Register unless the approval of the relevant approval body has been obtained.

There are no items within the project boundary which are the subject of an interim heritage order or which are listed on the State Heritage Register. Therefore the proposal does not require consent under the *Heritage Act 1977*.

2.7.5.6 *Fisheries Management Act 1994*

Section 201(1) of the *Fisheries Management Act 1994* prohibits the carrying out of “reclamation work” without consent except under the Authority of a permit issued by the Minister. However, s 201(2) provides that s 201(1) does not apply to work carried out, or authorised, by a relevant public authority. Public authority is defined by s 4 of the *Fisheries Management Act 1994* to mean “a person or body established or constituted by an Act for a public purpose, and includes a local government authority or a state-owned corporation.” The Hunter-Central Rivers Catchment Management Authority, the proponent of the proposal, is a public authority within the meaning of the *Fisheries Management Act 1994*. Therefore consent is not required under s 201(1) of the *Fisheries Management Act 1994*.

Section 205 of the *Fisheries Management Act 1994* prohibits a person from harming “marine vegetation” in a “protected area”, except under the authority of a permit issued by the Minister. Marine vegetation is defined to mean mangroves, seagrasses or any other marine vegetation declared by the regulations to be marine vegetation. A protected area relevantly means “land submerged by water (whether permanently or intermittently), being:

- (a) Crown land, or
- (b) land vested in a public authority, or
- (c) land vested in trustees for public recreation or for any other public purpose, or
- (d) land acquired by the Minister under Division 1 of Part 8.”

The proposal will result in significant vegetation changes within the swamp, however, the change will be from freshwater wetland species (such as *Phragmites*) to saltwater wetland species (such as mangroves and saltmarshes). As freshwater species are not included in the definition of marine

vegetation, the proposed change in vegetation will not ‘harm’ ‘marine vegetation’ in a ‘protected area’ as defined under the provisions of the *Fisheries Management Act 1994* Act. In fact, the project is aiming to re-establish ‘marine vegetation’, which has been lost in the past due to flood mitigation works and poor land management practices.

2.7.5.7 Roads Act 1993

Section 138(1)(a) of the *Roads Act 1993* provides that a person must not “carry out a work in, on or over a public road ... otherwise than with the consent of the appropriate roads authority”.

A number of public roads are located within the project boundary. Accordingly, the proposal will involve works for which consents under the *Roads Act 1993* are required. The “appropriate roads authority” for the roads shown on Diagram A (refer Figure 2.23), Diagram B and Diagram C (refer Figure 2.24) is the Newcastle City Council.

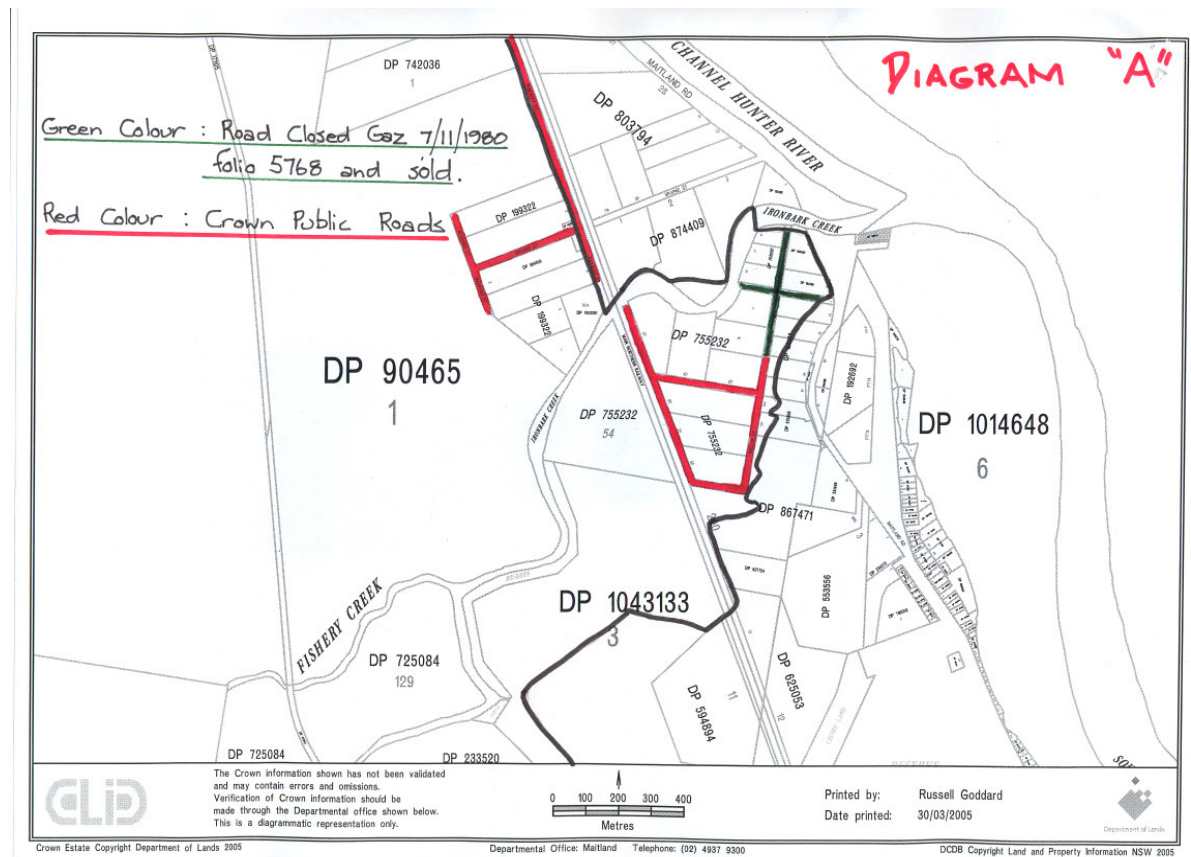


Figure 2.23 Council-controlled Public Roads (note text on figure is incorrect)

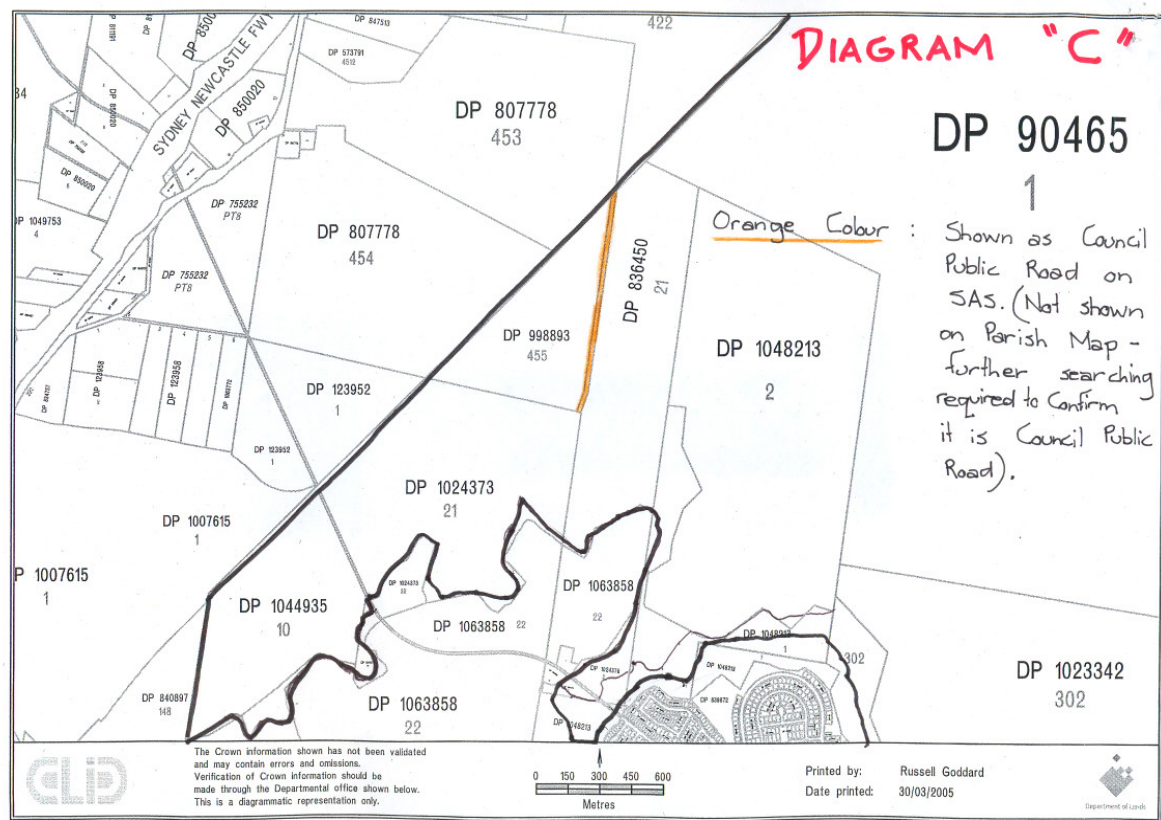
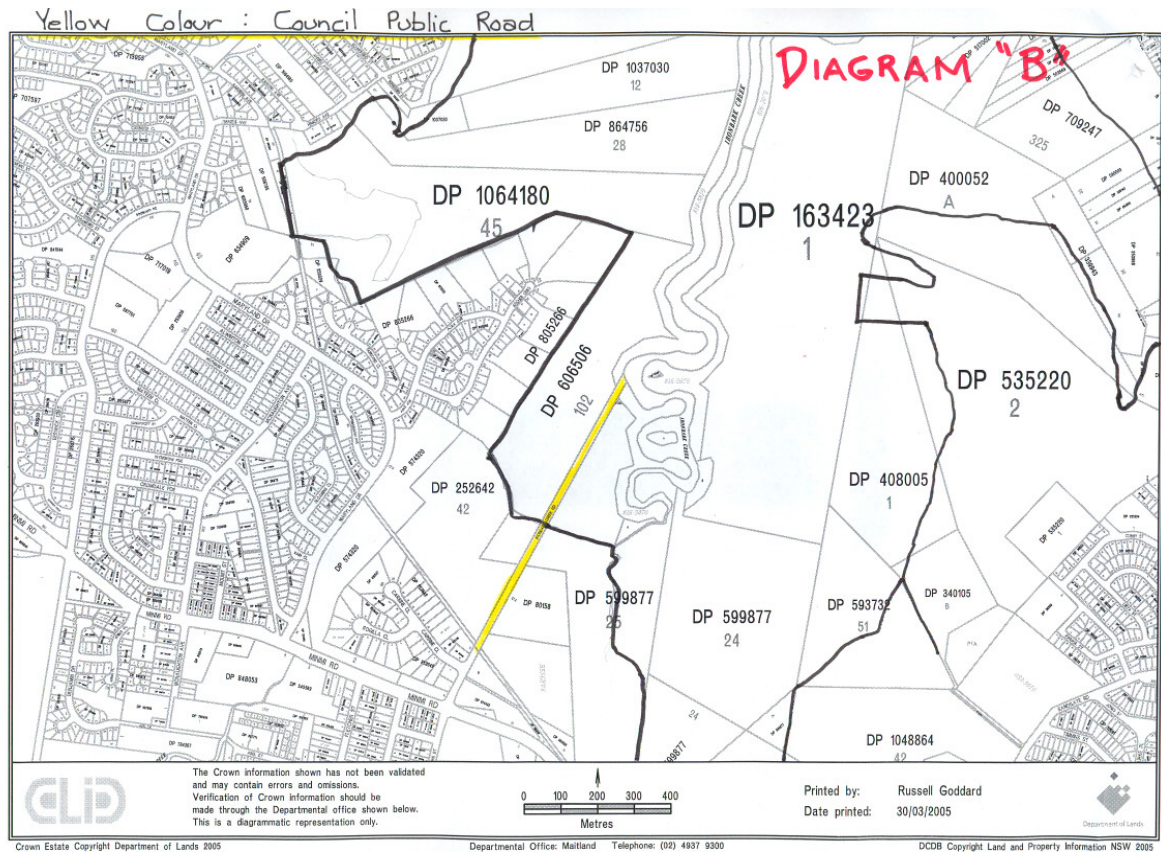


Figure 2.24 Newcastle City Council Public Roads

2.7.5.8 Water Management Act 2000

A flood work approval may be issued under s 90 of the *Water Management Act 2000*. The *Water Management Act 2000* defines a “flood work” to mean:

a work (such as a barrage, causeway, cutting or embankment):

- (a) that is situated:*
 - (i) in or in the vicinity of a river, estuary or lake, or*
 - (ii) within a floodplain, and*
- (b) that is of such a size or configuration that, regardless of the purpose for which it is constructed or used, it is likely to have an effect on:*
 - (i) the flow of water to or from a river, estuary or lake; or*
 - (ii) the distribution or flow of floodwater in times of flood;*

and includes all associated pipes, valves and equipment, but does not include any work declared by the regulations not to be a flood work.

The proposal will therefore involve flood works for which a flood work approval is required under the *Water Management Act 2000*.

2.7.6 Current Development Pressure

The south-eastern and southern margins of Hexham Swamp have been subjected to a variety of European impacts, including a municipal refuse dump, an industrial estate at Wallsend, a sewerage works (the Shortland Waste Water Treatment Works), a metal recycling facility, a private airfield, several parks/sportsgrounds, Wallsend Cemetery, and several radio masts. These facilities have often involved the encroachment of fill and the dumping of debris on the edge of the swamp floodplain. At the south-east corner of the swamp is The Wetlands Centre, formed on a number of reclaimed ponds. A major impact on the swamp margins has been from residential subdivisions established on higher slopes and ridges, often with yards extending downslope and onto the edge of the floodplain.

Drainage into the swamp from the numerous tributary creeks has been affected by the construction of roads and pipelines across the creeks which impedes natural flow regime and encourages the infilling and/or landscaping of the upstream channel to direct run-off from paved areas and to provide open recreational space.

The swamp floodplain has long been used for pastoral purposes, mainly the grazing of cattle and horses.

The area of western Newcastle surrounding Hexham Swamp to the south has been nominated under the Maryland Minmi Structure Plan (Newcastle Council, 1994) as a growth corridor for future residential development of the City.

This strategy of developing large tracts of land has implications for the environmental quality of the wetlands. However, as this increase in urban development surrounding the wetlands is allocated for land well above any high water or flood level designated for Hexham Swamp in general and Ironbark

Creek in particular, the implications of this urban expansion on the specific development as proposed in this application is minimal.

Essentially the development pressure experienced by the west of Newcastle is currently controlled adequately by the Newcastle LEP 2003 and the Maryland - Minmi Structure Plan.

2.8 Stakeholder and Community Consultation

2.8.1 Consultation with Stakeholders and Government Agencies

The Hexham Swamp Rehabilitation Project was formulated as part of the Ironbark Creek Total Catchment Management Strategy (ICTCMC, 1996). The Strategy was developed by the Ironbark Creek Total Catchment Management Committee, which contained representation from a broad range of local and state government agencies, as well as members of the community and stakeholder interest groups. The Ironbark Creek TCM Committee was replaced in 2002 by the Newcastle Catchment Management Forum, while a specific committee was also established to oversee the Hexham Swamp Rehabilitation Project. The Hexham Swamp Project Committee contains representatives from the community, as well as a broad selection of government agencies, including DPI (Fisheries), DIPNR, DEC (EPA and NPWS), DEH (federal), Newcastle City Council, Hunter Water Corporation and the HCRCMA. The Project Committee also contains representations from Landcare, commercial fishermen, Kooragang Wetlands Rehabilitation Project and the State Parliamentary Members for Port Stephens and Wallsend.

Formal consultation with stakeholders and Government agencies regarding the Hexham Swamp Rehabilitation Project commenced in 1998, with initial scoping requirements provided by each organisation consulted. These initial requirements are provided in **Appendix B: Volume 2**. These organisations have continued to be consulted during the development of the project proposal, both directly, and through the Newcastle Catchment Management Forum and the specific Hexham Swamp Project Committee.

All members of the Hexham Swamp Project Committee have had the opportunity to critically review a draft copy of this EIS, with considerable input provided by Craig Copeland and Bruce Pease of DPI (Fisheries).

Landholders within and around Hexham Swamp, including service providers, have received extensive consultation regarding the project, particularly in respect to the acquisition of land and easements. Numerous meetings have been held between the project team and owners of land and infrastructure located within the project boundary, including water, electricity, communications and rail corporations. Consultation has involved providing a description of the project and the predicted impacts of the works, and negotiation regarding proposed mitigation measures and/or compensation where the impacts would be detrimental to the owner.

2.8.2 Consultation with the Local Communities Surrounding Hexham Swamp

This project has largely been driven by the will of the wider Lower Hunter community and their desire to rehabilitate valuable wetlands that have been lost as a result of past land management actions. Consultation with the community has been facilitated through the Hexham Swamp Project

Committee, which includes several community representatives, as well as non-government stakeholders, such as commercial fishermen and Landcare groups.

Public meetings have also been held at a number of locations around Hexham Swamp (eg Shortland, Maryland) to provide information to the general community regarding the proposed project, and the ways in which the project would impact on them as local community members. Public meeting and workshops have been held regarding specific topics, including flooding, revegetation, habitat / ecology, and mosquitoes. Two public 'planting days' have also been organised as part of the community consultation program for this project. Between 10 and 30 people have typically attended each public event. A formal community consultation and communication plan has been prepared for the rehabilitation of Hexham Swamp (HCRCMA, 2004). This plan, which is reproduced in **Appendix N: Volume 2**, is currently being implemented by the HCRCMA, and will continue to be implemented before and after the opening of the floodgates in Ironbark Creek.

A series of public landholder meetings were also carried out at Shortland to agree on a proposed strategy for impact mitigation. As model predictions indicated saline inundation of several private properties along Marsden Street, this community was consulted regarding mitigation options. Through this community forum, it was decided that a low-level earthen bund will be constructed, to prevent saltwater intrusion onto private lands, but not to significantly inhibit or impede freshwater flooding. It was important to the residents that their existing usage of the private swamp land be retained.

2.9 Proposed Future Management of Hexham Swamp

A Plan of Management for Hexham Swamp has been developed by the HCRCMA, which sets out the proposed strategy for managing the area in the future. The existing Hexham Swamp Plan of Management (reproduced as **Appendix L: Volume 2**) runs from 2003-07. In preparing this document, it was anticipated that the first gate would be opened in early 2004, meaning that the Plan of Management would cover the first four years of management after the gates start to be opened. Given the delays in commencing the project and opening the gates, it is anticipated that any development consent conditions imposed by Council, as well as new information collected in the future, can be incorporated into the Plan when it is next reviewed (i.e. before 2007).

The Hexham Swamp Plan of Management is separated into a number of topics, similar to this EIS:

- Land acquisition, planning and future management;
- Flood risk and floodgate operation;
- Tidal inundation;
- Water quality;
- Creek erosion and sedimentation;
- Habitat;
- Pest and weed management;
- Fire;
- Access and infrastructure; and

- Community education and involvement and research.

For each of the abovementioned topics, the Plan of Management outlines the current status of the swamp, the future management problems, and the action required to resolve these problems. The problems and actions outlined in the Plan of Management relate to opening of the floodgates and the management requirements in response to the opening.

The Hexham Swamp Plan of Management is supported by a specific consultation and communications strategy, which is presented as **Appendix N: Volume 2**. Future management of the swamp will also be guided by the results of monitoring being carried out at present, and continuing in the future following opening of the gates. Meanwhile, management of the gates themselves will be carried out by the HCRCMA and DIPNR, to ensure that the existing level of flood mitigation is maintained, and that the inundation of tides into the swamp is also permitted in a controlled and adaptive manner.

3 DESCRIPTION OF THE EXISTING ENVIRONMENT

3.1 Location and History

3.1.1 Location

Hexham Swamp is located on a back plain on the true right bank of the Hunter River, approximately 15 kilometres upstream of the mouth of the River at the Port of Newcastle (refer Figure 1.1). The swamp is positioned on floodplain between the river and low hills along the Wallsend-Minmi (Nikkinba) ridge, which are subject to current development pressures. Hills surrounding the south eastern corner of the swamp, including the suburbs of Wallsend, Maryland and Shortland, and contain established urban development (refer Figure 3.1).

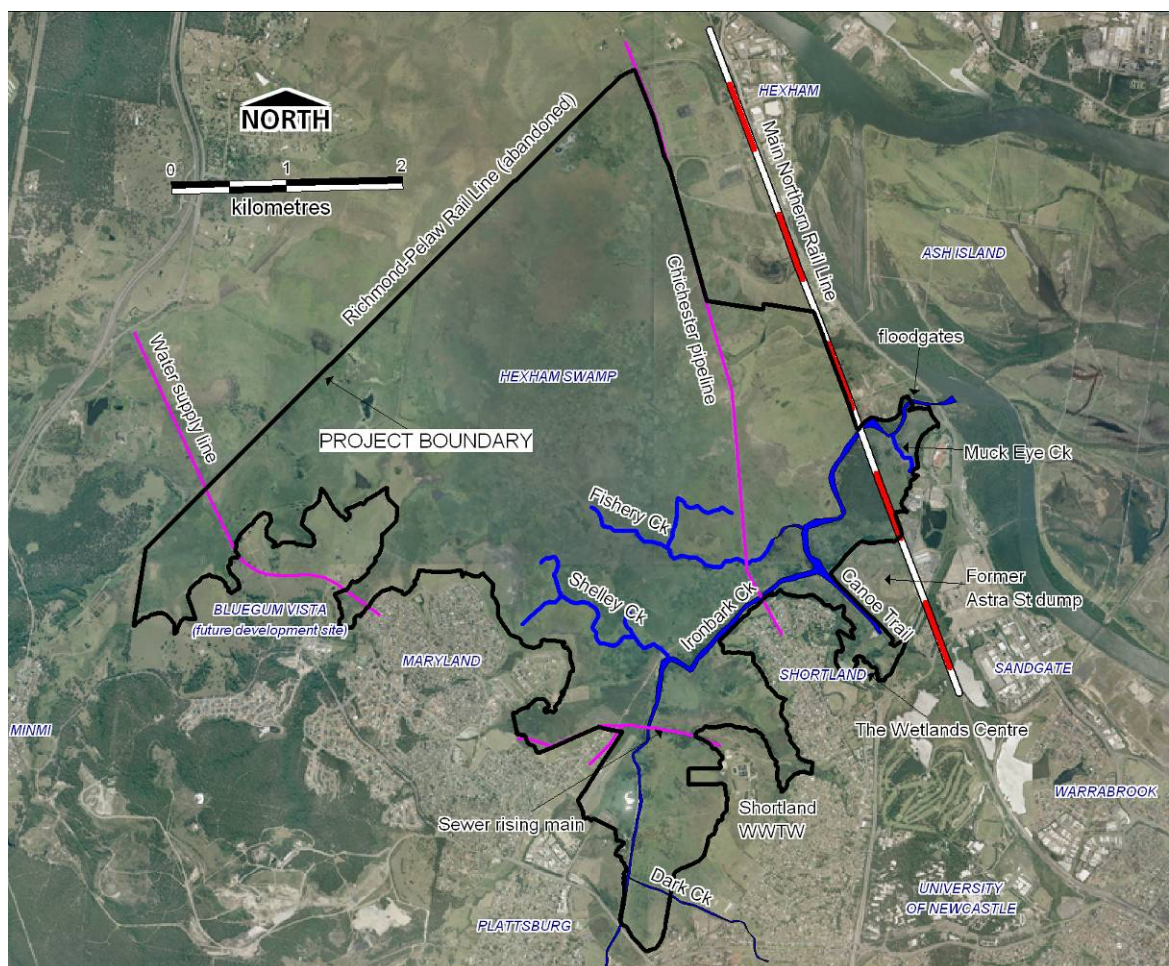


Figure 3.1 Hexham Swamp Locality Features

The swamp consists of two major sections that are hydrologically separated by the abandoned Richmond - Pelaw railway embankment. The area to the north-west of this embankment is drained by

Purgatory Creek, a tributary of the Hunter River, which enters the river upstream of Hexham Bridge. The area south-east of the embankment is drained by a number of small streams such as Fishery and Shelley Creeks. These creeks are tributaries of Ironbark Creek, which itself drains into the Hunter River approximately 4.5km downstream of Hexham Bridge. Other tributaries of Hexham Swamp include Wentworth Creek, Blue Gum Creek and Minmi Creek, which generally flow from the south-west.

For the purpose of this EIS, the *Project Area* includes all of Hexham Swamp to the south-east of the Richmond - Pelaw railway embankment, covering an area of approximately 1,946 ha (refer Figure 3.1). A list of properties located within the Project Area is provided in **Appendix J: Volume 2** of this document.

3.1.2 Recent History

Most early European use of the area was agricultural, based on the relatively fertile soils found on the floodplain. With continuing development of the area in the first half of the 20th century, a number of projects had a significant effect on the swamp (Ericsson, 1990). These included:

- A major railway corridor and its associated levee (1857);
- The Newcastle water supply pipeline including a levee and service track (1923-1960);
- The Richmond and Pelaw Main Colliery railway through the north-west of the Swamp;
- Installation of the eight floodgates at the mouth of Ironbark Creek (1970-1971);
- Urban and industrial development in the floodplain, including an airstrip for light aircraft (1972), a sewage treatment works, radio towers and a major refuse dump (Astra Street) with associated drainage and leachate ponds (1972);
- High voltage electricity transmission towers and service tracks (1982-1983); and
- Various road works around the Swamp.

Changes to the Lower Hunter River are also likely to have affected the hydrology of the swamp. Dredging of the Port of Newcastle, including large sections of the South Arm, along with other floodplain reclamation works on Kooragang Island, is likely to have increased the tidal range within the Hunter River estuary adjacent to the swamp. This would have increased tidal intrusion into the swamp, and inundated lands that had formerly been used for grazing (and hence the pressure from agriculturalists to construct floodgates at the mouth of Ironbark Creek).

The inflow of tidal water was restricted by the construction of levees along the Hunter River and the installation of floodgates near the mouth of Ironbark Creek in 1970-71. As a result, the area of tidally flushed wetlands has decreased substantially within Hexham Swamp allowing considerably greater use of the wetlands for seasonal grazing from spring to autumn.

The closure of the floodgates has been controversial from the outset, with adverse environmental conditions developing shortly after closure of the floodgates (DPW, 1972). The Ironbark Creek Total Catchment Management Committee released its Total Catchment Management Strategy in 1996, in response to the steady degradation of Hexham Swamp and surrounding catchments (ICTCMC 1996). This strategy is the platform for the current proposal.

3.2 Climate

The Hunter Valley is located in the transition zone between the northern and southern Australian climatic zones. It has temperate climatic conditions with conditions in some years resembling those of southern Australia (winter rain - summer drought) whereas in other years conditions resemble those of northern Australia (summer rain - winter drought).

Averaged climatic data (for the period 1862 to 2004) for Nobby's Signal Station are shown in Table 3.1. Average annual rainfall is moderate (1145 mm), with maximum rainfall generally occurring in autumn, and a minimum generally occurring around late winter - spring. Average temperatures vary from a mean daily maximum of 25.6 °C in January to a mean daily minimum of 8.4 °C in July.

Table 3.1 Averaged Climatic Data for Hexham Swamp (Source: BOM, 2005)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean daily max. temp. °C	25.6	25.4	24.7	22.8	19.9	17.4	16.7	18	20.1	22.1	23.5	24.9	21.8
Highest max. temp. °C	40.8	40.9	39	36.8	28.5	26.1	26.3	29.9	34.4	36.7	41	42	42
Mean daily min. temp. °C	19.1	19.3	18.2	15.3	11.9	9.6	8.4	9.2	11.4	13.9	16	18	14.2
Lowest min. temp. °C	12	10.3	11.1	7.4	4.7	3	1.8	3.3	5	6.5	7.2	11	1.8
Mean 9am relative humidity (%)	76	80	78	78	79	79	77	73	70	68	71	74	75
Mean 3pm relative humidity (%)	72	74	72	66	64	63	59	56	59	64	68	71	66
Mean rainfall (mm)	91.4	105.6	121.9	115.9	118.6	117.8	97.2	76.2	73.7	74.3	69.5	82.4	1144.6
Mean No. of raindays	11.1	11.1	12.2	11.9	12.1	11.7	10.8	10.3	10	10.9	10.5	10.5	133
Highest monthly rainfall (mm)	404	559.2	544.4	546.4	441.3	485.7	351.1	545.3	283.1	277.5	203.9	326.5	
Lowest monthly rainfall (mm)	2	0.5	2.8	0	2.1	3.6	0	0.8	1.6	4.6	2.4	4.6	
Highest recorded daily rain (mm)	144.8	252.7	283.7	231.1	181.9	190.3	118.6	168.9	157.5	96.5	103.7	177.5	283.7
Mean No. of clear days	6.3	5.3	6.4	7.4	6.9	7.5	9.7	10.8	9.3	7.4	5.5	6.3	88.7
Mean No. of cloudy days	12.4	12.1	11.7	10.7	11.9	11.7	9.5	8.3	9	12.1	12.3	11.7	133.4

During the warmer months from November to March, the prevailing winds blow from the south through to the north east, while during the cooler months from May to September the prevailing wind direction comes from the west and north west (DPW 1972). Both periods overlap the period of highest rainfall (from February to July), indicating that wind would be an important influence in determining the extent of mixing of any tidal water with freshwater runoff and direct rainfall inputs.

3.3 Hydrology

3.3.1 Hydrological Features of Hexham Swamp

Hexham Swamp is a major flood storage area on the south bank of the Hunter River between Tarro / Beresfield and Sandgate. The hydrology of the swamp is primarily controlled by major infrastructure levees across the low-lying floodplain, including the Main Northern Railway, the abandoned Richmond-Pelaw rail line, and the Hunter Water pipeline.

The majority of the swamp is drained by Ironbark Creek. A small section of the swamp on the northern side of the Richmond-Pelaw rail line is drained by Purgatory Creek, which discharges underneath the Main Northern Railway and New England Highway into the Hunter River. Another small section of the swamp in the north-east sector also drains to the Hunter River via an un-named tributary, discharging approximately 200 metres downstream of the Ash Island bridge. Tidal inundation of Hexham Swamp via this tributary is restricted due to structures under the Main Northern Railway and private property access roads. It is considered that this tributary would influence the hydrology of the swamp when the swamp is in major flood only.

The hydrology of Hexham Swamp is influenced by both the local urban developments on its peripheries and local catchment, and also the general development in the Lower Hunter Valley. The hydrology of the catchments draining to the swamp has been modified significantly through urbanisation. This has modified the quantity and quality of stormwater runoff from the catchment, and the critical time of concentration of flows. Urban catchments increase runoff by virtue of the increased impervious areas, and tend to provide a shorter response time by comparison with natural (vegetated) conditions.

3.3.2 Ironbark Creek Floodgates

As part of the Hunter Valley Flood Mitigation Scheme, floodgates were installed on Ironbark Creek upstream of the confluence with the south arm of the Hunter River in 1970-71. These gates impact the main drainage point for the swamp by:-

- restricting tidal waters from entering Ironbark Creek from the Hunter River; and
- marginally affecting the rate at which the swamp may drain after a flood event.

Prior to the installation of the Ironbark Creek floodgates, Hexham Swamp was a tidal wetland and daily tidal flows penetrated well into the swamp. Hence, many historical reports of flooding have been influenced by tidal processes. After installation of the floodgates, tidal effects within the swamp have been significantly reduced, while catchment developments have continued to increase pressure on the systems through increasing runoff flows and pollutant loads.

The floodgates and associated levee system were built to reduce nuisance Hunter River flooding of the area, and to restrict saline intrusion of low-lying farmlands around the swamp margins. The floodgates only afford protection to Hexham Swamp from Hunter River floods for events up to about the 1 in 10 year ARI (10% AEP). Beyond this level, the floodgates and associated levee system are overtopped by flooding from the Hunter River.

The floodgates consist of eight box culverts (2.13m wide x 2.13m high) each with a heavy, hinged flap gate on the Hunter River side.

The primary residual effects resulting from the construction and present operation of one-way floodgates and levee banks at the mouth of Ironbark Creek are:

- a lowering of the water table adjacent to Ironbark Creek (during persistent dry conditions);
- restricted saline waters entering the swamp area; and
- general stagnation of water behind the floodgates (although the one partially open gate prevents complete stagnation of the water).

3.3.3 Hexham Swamp Inundation Mechanisms

The hydrological / flooding regime of Hexham Swamp is complex, and influenced by a number of different and independent mechanisms, including:

- floodwater inundation from elevated flood levels in the Hunter River which overtop the levee between the Hexham Swamp and the River;
- freshwater runoff from Hexham Swamp's catchments (eg. Ironbark Creek, Wentworth Creek, Dark Creek);
- saltwater inundation from normal tidal variations in the Hunter River (assuming one or more of the Ironbark Creek floodgates are opened);
- saltwater inundation from elevated tidal levels in the Hunter River (assuming one or more of the Ironbark Creek floodgates are opened) due to atmospheric conditions (eg. tropical low pressure systems) or tidal anomalies;
- rainfall on the swamp itself; and
- a combination of any of the above.

The principal mechanisms are discussed in more detail below.

3.3.3.1 Hunter River Floods

The Lower Hunter River Flood Study indicates that the 1 % AEP Hunter River flood level in Hexham Swamp is 3.5 m AHD (PWD, 1994). This flood level would penetrate well into the Wallsend urban area, with Federal Park being completely inundated to a depth of over 1.0 m.

The Lower Hunter River Flood Study also indicates that the local catchment runoff (with a critical duration of 36 hours) has little impact on Hexham Swamp flood levels in the situation where the swamp is filled by a major Hunter River flood overtopping the levee system.

Flood levels in the Hunter River adjacent to Hexham Swamp are presented in Table 3.2, as taken from the Lower Hunter River Flood Study (PWD, 1994). Overtopping of the Ironbark Creek floodgates and associated levee system along the River will occur at a level of approximately 1.8m AHD, meaning that flooding from the Hunter River into Hexham Swamp should occur about every 8 to 10 years or so, on average. This is consistent with previous estimates made by DPW (1972) of overtopping every 8 years, on average.

During major Hunter River floods (which result in significant overtopping of riverbanks and overland flow along the floodplains), Hexham Swamp will receive flood flows from the north-west, which pass under the abandoned Richmond-Pelaw rail-line following river break-out in the vicinity of Purgatory Creek. The Hunter River Flood Study (PWD, 1994) indicates that during a 1% AEP (1 in 100yr ARI) event, approximately 33% of the total Hunter River flow would pass through Hexham Swamp via this flowpath. During a 2% AEP (1 in 50yr ARI) event, approximately 17% of total river flow would enter Hexham Swamp, while during a 5% AEP (1 in 20 yr ARI) event, just 8% of total river flow would enter Hexham Swamp from the Purgatory Creek floodplain (PWD, 1994). Floods smaller than the 5% AEP event were considered by PWD (1994) not to flow into Hexham Swamp from the north-west, under the Richmond-Pelaw rail-line.

Water level monitoring has been carried out by MHL at Hexham Bridge since 1985. Over this period, river levels have only reached a maximum of 1.66m AHD (on 5 February 1990), while levels in excess of 1.44m AHD (the 20% AEP level, from PWD, 1994) have only occurred on six occasions (Feb. 1990 – peak = 1.66m; May 2001 – peak = 1.57m; Aug. 1998 – peak = 1.54m; Oct. 1985 – peak = 1.51m; Mar. 2001 – peak = 1.51m; and Jun. 1989 – peak = 1.47m). Given the bias towards low-level flooding in recent times, the community surrounding Hexham Swamp may have an unbalanced and incorrect perspective regarding the flood liability of Hexham Swamp and the Hunter River floodplains.

Table 3.2 Hunter River Flood Levels adjacent to Hexham Swamp

Flood Event	Peak Flood Level
1% AEP (1 in 100yr ARI)	3.5m AHD
2% AEP (1 in 50yr ARI)	2.6m AHD
5% AEP (1 in 20yr ARI)	2.3m AHD
10% AEP (1 in 10yr ARI)	1.9m AHD
20% AEP (1 in 5yr ARI)	1.4m AHD

Source: Lawson and Treloar, 1994

3.3.3.2 Local Catchment Runoff

Local Catchments

The Ironbark Creek catchment is the main watershed draining to Hexham Swamp, with an area of approximately 1250 ha (upstream of Minmi Road). The catchment has been extensively developed and is almost fully urbanised, except for parts of the upper catchment (refer Figure 3.2). The commercial centre of Wallsend lies at the base of the catchment on low-lying flood liable land.

Ironbark Creek continues through Hexham Swamp, picking up inflows from Dark Creek, Shelley Creek and Fishery Creek.

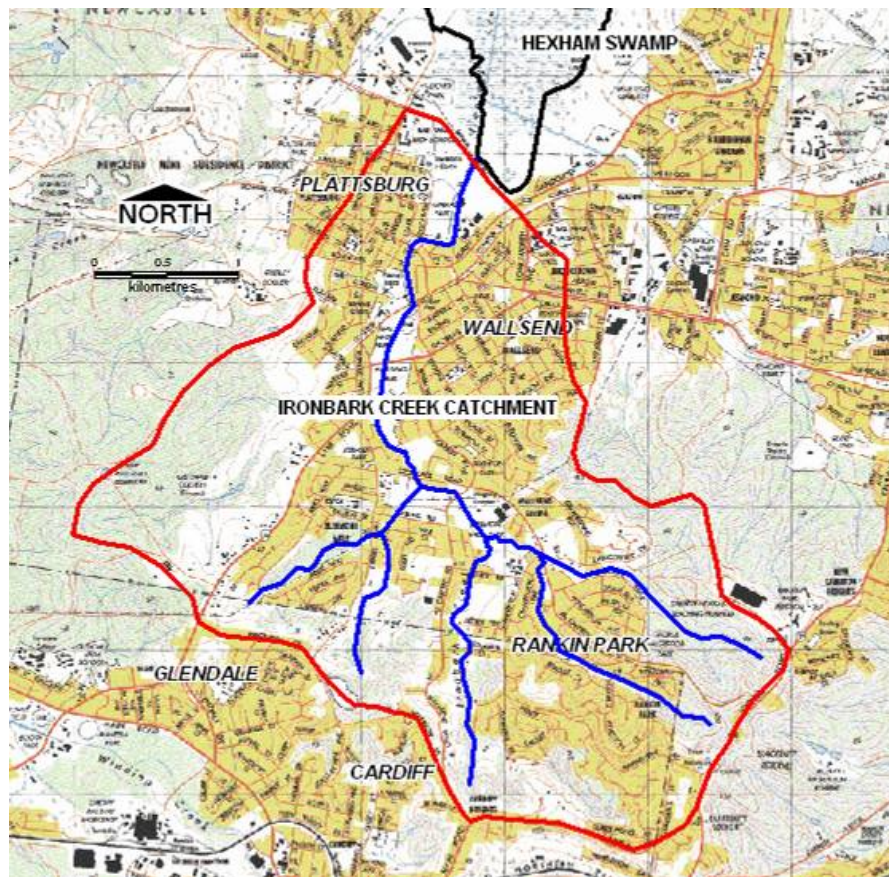


Figure 3.2 Ironbark Creek Catchment, upstream of Minmi Road

Dark Creek is the second largest urban catchment draining to Hexham Swamp, with an area of approximately 610 ha above Sandgate Road. The lower half of the catchment has been extensively developed (refer Figure 3.3). The commercial area of Jesmond on Bluegum Road lies on a low-lying section of the catchment at the base of the steeper upper catchment areas.

Other catchments, mostly to the south and east of Hexham Swamp, also drain to the Swamp and are relatively undeveloped (with the exception of the lower sections of Minmi Creek and Sandgate). These catchments are presented in Figure 3.4. Increasing urban development in the Wentworth Creek, Minmi Creek and Maryland Creek catchments represents one of the main threats to the future ecological sustainability of Hexham Swamp.

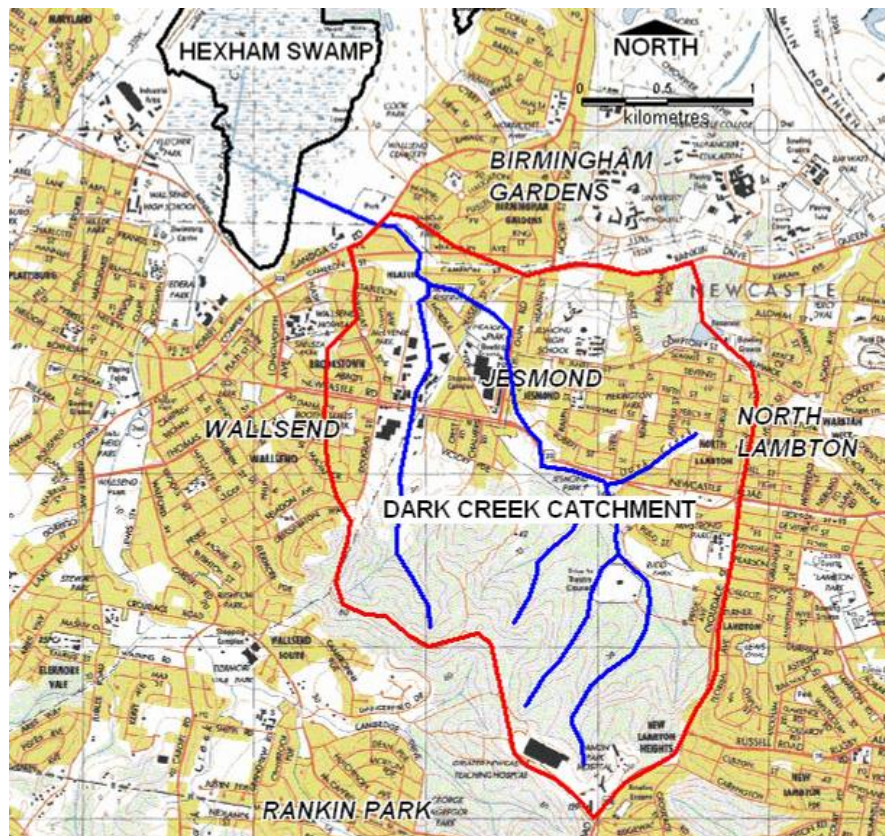


Figure 3.3 Dark Creek Catchment, upstream of Sandgate Road

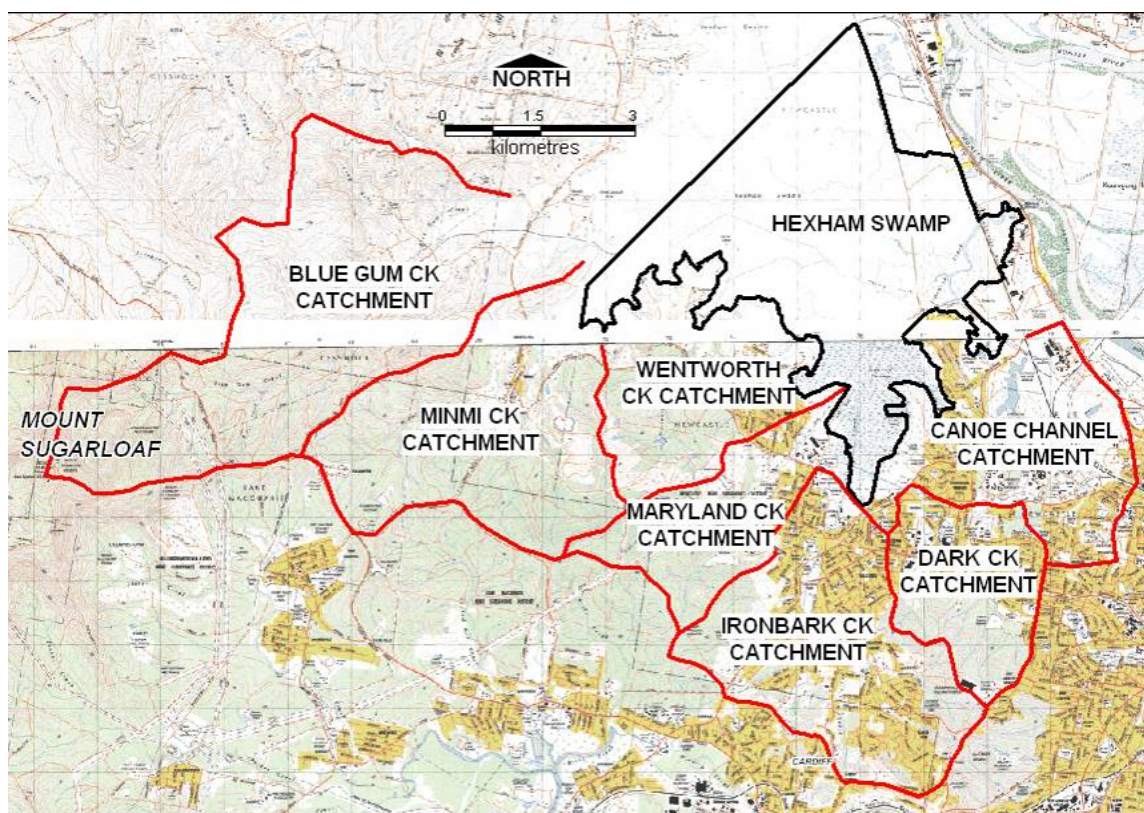


Figure 3.4 Local Catchments of Hexham Swamp

Flooding From Local Runoff

A number of studies have been carried out on the flooding characteristics of Ironbark Creek and Hexham Swamp. The Hexham Swamp Inundation Study (Lawson and Treloar 1993) reported peak flood levels in Hexham Swamp for the floodgate arrangement at the time (i.e. one gate opened 0.15m). The critical duration rainfall event for Hexham Swamp was determined by Lawson and Treloar to be the 36 hour event. Peak flood levels in Hexham Swamp, as presented in the Inundation Study, are outlined in Table 3.3.

Table 3.3 Peak Flood Levels from Local Runoff (source, Lawson and Treloar, 1993)

Flood Event	Peak Level in Hexham Swamp (mAHD)
1 % AEP with Spring tide	1.77
1 % AEP with Neap tide	1.76
5 % AEP with Spring tide	1.61
5 % AEP with Neap tide	1.59

It is apparent from the above results that the state of the tide has little influence on the peak flood level for major flood events.

A flood study has also been carried out for Ironbark Creek, upstream of Minmi Road on behalf of Newcastle City Council (NCC, draft 2003). This study indicates that local floods in the Ironbark Creek catchment have a significant potential to generate flood hazards within the Wallsend business district, and along Croudace Road. Floodplain works within the catchment, such as wetlands construction, could reduce flood hazard for minor flood events, but not for major events (Newcastle City Council, draft 2003).

The Newcastle Flood Information Atlas (NCC, draft 2003) indicates that Dark Creek also contains areas of high flood hazard. Bluegum Road, First Street and Steel Street in Jesmond would be susceptible to deep and fast flowing flood flows.

The Ironbark Creek Total Catchment Management Study (ICTCMC, 1996) investigated flooding of the local catchments using the Lawson and Treloar hydrologic and hydraulic models (Lawson and Treloar, 1993). Table 3.4 shows the impact of local catchment runoff in terms of resulting catchment runoff volumes and water level increases in Hexham Swamp for a range of design storm conditions.

Overall, it is concluded that the flood levels in Hexham Swamp generated by local catchment runoff are significantly lower than the levels associated with inundation from flooding of the Hunter River (refer Table 3.2), however, the operation of the floodgates prevents Hunter River floods from entering Hexham Swamp until flooding in the Hunter River exceed the approximate 1 in 10yr ARI level (refer Section 3.3.3.1).

Table 3.4 Design Storm Volumes in Hexham Swamp (from ICTCMC, 1996)

Frequency	Volume of Catchment Runoff (m ³)	Rise in water levels in Hexham Swamp (= volume of catchment runoff / area of Hexham Swamp*), (m)
1% AEP	12,000,000	0.60
2% AEP	11,200,000	0.56
5% AEP	9,200,000	0.46
10% AEP	7,700,000	0.39
20% AEP	6,600,000	0.33
PMF	55,800,000	2.79

* Area of Hexham Swamp assumed to be 20km².

3.3.3.3 Astronomical Tides

The ingress of normal tidal flows from the Hunter River into Ironbark Creek is significantly attenuated by the floodgates at the entrance of the creek. At present, one of the eight floodgates is open two notches (approximately 0.30 m) and allows a small amount of tidal water to pass into and out of Ironbark Creek. These tidal flows do not presently overtop the banks of Ironbark Creek or its tributaries.

Current water levels variations within Ironbark Creek are generally in the range 0.2m AHD to -0.4m AHD. Tidal analyses of water level recorders located within Ironbark Creek have been carried out by Manly Hydraulics Laboratory (MHL, 2004), and are summarised in Table 3.5 and Figure 3.5. This analysis shows that the typical tidal range within Hexham Swamp is about 0.2 to 0.4 metres, while the mean water level (half tide level) is below the mean level of the ocean, with a value of approximately -0.1 to -0.15m AHD.

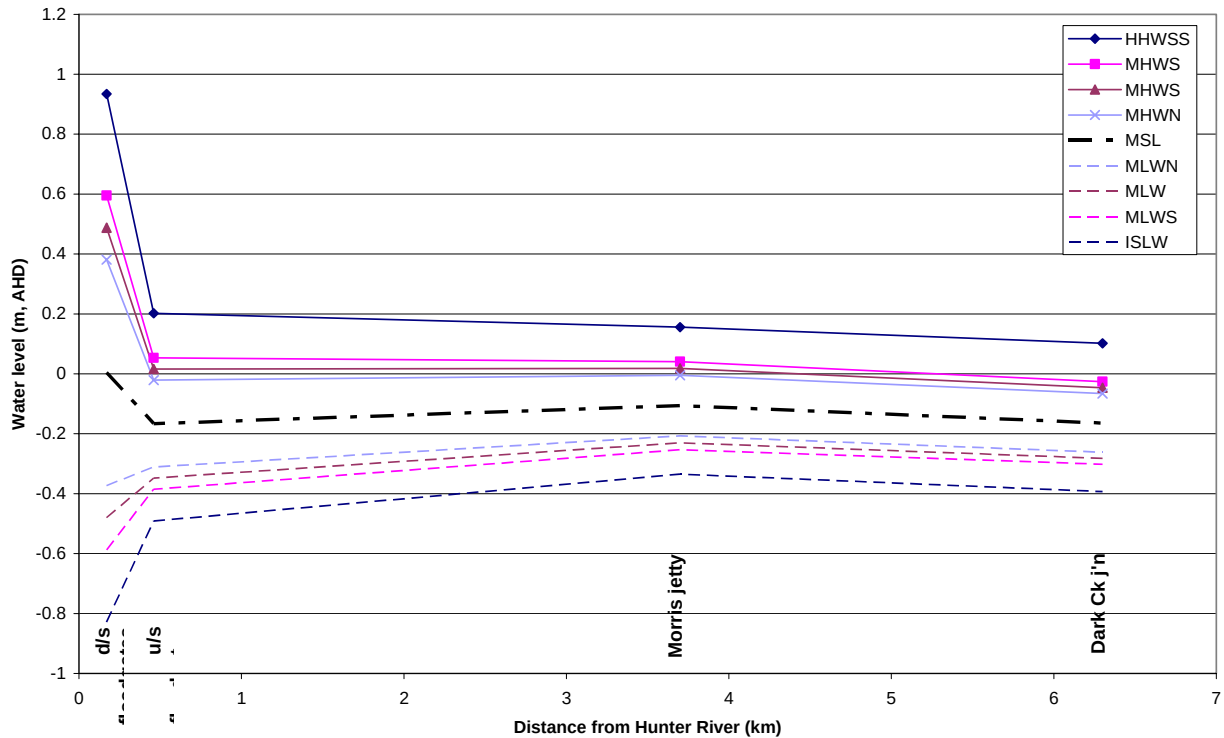


Figure 3.5 Tidal Planes for Ironbark Creek (source: MHL, 2004)

Table 3.5 Tidal Planes for Sites within Ironbark Creek (metres, AHD)

	Downstream of floodgates	Upstream of floodgates	Morris Jetty	Dark Creek junction
Distance from Hunter River (km)	0.17	0.46	3.7	6.3
High High Water Solstice Springs (HHWSS) = peak king tide level	0.934	0.202	0.156	0.102
Mean High Water Springs (MHWS) = average high water level during spring tides	0.595	0.053	0.041	-0.026
Mean High Water (MHW) = average high water level during all tides	0.488	0.016	0.018	-0.046
Mean High Water Neaps (MHWN) = average high water level during neap tides	0.381	-0.021	-0.005	-0.066
Mean Sea Level (MSL) = average water level	0.004	-0.166	-0.106	-0.164
Mean Low Water Neaps (MLWN) = average low water level during neap tides	-0.373	-0.311	-0.207	-0.262
Mean Low Water (MLW) = average low water level during all tides	-0.48	-0.348	-0.23	-0.282
Mean Low Water Springs (MLWS) = average low water level during spring tides	-0.588	-0.385	-0.253	-0.302

	Downstream of floodgates	Upstream of floodgates	Morris Jetty	Dark Creek junction
Indian Springs Low Water (ISLW) = lowest low water level during king tides	-0.829	-0.491	-0.335	-0.393
<u>Ranges (m)</u>				
King (solstice)	1.763	0.693	0.491	0.494
Mean Spring	1.183	0.438	0.295	0.276
Mean	0.968	0.364	0.248	0.236
Mean Neap	0.754	0.290	0.202	0.196

Source: MHL, 2004

3.3.3.4 Flooding from High Ocean Water Levels

Elevated ocean water levels above normal tidal levels can occur at the shoreline or in entrances of estuaries or lakes, and can result in inundation or flooding of low-lying lands surrounding the waterway. The main components of this increased water level include wind setup, wave setup and inverse barometric setup (i.e. low atmospheric pressure will raise ocean levels), all of which can be associated with severe coastal storms. This abnormal elevation is typically characterised by a relatively rapid increase to a peak followed by a subsequent decline over periods up to 3 days. This elevation is super-imposed upon the normal tidal variation. The probability of the peak elevated ocean level occurring at similar times to peak water levels due to catchment runoff depends on the response time of the catchment, and the duration of the elevated ocean levels assuming that both conditions are caused by the same meteorological storm. This assumption of a common storm is not always valid or if so, not necessarily representative of the most severe conditions.

The Lower Hunter River Flood Study (Lawson and Treloar, 1994) analysed the Port of Newcastle tide data and concludes that the 1% elevated ocean water level is 1.34 m AHD, which is 0.74m higher than MHWS level, and 0.34m higher than the Highest Astronomical Tide (HAT) level at Newcastle. The ocean level was based on nearly 20 years of tidal level information, and does not include wave and wind setup components, as the entrance to the Port is very deep and is not subject to these shallow water influences. The highest water level recorded at the Port of Newcastle was 1.37 m AHD on 26th May, 1974, caused by extreme ocean conditions. No coinciding flood was recorded in the Hunter River at that time.

Analysis of the water level recorder downstream of the Ironbark Creek floodgates (which is typical of the conditions in the Hunter River immediately adjacent to Hexham Swamp), shows that the maximum typical spring tide level (MHWS) is RL 0.60 m, AHD, while the typical king tide level downstream of the gates is approximately RL 0.93 m, AHD. These levels are consistent with records for Newcastle Harbour, and indicate that there is little tidal attenuation through the 14km of river between the Harbour entrance and the Ironbark Creek confluence.

Greenhouse Effect

The term 'Greenhouse Effect' relates to projections by atmospheric scientists that an increase in the concentration of particular gases in the atmosphere will lead to an increase in the earth's temperature.

There appears to be substantial agreement that this is occurring, but with wide variation in the projections of the rate of change. Predicted consequential effects that impact on coastal and floodplain management include sea level rise and an increase in frequency and intensity of storms and floods.

The latest projections by Working Group I of the Intergovernmental Panel on Climate Change (IPCC) released a report in 2001 (IPCC, 2001). Table 3.6 presents three values representing the IPCC 2001 low, medium and high extents of expected sea level rise. High values include an allowance for the melting of glaciers and ice sheets.

Any rise in oceanic water level would translate to an equivalent rise in mean water level within Hexham Swamp, which would then have follow on effects on groundwater levels, vegetation communities and overall flood liability (due to reduced flood storage capacity within the Swamp).

**Table 3.6 Projected Sea Level Rise due to Greenhouse Effect relative to 2000
(source, IPCC, 2001)**

Year	Low Estimate (m)	Medium Estimate (m)	High Estimate (m)
2020	0.02	0.06	0.08
2050	0.08	0.16	0.29
2100	0.19	0.48	0.84

Adopting the high estimate of sea level rise, it is possible that the ocean level attained by the 1974 storm (i.e. 1.37m AHD – refer above discussion), which is currently considered to be a 1% (or 1 in 100yr) event, could be reached on an annual basis by the year 2050, or could be reached daily by the year 2100.

Other projections relating to climate change relevant to the Hexham Swamp area are documented in CSIRO (Hennessy *et al.*, 2004), and include increasing temperatures and reduced rainfall.

It is expected that sea level rise will have significant impacts on the Lower Hunter Estuary, as it is fringed by substantial areas of low-lying wetlands, which are backed by formal levees and infill in many areas. A general upward shift in water levels will result in a transition of existing saltmarsh land to mangroves, while current low-lying floodplain may become more salt affected, and revert to saltmarsh-dominated vegetation. Given the proliferation of levees and infill along the estuary, however, saltmarsh communities will be unable to migrate up-slope at all locations. Therefore, it is expected that the rise in sea level will reduce the extent of saltmarsh communities within the Lower Hunter Estuary.

With regard to Hexham Swamp, sea level rise increases the ‘marinisation’ of the swamp, with an expected long-term increase in mangroves, while tidal inundation and saltmarshes communities would likely spread to more upstream sections of the swamp. The crest level of proposed bunds would need to be raised to ensure that they are not overtopped. It may be possible to mitigate some of the effects of sea level rise in Hexham Swamp through management of the floodgates (i.e. sequentially close off floodgates to limit the additional tidal inundation experienced by the higher

tidal levels in the river. Given the expected loss of saltmarsh from the Lower Hunter Estuary in general, restoration of this community type as part of the Hexham Swamp Rehabilitation Project is considered to be a pro-active measure at combating the expected effects of future sea level rise.

3.4 Water Quality

Historical information on water quality within Hexham Swamp is presented in Section 3.4.1, while results from current water quality monitoring programs are detailed in Section 3.4.2.

A summary of the water quality results and an overview of the important water quality processes occurring within Hexham Swamp are provided in Section 3.4.3.

3.4.1 Previous Studies of Water Quality in Hexham Swamp

Numerous water quality studies have been carried out in Hexham Swamp and Ironbark Creek, all of which have been undertaken since the installation of the floodgates in 1970/71. A review of available water quality information is provided below.

3.4.1.1 SPCC / EPA Data 1967-1997

Water quality data was obtained from the DEC (formerly EPA) for Ironbark Creek, Hexham Swamp and the Hunter River (in the vicinity of the Ironbark Creek junction) (refer Figure 3.6, Figure 3.7, and Figure 3.8). Some of the earlier data was considered by the EPA to be of varying quality, and contained provisos that results should be interpreted considering this varying quality. Nonetheless, the data record gives some indicative information on the water quality in these waterbodies over the last thirty years.

Although no comparative data are available before the floodgate installation, the available physical water quality data from the Hunter River and Hexham Swamp/Ironbark Creek show some differences in water quality. As expected, salinity is typically lower in Hexham Swamp/Ironbark Creek than in the Hunter River, which is attributed to the floodgates limiting tidal flow to the creek and swamp areas.

Dissolved oxygen concentrations in the Hunter River are typically above the ANZECC (2000) trigger value for estuaries of 80% saturation for the protection of aquatic ecosystems. Concentrations in Hexham Swamp/Ironbark Creek are above the trigger value for approximately half the time, although the data were daytime concentrations, which would be expected to be higher than overnight concentrations due to photosynthesis of algae within the water column. It would be expected that if overnight concentrations were included, concentrations would have a much larger variation.

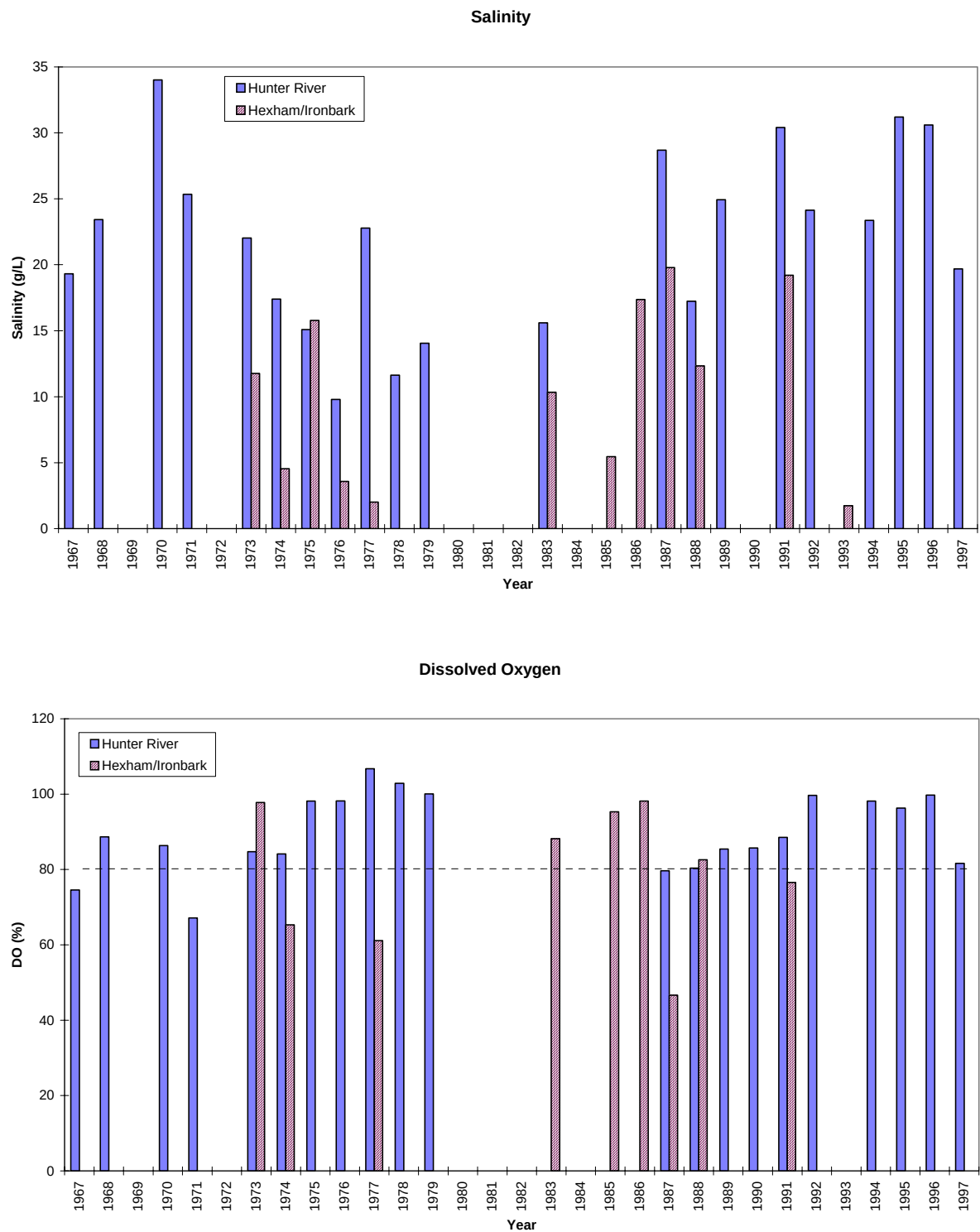


Figure 3.6 Salinity and DO in Hexham Swamp and the Hunter River (source: SPCC / EPA)

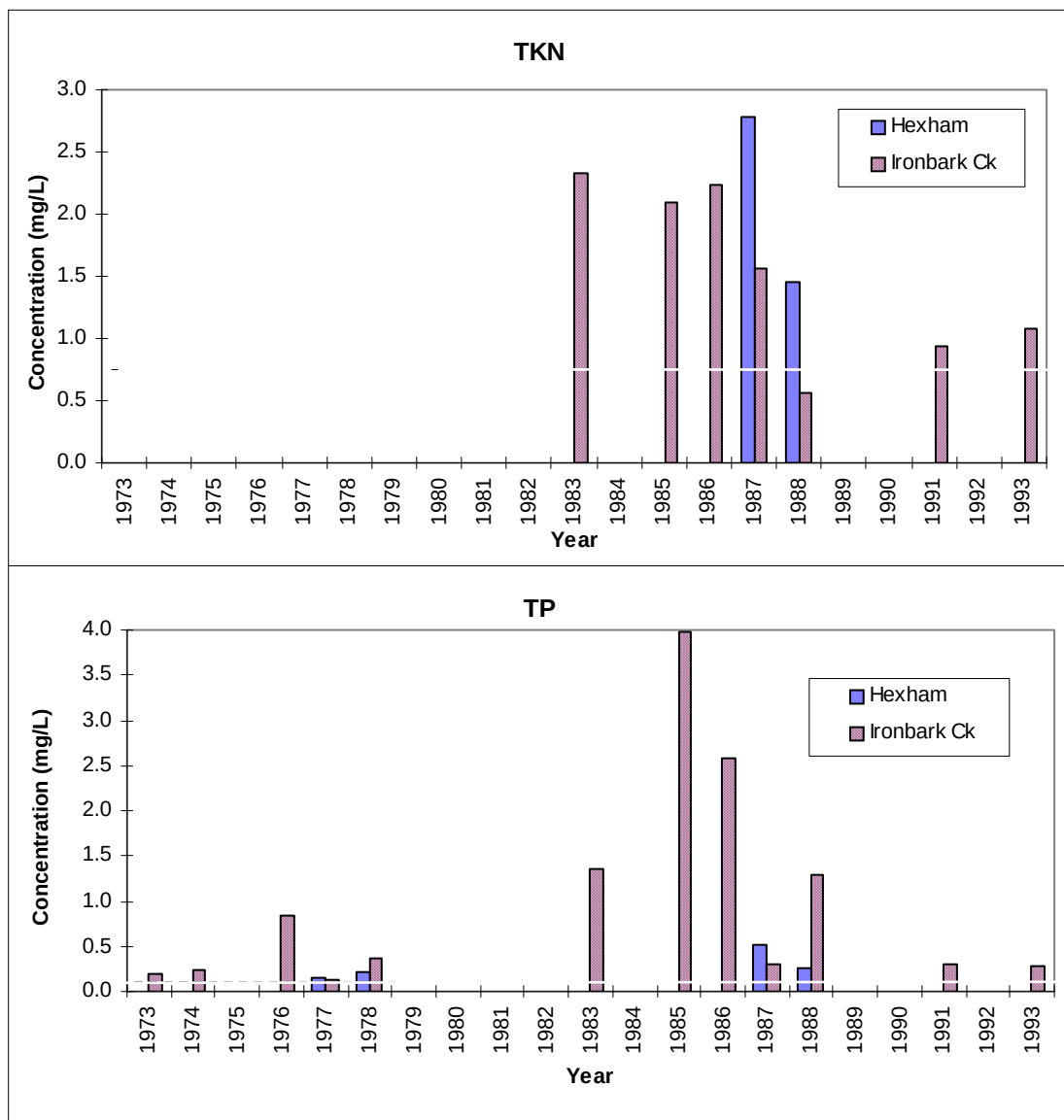


Figure 3.7 Nutrient Data in Hexham Swamp (source: SPCC / EPA)

No comparative chemical data between the river, the wetland and the creek were available, although comparative data between Hexham Swamp and Ironbark Creek were examined. Concentrations of nutrients (both nitrogen and phosphorus) were elevated, with ANZECC (2000) trigger value for estuaries of 300µg/L for total nitrogen and 30µg/L for total phosphorus frequently exceeded. No distinct trend in nutrient concentrations could be observed, due to the limited dataset, however, more recent data suggests that nutrient concentrations appear to be lower than 1980's data.

Chlorophyll *a* concentrations (an indicator of algal productivity) exceeded the ANZECC (2000) trigger value for estuaries of 4µg/L for the protection of aquatic ecosystems for all years based on

available data. This indicates that Ironbark Creek can support large numbers of algae, and taking into account the high nutrient concentrations recorded in the creek, the possibility for algal blooms exists.

Water turbidity (measured by total suspended solids (TSS) concentrations) appears to be reasonably low in the creek and swamp, with few concentrations greater than 20mg/L recorded.

Overall, the SPCC/EPA data indicate that water quality in Hexham Swamp/Ironbark Creek is poor. The water quality in the Hunter River is not well described by the available SPCC/EPA data, although dissolved oxygen concentrations indicate reasonable water quality, with no significant supersaturation or oxygen depletion, which may otherwise indicate excessive algal populations.

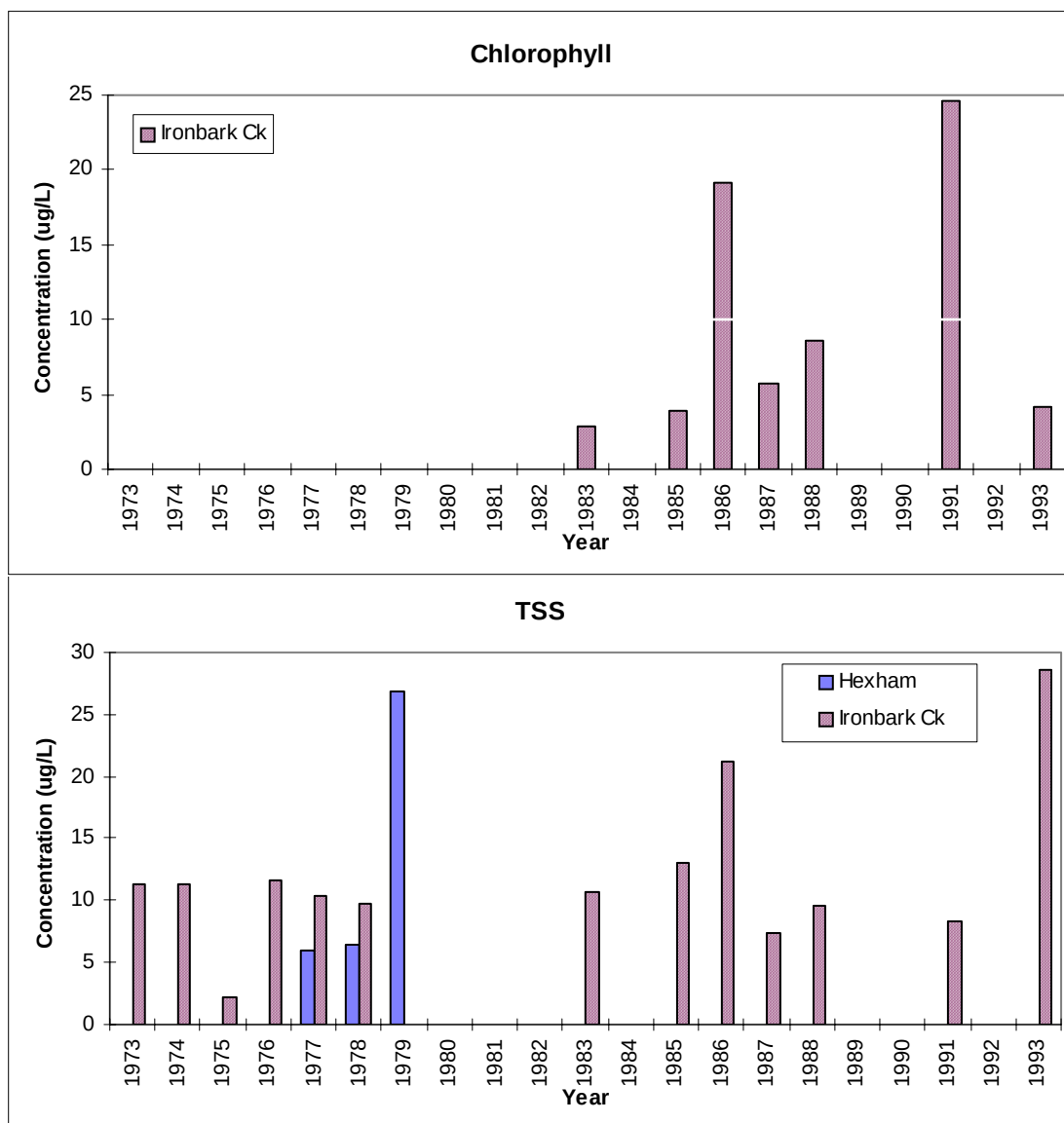


Figure 3.8 Chlorophyll-a and TSS Data for Hexham Swamp (source: SPCC / EPA)

3.4.1.2 NSW Department of Health (1973)

The NSW Department of Health assisted in the preparation of an Environmental Impact Statement for the Flood Mitigation Works at Hexham Swamp (NSW Department of Health, 1973), which addressed potential water quality impacts from the flood mitigation works.

Water quality investigations were undertaken in January 1973, in order to determine the water quality in Ironbark and Purgatory Creeks. This water quality survey indicated dissolved oxygen concentrations in the creeks were high, with a maximum of 142% recorded. The elevated dissolved oxygen concentrations were attributed to high algal growth in some locations of the creek. Suspended solids concentrations ranged from 1 to 13mg/L and 8 to 80mg/L in Ironbark and Purgatory Creeks respectively.

Ammonia concentrations ranged from 0.06-0.19mg/L and 0.01-0.04mg/L in Ironbark and Purgatory Creeks respectively. Albuminoid nitrogen (believed to be dissolved, organic N) ranged from 0.06-0.11mg/L and 0.07-1.4mg/L in Ironbark and Purgatory Creeks respectively. Total phosphorus concentrations in Ironbark Creek ranged from 0.06-0.3mg/L with a greater range (0.05-0.5mg/L) observed in Purgatory Creek.

Examination of stormwater inflows to the creeks in the EIS indicated that stormwater was “natural runoff and contained no pollutants”. Suspended solids concentrations were generally low (<20mg/L) in the inflows that were monitored, except in the samples from waters adjacent to the washery settling pond (164 and 5,550mg/L). Total phosphorus concentrations in the inflow samples were low, with concentrations ranging between 0.03 and 0.08mg/L (although no nutrient analysis was undertaken of coal washery samples). Nitrogen concentrations were low in the inflow samples, with ammonia concentrations of 0.07mg/L, and albuminoid N between 0.03 and 0.04mg/L.

Major sources of pollutants identified by the EIS included the Shortland sewage treatment plant and intermittent discharges from the coal washery settling ponds.

The study concluded “existing water quality is satisfactory and is appropriate for the maintenance of all previous beneficial uses” (NSW Department of Health, 1973). Additionally the study stated that there was “no evidence that construction of the floodgates on Iron Bark [sic] and Purgatory Creeks had an adverse effect on the quality of waters in these creeks”.

3.4.1.3 McGregor (1979)

McGregor undertook a study between 1977 and 1979 in Hexham Swamp/Ironbark Creek, as part of his Masters Thesis. This study included investigation of water quality in the areas upstream and downstream of the floodgates, when one floodgate was progressively opened and closed. It should be noted that the scenario McGregor studied (one gate partially open) is currently the state in which the floodgates exist.

The changes in salinity during periods when the gate was open and closed were observed by McGregor, and showed that one open gate allowed saline waters (of 20g/L) to penetrate 3.5km upstream of the gates. Closure of the floodgate resulted in an essentially freshwater system upstream of the floodgates. After closure of the gate, saline stratification upstream of the floodgates was

observed, which slowly dissipated until sufficient freshwater inflows occurred to eliminate the stratification.

McGregor found dissolved oxygen concentrations in the creek to be quite high, with lower concentrations recorded at all sites when the gates were closed. More stable conditions (from a dissolved oxygen perspective) were observed when one gate was partially open. McGregor stated that the dissolved oxygen supersaturation (observed on various occasions, at all sites upstream of the floodgates) was caused by excessive algal growth. Overnight dissolved oxygen concentrations were less than 60% at all sites upstream of the floodgates, which was likely to have been caused by algal respiration. Low dissolved oxygen concentrations were also observed in saline waters in stratified areas.

Total Phosphorus (TP) concentrations below the floodgates decreased upon closure of the gate, whilst upstream of the gates, total phosphorus levels generally increased. The apparent decrease in TP at Station 90 (near the confluence of Shelley and Ironbark Creeks) was thought to be attributed to the augmentation of the Shortland sewage treatment plant, rather than any floodgate effect. McGregor also noted that during a high flow event (March 1978), inflows contained high total phosphorus concentrations and high suspended solids concentrations. The assistance of saline waters in flocculation and subsequent settlement of suspended solids was suggested as one reason for the decrease in total phosphorus concentrations when the floodgate was opened, as phosphorus can be adsorbed onto sediment particles.

Trends in nitrogen levels were similar to those observed for phosphorus, with the reduction of tidal flushing causing increased nitrogen concentrations above the floodgates. McGregor also noted chlorophyll *a* concentrations (an indicator of algal population) were quite variable, with strong seasonal trends, although absolute maxima increased on closure of the gates.

The partial opening of one floodgate was found to have no significant effect on temperature, pH or Biological Oxygen Demand (BOD) at the time of McGregor's (1979) survey. A summary of the average water quality data measured by McGregor during his study is outlined below in Table 3.7.

Table 3.7 McGregor Average Water Quality Data (1977/78)

Site	DO (%Sat)		TP (mg/L)		Ammonia (mg/L)		Alb-N (mg/L)	
	Open	Closed	Open	Closed	Open	Closed	Open	Closed
Below Gates	86	74	0.140	0.083	0.246	0.200	0.320	0.193
Above Gates	95	86	0.282	0.530	0.464	1.120	0.344	0.447
Fishery Creek	105	80	0.306	0.697	0.730	1.411	0.294	0.400
Station 90*	103	62	0.530	0.215	0.966	0.037	0.495	0.168
ANZECC (2000) trigger value	80% lower 110% upper		0.03		0.015		0.3 (total N)	

* Station 90 is upstream in Ironbark Creek, near the junction of Shelley Creek and the Shortland Sewage Treatment Plant discharge

McGregor concluded that the water quality was degraded in the swamp area, and restoration of pre-gate flushing levels may improve the water quality. McGregor recommended the relative costs and benefits of restoring tidal exchange to Hexham Swamp be investigated.

3.4.1.4 Trengove (1983)

A water quality study of Ironbark Creek was undertaken by the SPCC in 1983 (Trengove, 1983). The study measured dissolved oxygen, nutrients and chlorophyll *a* concentrations at 11 sites within the creek (all upstream of the floodgates).

Dissolved oxygen concentrations between 75 and 103% were observed, which were considered typical of the dry weather, spring time conditions. Nutrient and chlorophyll *a* concentrations were measured by the study at Station 90 (as per McGregor's study above). A comparison to McGregor's data was made by the Trengove study and is included in Table 3.8. ANZECC criteria for the protection of aquatic ecosystems, and McGregor's mean concentrations for the closed gate scenario, have also been included for comparison.

Table 3.8 Water Quality Data Comparison 1978 to 1983

Parameter (unit)	McGregor Data (1978)				1983 Data	ANZECC (2000) trigger values
	Max	Min	Mean (open)	Mean (closed)	24/8/83	
TP (mg/L)	0.85	0.22	0.53	0.22	0.20	0.03
Ammonia-N (mg/L)	1.85	0.48	0.97	0.04	0.28	0.015
Chlorophyll <i>a</i> (µg/L)	90	1	13		1.3	4

Trengove suggested that "the creek is healthier" during the 1983 survey than it was during the earlier McGregor study, as Trengove compared his data to McGregor's open gate scenario. However, McGregor's closed gate scenario is similar to the 1983 Trengove data, which McGregor attributes to the sewage treatment plant augmentation rather than a floodgate effect. There is little difference in total phosphorus concentration and a considerable increase in ammonia concentration between the 1978 and 1983 surveys, which is not acknowledged by the Trengove study.

Trengove discussed the possible major sources of pollutants to Ironbark Creek, which include the colliery (during wet weather) and the Shortland Sewage Treatment Plant (STP). The STP commissioned a 30 day maturation pond for effluent polishing in 1978, which significantly reduced pollutant inputs to the creek (nitrogen, phosphorus and suspended solids). Trengove mentioned the Shortland Garbage Depot, which was known to contribute leachate to the creek, but recognised that the surface runoff was contained and pumped to evaporation areas.

Trengove calculated relative pollutant loadings to the creek, and concluded urban runoff and the STP contributed significant pollutant loads to the creek, which is less able to assimilate pollutants because of the floodgates. Trengove recommended improvement of urban stormwater, improving flushing in

the creek by modification of the floodgates' operation and/or reduction of nutrient loads from the sewage treatment plant as being required to improve water quality in Ironbark Creek.

3.4.1.5 *Shepherd (1994)*

An ecological study of Ironbark and Mosquito Creeks was undertaken by Margaret Shepherd between December 1990 and February 1992, which included measurement of salinity and temperature (Shepherd 1994). Shepherd found a negative correlation between salinity and rainfall, although Ironbark Creek showed lower than expected salinities. This was attributed to the one way flap gates installed on Ironbark Creek. No significant temperature differences between the two creeks were noted by the study.

3.4.1.6 *Department of Public Works and Services (1995)*

Manly Hydraulics Laboratory (MHL) was commissioned in 1995 by the Department of Land and Water Conservation (DLWC) to undertake a data collection program on the Hunter River. This data collection included water quality measurements at several locations in the Hunter River near Ironbark Creek and two sites in Ironbark Creek itself (one upstream and one downstream of the floodgates). A summary of the water quality data collected is summarised in Table 3.9.

Table 3.9 Water Quality Data (Source: MHL, October 1995)

Site	Temp (°C)		Salinity (g/L)		DO (mg/L)		pH (0-14)	
	Min	Max	Min	Max	Min	Max	Min	Max
Hunter River (6)	17.9	19.5	23.7	33.5	-	-	-	-
Below Gates (7a)	18.2	21.3	17.8	31.4	5.73	8.02	7.4	8.0
Above Gates (7b)	18.0	21.1	14.8	28.6	6.19	7.98	7.3	7.9

Higher salinity can be noted in the Hunter River when compared to the two sites in Ironbark Creek. Similar temperatures were noted at the three sites monitored, and only minor differences in dissolved oxygen concentrations were observed in the creek sites.

3.4.1.7 *WBM Oceanics Australia (1995)*

WBM Oceanics Australia was commissioned to develop a Catchment Management Strategy for Blue Gum Hills, which was an undeveloped catchment located upstream of the Hexham Swamp. Part of this Catchment Management Strategy involved the sampling of stormwater runoff from the catchment upstream of Hexham Swamp. Results of this stormwater sampling are included below in Table 3.10. ANZECC (2000) trigger levels for the protection of aquatic ecosystems are also included for comparison.

The monitoring results indicated that inflows to Hexham Swamp, from catchment runoff, may be elevated in nutrients and suspended solids, although the nutrients appear not to be in forms that are the most readily taken up by algae (dissolved, inorganic forms).

Table 3.10 Runoff Quality Wentworth Creek Catchment (source: WBM 1995)

Parameter	Site		ANZECC (2000)
	Under Minmi Road	Side Tributary	Trigger Value
Ammonia-N (as N)	<0.1mg/L	<0.1mg/L	0.015 mg/L
TKN (as N)	0.7mg/L	1.6mg/L	
Oxidised N (as N)	<0.01mg/L	<0.01mg/L	0.015 mg/L
Total N (as N)	0.8mg/L	1.7mg/L	0.3 mg/L
Ortho-P (unfiltered)	<0.05mg/L	<0.05mg/L	0.005 mg/L
Total-P (filtered)	0.2mg/L	0.1mg/L	0.03 mg/L
Total-P (unfiltered)	0.5mg/L	0.5mg/L	0.03 mg/L
Suspended Solids	29mg/L	34mg/L	

3.4.1.8 Ironbark Creek TCM Committee (1996)

A report on the ecosystem of Ironbark Creek for the Ironbark Creek Total Catchment Management (TCM) Committee was prepared in 1996 (ICTCMC 1996) documenting past and present characteristics of the natural environment. This report identified issues relevant to the protection and restoration of the ecosystem and formulated management options for the protection and restoration of the creek's ecosystem.

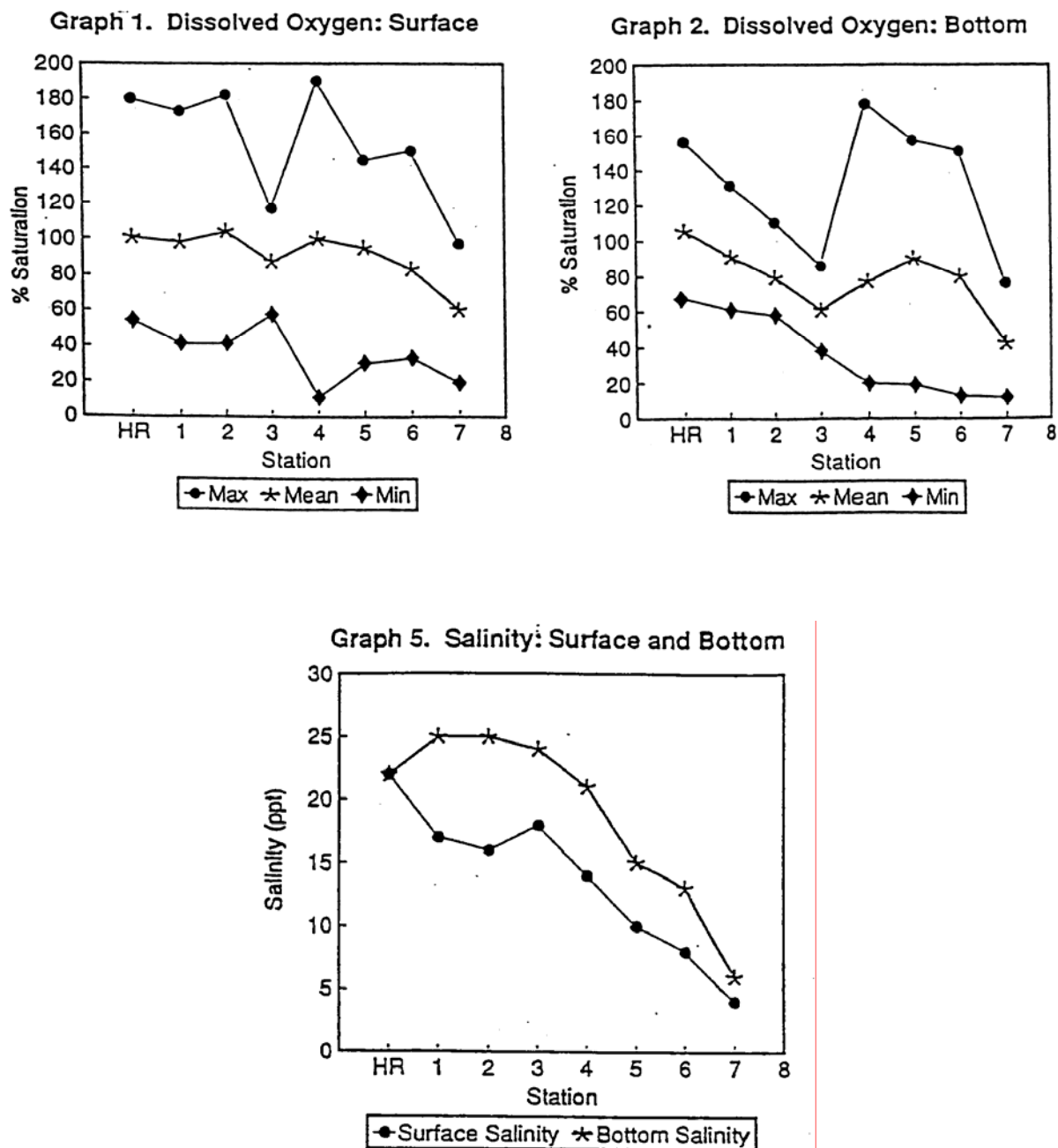
The ICTCMC (1996) included a summary of water quality in the creek and issues relating to water quality management. The report acknowledged the influence of point and non-point sources of pollution, including Shortland Sewage Treatment Plant, urban and rural runoff, drainage from disturbed acid sulfate soils and other influences. Note that discharges from Shortland STP are no longer directed into Ironbark Creek following the construction of a pipeline to convey treated effluent from the Plant to the Hunter River.

The concentration of dissolved oxygen was noted to be highly variable in the creek, with variations between 12 and 190% saturation observed. The dissolved oxygen fluctuations were attributed to the inflow of poor quality water from adjacent canals and tributaries. Dissolved oxygen was also shown to decrease with distance upstream from the floodgates (Figure 3.9).

The report noted saline waters can extend up Ironbark Creek to beyond Station 7, adjacent to Shortland STP. The low degree of vertical mixing in the creek was thought to cause a salt water wedge (salinity stratification) which can deplete dissolved oxygen in the underlying saline waters. The report indicates "inhibition of tidal currents by the floodgates causes increased salinity stratification".

A review of available water quality data indicated no particular elevation of nutrients in the vicinity of the sewage treatment plant, with relatively low nitrogen levels being discharged by the STP.

Phosphorus concentrations, however, were observed to have a definite trend of increasing concentration with distance upstream, with concentrations being higher than in the Hunter River.



Stations are arranged sequentially along Ironbark Creek, with station 1 adjacent to the Hunter River, and station 7 adjacent to the Shortland Sewage Treatment Plant

Figure 3.9 Dissolved Oxygen and Salinity Data Summary (ICTCMC 1996).

The report also studied the nitrogen to phosphorus ratios in Ironbark Creek. Algae and plants require both nitrogen and phosphorus for growth. The ratio of nitrogen to phosphorus (N:P) considered to be optimal for algal growth is 16-20:1. ICTCMC (1996) calculated the N:P ratio to vary between 0.69 and 1.65, indicating Ironbark Creek is a strongly nitrogen limited system. The report notes the lack of blue green algal blooms as surprising, given the high nutrient concentrations and strong nitrogen limitation. Blue green algae have the ability to sequester nitrogen directly from the atmosphere if insufficient nitrogen is available in the water column (and thus outcompete other forms of algae in nitrogen-limited environments).

The report also notes that chlorophyll *a* concentrations were lower than would be expected for the nutrient concentrations observed, and that “the limited tidal influence is sufficient to inhibit frequent large algal blooms”. ICTCMC (1996) also reports that water clarity is higher in the creek than in adjacent sections of the Hunter River. Penetration of river waters is inhibited by the floodgates, which reduces tidal flushing, and the floodgates also induce a ponding effect which allows settling and clarification to occur within the creek. As a result of these processes, accumulation of solids and other materials is occurring within the creek.

Water quality data presented in ICTCMC (1996) are shown in Table 3.11.

Table 3.11 Mean Water Quality Values for Ironbark Creek (Source: ICTCMC 1996)

Parameter	NH ₃	NO _x	TKN	OP	TP	pH
	µg/L	µg/L	µg/L	µg/L	µg/L	
Fishery Ck	136	212	1201	25	111	6.5
Swamp Centre	298	109	3001	120	410	6.8
Minmi	183	144	1124	30	268	7.5

The report concluded that “...water quality in Ironbark Creek is moderately to highly eutrophic. The creek is characterised by high phosphorus levels, undesirable variability in dissolved oxygen and excess plant growth. Poor quality is evident in tributaries where tidal exchange and salinity have been diminished. Floodplain drainage has also resulted in acid sulfate soil oxidation affecting several tributaries by lowering pH levels and contributing significant quantities of soluble iron to the waterways” (ICTCMC 1996).

3.4.1.9 Department of Land and Water Conservation (1996)

This report was prepared by DLWC as a response to the proposal to dredge Ironbark Creek. A brief review of water quality was made and water quality sampling was undertaken at three sites immediately downstream of the formalised Ironbark Creek channel, in the southern part of the study area (Table 3.12).

Table 3.12 Water Quality Sampling Results (Source: DLWC, 1996)

Site	pH (0-14)	Salinity (g/L)	Turbidity (NTU)	TP (mg/L)
1	7.2	0.57	9.8	-
2	7.4	0.56	12.0	0.7
3	7.4	0.57	9.9	-

The DLWC (1996) study concluded that the water quality in Ironbark Creek met ANZECC (1992) criteria at the time of monitoring, with the possible exception of turbidity and total phosphorus. Total phosphorus concentrations were recorded seven times higher than the ANZECC (1992) criterion of 0.1mg/L.

3.4.1.10 NSW National Parks and Wildlife Service (1996a)

This report by NSW National Parks and Wildlife Service (1996a) reviewed the EPA water quality data for Hexham Swamp/Ironbark Creek and concluded the creek was moderately to highly eutrophic. The report stated that increasing flushing in the Hexham Swamp/Ironbark Creek system would be beneficial in reducing pollutant and nutrient levels. The report also stated additional control of sediment sources was needed.

3.4.1.11 Department of Land and Water Conservation (1997)

In the week ending 18 April 1997 a full high tide penetrated Ironbark Creek and Hexham Swamp, due to the vandalism and opening of the floodgates. Following the re-closure of these gates, a fish kill and an algal bloom were recorded in the creek. In response to this vandalism and fish kill, DLWC monitored water quality at four sites in Ironbark Creek. A summary of the water quality results obtained by DLWC are provided in Table 3.13. ANZECC (2000) trigger values have been included for comparison.

Within Table 3.13, sites are arranged sequentially along Ironbark Creek, from upstream to downstream, with Site 1 near the start of the formalised channel at Minmi Road, Site 2 adjacent to the Shortland Sewage Treatment Plant, Site 3 at the Chichester Water Main bridge, and Site 4 near the floodgates. The report concludes that “upper Ironbark Creek is a system with poor water quality, particularly in the upper reaches. Nutrient levels are quite excessive, with total phosphorus levels nine times the upper range of ANZECC (1992) criteria which is expected to cause excessive algal growth. As expected, nutrient concentrations increase with distance away from floodgates. This corresponds with a decrease in the effects of flushing from the Hunter River waters.”

The high aluminium levels observed were attributed to the oxidation of acid sulfate soils. The report also speculated that flooding of acid sulfate lands could contribute soluble iron to the system, which can form iron oxide flocs which in turn can clog fish gills. The fish kill was therefore concluded to have been caused by low dissolved oxygen and/or toxic effects from the flooding of leached acid sulfate soil runoff.

Table 3.13 Water Quality in Ironbark Creek (Source: DLWC, April 1997)

Parameter	Site 1	Site 2	Site 3	Site 4	ANZECC (2000) trigger values
Temperature (°C)	18	19	20	21	-
pH	7.3	7.3	6.5	6.9	7.0 – 8.5
Conductivity (µS/cm)	2530	3910	22500	35300	-
DO (mg/L)	6.4	4.2	5.6	9.8	80% saturation
Ortho-P (mg/L)	0.061	0.250	0.016	0.006	0.005 mg/L
TP (mg/L)	0.92	0.9	0.1	0.025	0.03 mg/L
Ox N (mg/L)	0.2	0.22	0.08	<0.01	0.015 mg/L
Aluminium (mg/L)	0.08	0.175	0.25	0.28	0.055 (pH>6.5) for 95% level of species protection

3.4.1.12 Winning (1998, 2000)

A baseline ecological survey of Hexham Swamp was commenced in 1997 by Winning (2000). The results of the two year survey provided data on surface water quality monitoring (Winning 1998 & 2000). A summary of the salinity and pH data for 1997 & 1998 are outlined below in Table 3.14. A map showing the sites from this monitoring exercise is presented in Figure 3.10.

The February and May surveys show the possible influence of acid sulfate soils, with lower than desirable pH. The issue of acid sulfate soils is discussed separately (refer Section 3.5).

Table 3.14 Water Quality Data Summary (Source: Winning, 1998)

Date	28/2/97		2/5/97		7/7/97		4/9/97		7/11/97		12/1/98	
Site	pH	Sal g/L	pH	Sal g/L	pH	Sal g/L	pH	Sal g/L	pH	Sal g/L	pH	Sal g/L
1	-	-	5.3	25	7.4	1	7.5	4	-	-	-	-
2	4.3	9	4.0	28	7.3	1	7.0	4	-	-	-	-
3	3.6	11	-	-	7.6	0	7.3	6	-	-	-	-
4	-	-	-	-	7.9	1	-	-	-	-	-	-
5	-	-	-	-	7.6	1	-	-	-	-	-	-
6	5.2	5	-	-	7.6	0	-	-	-	-	-	-
7	4.7	3	6.5	9	7.7	1	7.5	1	7.8	6	-	-
8	4.9	1	-	-	7.5	1	7.5	1	7.8	6	-	-
9	5.3	2	-	-	7.5	1	7.5	1	7.8	6	-	-
10	-	-	-	-	7.6	1	-	-	-	-	-	-
11	7.1	10	-	-	7.7	0	7.5	4	-	-	-	-
12	-	-	-	-	7.7	2	7.6	2	-	-	-	-
13	4.0	4	7.0	4	8.5	0	8.1	2	7.9	4	-	-
14	-	-	-	-	7.8	3	-	-	-	-	-	-
15	6.6	6	-	-	7.3	1	7.9	3	-	-	-	-
16	7.1	0	7.2	1	8.3	0	8.3	0	7.3	1	-	-

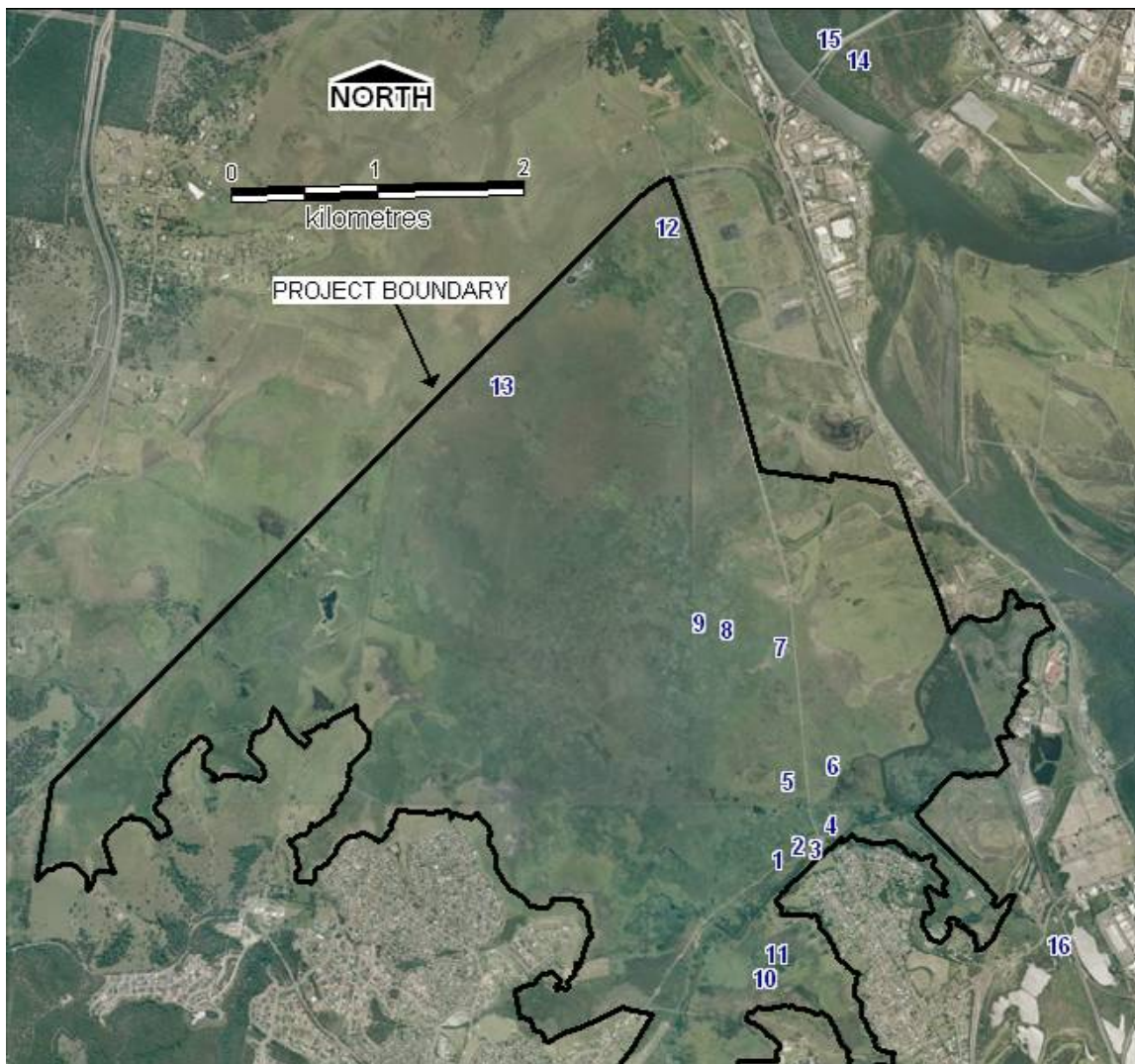


Figure 3.10 Water quality sampling sites (Winning, 1998)

3.4.1.13 NSW Department of Public Works and Services (2000)

This report by DPWS Manly Hydraulics Laboratory summarises the results of water quality monitoring at sites upstream and downstream of the Ironbark Creek floodgates during the period June 1999 to July 2000. The results are presented in Table 3.15.

Table 3.15 Water Quality Data 1999 – 2000 (Source: DPWS, 2000)

		Downstream of floodgates	Upstream of floodgates
Conductivity (mS/cm)	Maximum	58.8	54.4
	50%ile (median)	28.3	22.9
	Minimum	0.2	0.48
pH	Maximum	8.39	8.13
	50%ile (median)	7.67	7.31
	Minimum	6.34	6.32
Temperature (deg. C)	Maximum	28.8	29.3
	50%ile (median)	19.1	19.0
	Minimum	10.2	9.9
Dissolved Oxygen (mg/L)	Maximum	13.9	12.4
	50%ile (median)	5.05	3.44
	Minimum	0.07	0.08

3.4.1.14 NSW Department of Public Works and Services (2002)

DPWS Manly Hydraulics Laboratory (MHL) were commissioned by the Hunter Catchment Management Trust (now HCRCMA) to monitor water quality at a number of locations within Hexham Swamp, including upstream and downstream of the floodgates, at Morris Jetty, and in The Wetland Centre Canoe Trail. MHL were already collecting data from some of these sites before the commissioning by the Trust. A summary of the water quality data from these sites is presented in Table 3.16.

Table 3.16 Water Quality Data 1998 – 2002 (Source: DPWS, 2002)

		Downstream of floodgates (May 1998 – May 2002)	Upstream of floodgates (May 1998 – July 2000)	TWC Canoe Trail (July 2000 – June 2002)	Morris Jetty (July 2000 – May 2002)
Conductivity (mS/cm)	Maximum	74.9	54.4	45.5	44.0
	50%ile (median)	30.1	21.5	26.0	18.3
	Minimum	0	-	0.35	0.23
pH	Maximum	8.79	8.79	8.84	7.92
	50%ile (median)	7.75	7.28	7.31	7.02
	Minimum	6.03	6.06	5.84	6.08
Temperature (deg. C)	Maximum	30.5	29.8	32.3	31.2
	50%ile (median)	20.1	19.2	21.1	20.9
	Minimum	8.9	8.6	10.6	11.2

		Downstream of floodgates (May 1998 – May 2002)	Upstream of floodgates (May 1998 – July 2000)	TWC Canoe Trail (July 2000 – June 2002)	Morris Jetty (July 2000 – May 2002)
Dissolved Oxygen (mg/L)	Maximum	14.4	12.35	12.2	14.1
	50%ile (median)	4.55	3.54	3.65	1.2
	Minimum	0	0	0	0
Turbidity (NTU) (monitoring started July 2000)	Maximum	551	-	646	354
	50%ile (median)	33.0	-	0	5
	Minimum	0	-	0	0

The results show that there is a notable difference in water quality between the sites within the swamp and the site downstream of the floodgates (which would be influenced primarily by the water quality of the Hunter River). Typically, sites within Hexham Swamp showed lower conductivity (salinity), pH, turbidity and dissolved oxygen. The lower conductivity and pH within the swamp would be the result of a greater influence by freshwater runoff from the local catchment. Lower turbidity would be the result of settlement of fines and particulate matter within the swamp (due to the 'ponding' effect of the floodgates), while the lower dissolved oxygen would be the result of oxidation of a higher organic load, which has accumulated within the Swamp. Caution must be given to the dissolved oxygen results, however, as biological fouling of the in-situ sensors can distort readings.

3.4.1.15 Sanderson and Redden (2001)

Water quality of the Hunter River estuary was collated and reviewed by the University of Newcastle (Sanderson and Redden, 2001) as part of the Hunter River Estuary Processes Study (MHL, 2003).

Below are extracts from the water quality report considered relevant to Hexham Swamp.

- Shortland WWTW discharges high quality effluent directly into the South Arm (Zone B) of the Hunter River. It is perhaps noteworthy that BOD in the South Arm is less than in the North Arm (Zone C).
- In the lower more saline sections of the estuary, average chlorophyll-a values are in the range 5 – 10 µg/L, with a median of 4 µg/L. The maximum value in zone B (South Arm) is 42 µg/L.
- Dissolved oxygen in the Hunter River has a median value of 6.5 mg/L, although there are many recordings of less than 5 mg/L, which is considered to be stressful to fish. Oxygen levels are substantially lower in side creeks than the main estuary, which may limit the potential of these areas as nursery habitat for juvenile fish.
- Ammonia concentrations are very much higher in zones B (South Arm) and C, indicating there may be a source of ammonia in this region. Possible sources may include anoxic sediments, industry and waste water treatment works.
- Oxidised nitrogen concentrations are considered to be high.

- pH of the estuary is relatively consistent throughout its length with a value of about 8.1. However, pH in the up-estuary side creeks tends to be lower than in the main channels of the estuary.
- Soluble reactive phosphorus concentrations are high, with values in the more saline lower reaches of the estuary averaging higher than 15 µg/L.
- The mean turbidity in the Hunter River is 15 NTU, while the median value is 9 NTU, and a 90%ile value of 31 NTU. Turbidity is higher in the upper estuary than in the lower estuary, probably because of better tidal mixing with seawater in the lower estuary.

Further details of the water quality results for the Hunter River are available in the electronic version of the university report (Sanderson and Redden, 2001) available through Newcastle City Council.

3.4.1.16 Astra St landfill monitoring surface water monitoring

Surface runoff from the former Astra Street landfill site has been monitored by Newcastle City Council since 1990. Monitoring is carried out around the perimeter of the site, as well as in Ironbark Creek upstream and downstream of the Canoe Channel junction. Robert Carr and Associates (2001) report that an assessment of surface water quality monitoring results up to December 2000 identified a number of contaminants of concern, including zinc, ammonia, total cyanide, lead, selenium, cadmium, total PAHs, PCBs and OCPs. Some of these contaminants exceeded the recommended ANZECC guideline values. The assessment also identified that elevated zinc concentrations found in Ironbark Creek was related to a combination of site impacts and background factors.

Surface water quality monitoring carried out in 2001 is also reported in Robert Carr and Associates (2001), although this was limited to one occasion at most sites, and two occasions at the Golf Range site. Higher concentrations of heavy metals were typically found down-gradient of the landfill site, compared to upstream background sites.

Based on surface water quality data, as well as groundwater quality data (refer Section 3.5.1.3), Robert Carr and Associates (2001) concluded that there were a number of contaminants of concern, and that the site should be considered a Significant Risk of Harm site, as notified under Section 60 of the Contaminated Lands Management Act 1997. The contaminants of concern are:

- Ammonia as N;
- Nitrate as N;
- Cadmium;
- Copper;
- Nickel;
- Lead;
- Zinc;
- Iron;
- Aluminium;
- Cobalt;

- Manganese;
- Chromium (VI);
- Free Cyanide;
- Arsenic;
- Mercury (inorganic);
- Nickel;
- Phenanthrene;
- Flouranthene;
- Benzo(a)pyrene.

Newcastle City Council has indicated that a 12 month study of the Astra Street dump is planned, which will determine long-term remediation requirements for the site, and will take into consideration the proposed opening of the Ironbark Creek floodgates (pers comm., Paul McMurray, NCC, 2004).

3.4.2 Current Water Quality Monitoring of Hexham Swamp

3.4.2.1 Department of Commerce, Manly Hydraulics Laboratory

Manly Hydraulics Laboratory (MHL) is currently carrying out water quality monitoring at four (4) sites within Hexham Swamp. This monitoring was commissioned by the HCRCMA in 2002, and followed on from monitoring that was previously carried out by MHL at similar sites in the Swamp (refer Sections 3.4.1.13 and 3.4.1.14). MHL's commission also includes monitoring of water levels at two additional locations (refer Figure 3.11 for monitoring site locations).

Water quality results from MHL's current monitoring program (August 2003 to July 2004) are presented in Table 3.17. Median values and standard deviations have been reported to provide an indication of typical conditions and the degree of variability in the data.

The results indicate that water quality immediately upstream and downstream of the floodgates was not too dissimilar – the only parameter showing notable differences was turbidity. Flushing of the lower reaches of Ironbark Creek is achieved through the partial opening of one gate. Further upstream, significant water quality variations were observed at Morris Jetty and Fishery Creek. Although both of these sites had a reduced monitoring record due to vandalism, the results still indicate reduced pH, slightly reduced conductivity (salinity) and significantly reduced dissolved oxygen concentrations. These results are consistent with previous monitoring, which indicate a more freshwater-dominated system that is subject to anoxia due to decay of trapped organic material within the wetland environment.

The significantly suppressed pH levels compared to the conductivity, suggest that the lower pH values are not solely the result of freshwater inputs. Other reasons for the low pH could be related to oxidation of acid sulfate soils within the swamp.

The turbidity records for all sites upstream of the floodgates are highly variable, and indicative of a predominantly depositional environment.

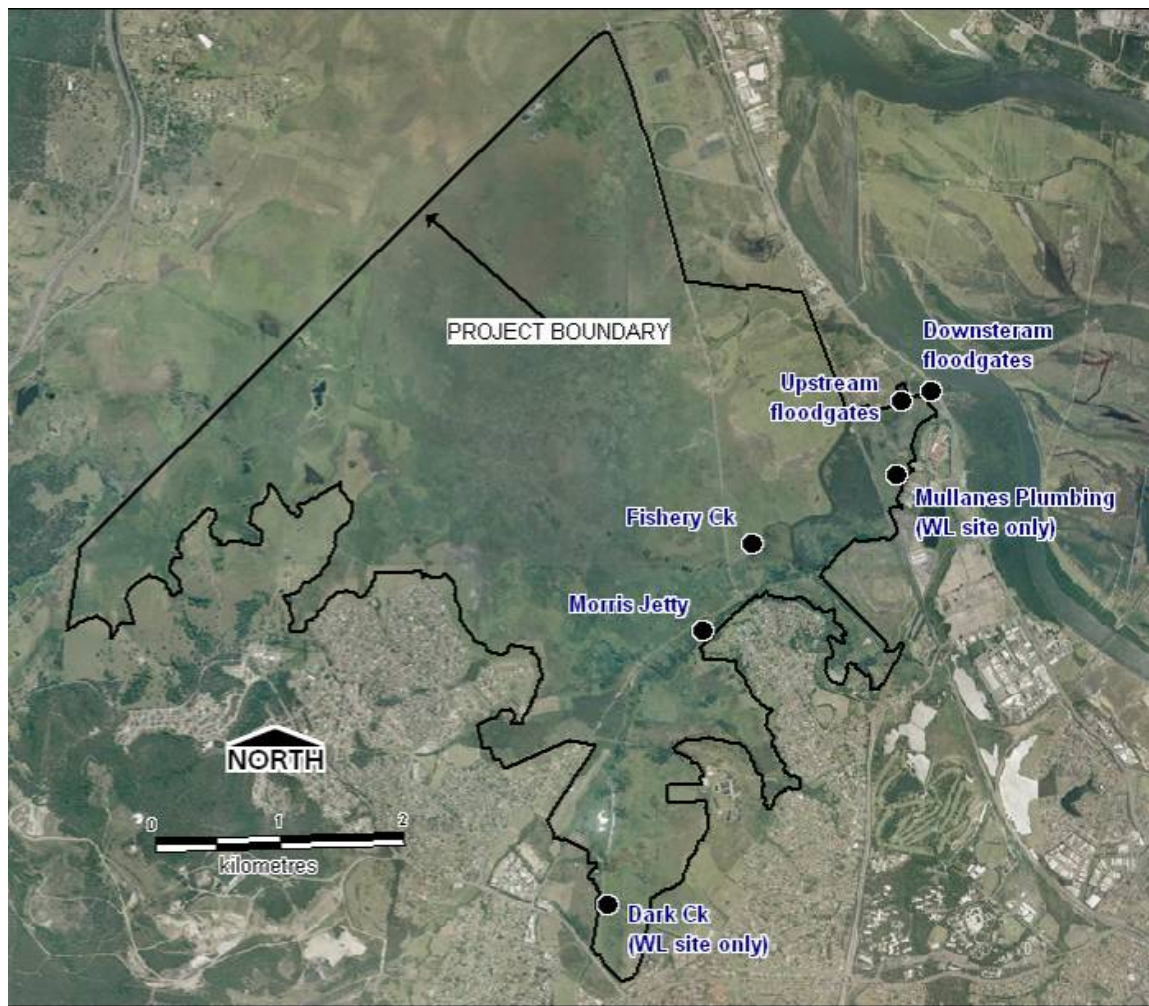


Figure 3.11 MHL Water quality and level recording stations (2002 - 2004)

Apart from the Mullanes Plumbing site, the water level data captured by the MHL recorders have been summarised into the tidal planes analysis, as presented in Table 3.5 and Figure 3.5. The water level recorded at the Mullanes Plumbing gauge (located in the upper reaches of Muck Eye Creek), exhibited minimal tidal signal. During dry weather periods, levels at this gauge remained mostly constant at approximately 0.03m AHD. Following rainfall, however, water levels generally increased rapidly and drained slowly after the event. Water levels at the site also responded to elevated levels within Hexham Swamp, as a result of backwater inundation from Ironbark Creek.

**Table 3.17 Median Water Quality Results from MHL's Current Monitoring Program
(August 2003 – July 2004)**

	Water level (m, AHD)	Spec. cond. (mS/cm)	pH	Temp (deg C)	DO (mg/L)	Turbidity (NTU)
Downstream of Floodgates (Std Dev)	-0.01 0.41	42.3 10.6	8.1 0.4	20.2 4.7	6.7 2.2	1 13
Upstream of floodgates (Std Dev)	-0.19 0.23	41.2 11.1	8.1 0.7	20.1 4.9	6.0 2.2	19 41
Morris Jetty (Std Dev)	-0.12 0.18	34.8 12.3	7.1 0.4	21.0 5.5	3.5 3.3	96 159
Fishery Creek (Std Dev)	-0.12 0.2	36.7 0.11*	7.3 0.6	21.1 5.5	4.3 2.9	19 141
Dark Creek (Std Dev)	-0.18 0.21	Water level site only				
Mullanes Plumbing (Std Dev)	0.03 0.10	Water level site only				

* Suspected error with this calculation

3.4.2.2 Hunter-Central Rivers Catchment Management Authority

The Hunter - Central Rivers Catchment Management Authority (formerly HCMT) has been monitoring water quality within Hexham Swamp and its inflowing tributaries on a regular basis since August 2002. Monitoring has been carried out using a hand-held water quality probe, which measures temperature, conductivity, salinity, turbidity, total dissolved solids (TDS), dissolved oxygen and oxidation-reduction potential (ORP).

The locations of the water quality monitoring sites are presented in Figure 3.12, while the averaged results are given in Table 3.18. Typically, water quality was recorded at three points at each site during each monitoring round. Seven monitoring rounds are included in the averaged results, however, not all sites were monitored during each round. Standard deviations for the data are also presented in Table 3.18 to show the variability in results between the sampling rounds.

Table 3.18 Averaged Water Quality Results: Aug 02 – Oct 03 (Source: HCRCA)

	No. of samples	Temperature (oC)	pH	Specific Conduct. (mS/cm)	Salinity (ppt)	TDS (g/L)	Turbidity (NTU)	DO (mg/L)	ORP (mV)
Minmi Ck (Std Dev)	7	13.98 (4.57)	7.31 (0.42)	0.37 (2.66)	0.20 (0.06)	0.25 (0.07)	20.29 (13.81)	4.05 (1.58)	325.26 (101.52)
Wentworth Ck (Std Dev)	4	11.58 (3.28)	7.47 (0.48)	0.45 (0.08)	0.22 (0.04)	0.31 (0.05)	527.67 (313.66)	4.38 (2.33)	238.00 (117.87)
Maryland Ck (Std Dev)	3	15.88 (2.62)	8.09 (0.26)	0.49 (0.20)	0.25 (0.11)	3.13 (4.74)	9.87 (15.20)	10.13 (1.81)	183.00 (34.77)
Ironbark Ck (Std Dev)	7	17.19 (3.52)	7.72 (0.43)	1.46 (2.97)	0.91 (0.93)	1.09 (1.08)	17.15 (19.09)	6.69 (3.00)	277.76 (93.55)

	No. of samples	Temperature (oC)	pH	Specific Conduct. (mS/cm)	Salinity (ppt)	TDS (g/L)	Turbidity (NTU)	DO (mg/L)	ORP (mV)
Dark Ck (Std Dev)	7	18.20 (3.52)	8.72 (0.43)	0.49 (3.09)	0.24 (0.05)	0.31 (0.07)	55.87 (89.95)	8.68 (4.89)	258.93 (84.78)
Canoe Channel (Std Dev)	7	16.70 (4.45)	7.73 (0.44)	0.68 (2.64)	0.30 (0.23)	0.68 (0.98)	25.20 (34.86)	6.11 (2.85)	243.00 (77.10)
Shelley Ck u/s (Std Dev)	2	11.70 (1.32)	7.15 (0.48)	3.67 (1.44)	2.00 (0.81)	2.35 (0.93)	23.42 (22.89)	4.10 (2.14)	190.17 (98.76)
Shelley Ck d/s (Std Dev)	7	19.07 (5.48)	7.04 (0.29)	13.16 (10.14)	10.17 (8.72)	10.71 (8.75)	10.10 (12.58)	7.27 (3.22)	249.81 (89.45)
Fishery Ck u/s (Std Dev)	5	17.96 (4.73)	6.07 (0.93)	3.55 (1.08)	2.13 (0.71)	2.50 (0.81)	13.24 (25.92)	5.41 (1.43)	277.73 (137.39)
Fishery Ck d/s (Std Dev)	7	18.07 (6.06)	6.86 (0.48)	19.21 (14.67)	14.14 (10.92)	14.53 (10.66)	23.95 (13.41)	6.33 (4.37)	192.64 (143.12)
Floodgates u/s (Std Dev)	6	20.73 (4.01)	8.25 (0.23)	35.80 (11.97)	24.26 (4.64)	24.28 (4.16)	8.34 (11.39)	7.36 (2.61)	271.61 (53.12)
Floodgates d/s (Std Dev)	4	21.14 (4.00)	8.14 (0.28)	40.30 (16.35)	27.56 (4.35)	27.47 (3.73)	11.58 (16.14)	6.93 (2.77)	261.88 (71.50)

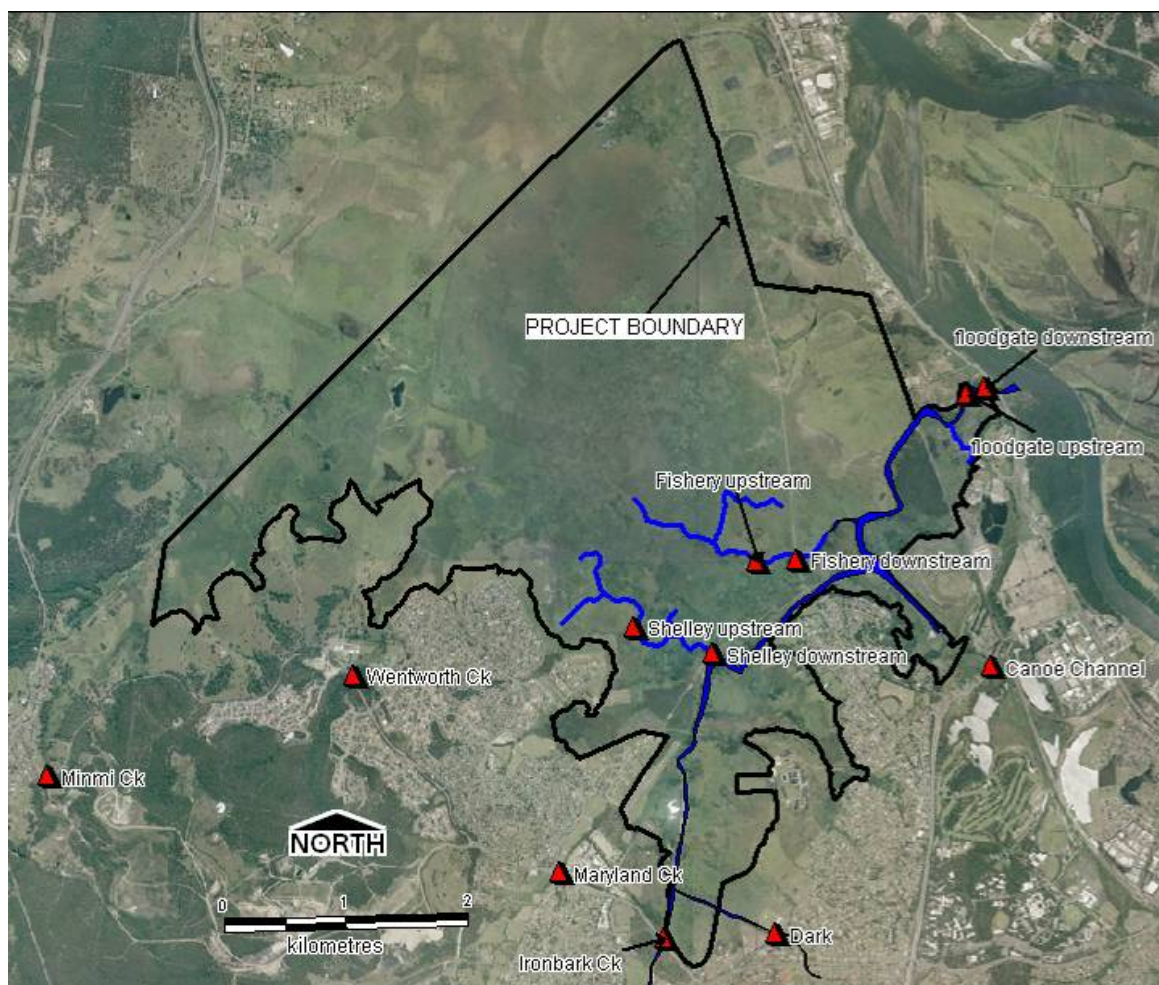


Figure 3.12 Location of HCRMA WQ Monitoring Sites

Investigation of the salinity results shows that very saline waters were generally present both upstream and downstream of the floodgates. Within the tidal reaches, at the downstream ends of Fishery and Shelly Creeks, the salinity was quite variable (with a large standard deviation), meaning that these sites are influenced by both tidal intrusion from the river and from freshwater catchment runoff. Sites at the upstream ends of these tributaries were predominantly brackish, with relatively little influence from tidal flushing. All other sites, representing the catchment 'inputs' to the swamp were essentially freshwater, including the upstream end of Ironbark Creek at Minmi Road.

The pH results presented in Table 3.18 are also of interest. Tidal waters entering the swamp from the Hunter River typically have a higher pH value due to the natural alkalinity of seawater, while the freshwater inputs from the catchment are more neutral (with values typically in the order of 7). However, pH of water in Dark Creek has an averaged value of 8.72, which is quite alkaline for a freshwater stream, which would likely be the result of specific inputs within the Dark Creek catchment. Also, the pH at the upstream end of Fishery Creek has a low value (average = 6.07), and on one occasion had a value of 4.6. It is expected that the acidity of waters at this site may be related to the oxidation and runoff from acid sulfate soils within the local Fishery Creek area.

Dissolved Oxygen (DO) levels within Hexham Swamp were typical of wetland environments. In areas that are tidally flushed (i.e. the downstream tidal reaches of Ironbark, Fishery and Shelley Creeks), DO has reasonably high. At most of the tributary sites, DO was depressed to about 50 – 60% of saturation concentrations. At the Maryland Creek and Dark Creek sites, however, DO was higher than saturation concentrations. This would be the result of significant aeration of the water due to turbulence (i.e. a riffle sequence), or significant photosynthesis by floating and/or attached algae within the water.

3.4.3 Overview of Water Quality in Hexham Swamp

As early as 1979, only a few years after the construction of the floodgates, it was determined that water quality within Hexham Swamp had deteriorated, and that modification to the floodgates was required to improve water quality (McGregor 1979, Tengrove 1983). Recent automated water quality monitoring by MHL (2000, 2002, 2004) confirms the influence of the floodgates on water quality within Hexham Swamp.

Given Hexham Swamp's large spatial extents, the water quality of the swamp shows notable spatial variability. Typically, water quality tends to be poorer with distance away from the floodgates (i.e. with distance away from the main flushing mechanism of the swamp), which also correlates with distance closer to the upper catchment (i.e. the main source of most of the swamp's pollutants).

An overview of the different water quality parameters in Hexham Swamp is provided in the following Sections.

3.4.3.1 Physio-chemical Parameters

Salinity

Salinity in the swamp is generally lower than in the river, due to the restricted tidal flushing by the gates and the input of freshwater inflows from local catchment runoff. Salinity varies spatially across the swamp, with a notable gradient between the floodgates (and lower reaches of Ironbark Creek) and

the freshwater tributary inputs. Salinity within the swamp is dependent on the antecedent rainfall and runoff from the local catchment, with sites in the lower reaches of tributaries, such as Fishery and Shelley Creeks, ranging between full ocean salt conditions and completely fresh water. The rate of salt recovery within the swamp following a local catchment runoff event is significantly attenuated by the tidal restrictions imposed by the floodgates;

pH

pH levels are variable throughout Hexham Swamp. Typically, pH within the main channels and creeks is within the normal range for estuarine and brackish environments. However, in some more remote sections of the Swamp, pH levels can be low, which is indicative of the production of acidic runoff from Acid Sulfate Soils (ASS). ASS are discussed further in Section 3.5.1.1.

Turbidity / Water Clarity

Apart from the latest MHL monitoring, turbidity within Hexham Swamp was generally shown to be lower than in the Hunter River due to the 'ponding' effect behind the floodgates, which allows settlement of sediment and organic particles within the swamp. The Hunter River typically has higher turbidity due to catchment runoff within its large (20,000km²) catchment. For periods when catchment runoff from the Hunter River catchment is minimal (i.e. the recent drought-dominated conditions), it is considered that turbidity generated within the swamp could exceed the turbidity in the river (as evidenced by the most recent MHL results – refer Section 3.4.2.1).

Water clarity is another measure of the turbidity, with results also showing higher clarity in the Swamp compared to the River.

Dissolved Oxygen

Dissolved oxygen (DO) levels in the Hunter River are generally stable and above ANZECC thresholds. DO levels in Hexham Swamp, however, are more variable, and typically lower than levels in the river. Supersaturated conditions have also been recorded in the swamp, indicating high rates of photosynthesis by pelagic algae. Although not measured explicitly, it is expected that algal respiration and general organic decay would deplete DO concentrations during the night.

Low oxygen conditions were partially responsible for a fish kill in 1997 following opening and then closing of the gates, which is likely to have generated a 'pulse' of oxygen-demanding organic matter to the waterways.

3.4.3.2 Nutrients and Algae

Nutrients are generally higher in Hexham Swamp than in the adjacent Hunter River, and are sufficiently high for the swamp to be considered moderately to highly eutrophic. The nutrient levels (both TN and TP) are often higher than recommended guideline values (ANZECC), but appear to be lower in recent times than historically. One reason for this is probably the fact that the Shortland WWTW no longer discharges effluent to Ironbark Creek. Instead, effluent is now discharged directed to the Hunter River.

Close examination of the data suggests that high nutrient concentrations are derived from the catchment, however, these nutrients are mostly in non-bioavailable (organic) forms. Within the upper

reaches of the swamp, heterotrophic processes convert the organic nutrients to inorganic (bioavailable) forms, resulting in elevated concentrations of NO_x , NH_3 and PO_4 . Algae within the Swamp subsequently consume the bioavailable nutrients.

Excessive algae are indicated by high chlorophyll-a concentrations in the swamp, and periodic supersaturation of dissolved oxygen (refer Section 3.4.3.1). Chlorophyll-a concentrations typically exceed ANZECC guidelines.

3.4.3.3 Bacteria

Negligible information regarding bacteria is available for Hexham Swamp. Given the extent of urbanisation within its catchment, it is expected that bacteria levels within Ironbark Creek and Hexham Swamp would be high following rainfall periods. This would be due to inefficient sewerage systems, illegal connections to stormwater drains, and runoff from on-site / septic systems within the rural areas of the catchment.

As a standard precaution, it would be advisable to avoid primary contact activities within Hexham Swamp following rainfall.

3.4.3.4 Metals and other Toxicants

Monitoring of the Astra Street landfill site has found elevated concentrations of a number of heavy metals within the leachate of the site as well as within the Canoe Channel and Ironbark Creek downstream of the site (RCA, 2001). Contaminants of concern were determined to be ammonia, nitrate, cadmium, copper, nickel, lead, zinc, iron, aluminium, cobalt, manganese, chromium VI, free cyanide, arsenic, mercury, and nickel.

Also, RCA (2001) indicated that some organics were also problematic within the leachate, including phenanthrene, flouranthene and benzo(a)pyrene.

As indicated in Section 3.4.1.16, Newcastle City Council is preparing a rehabilitation plan for the former Astra Street dump, which will address soil contamination, leachate generation and the possible impacts associated with opening of the floodgates.

3.5 Soils and Groundwater

A comprehensive study of the soils and groundwater characteristics of Hexham Swamp is provided in Robert Carr and Associates (1998). A summary of the findings of this study is outlined below, while a copy of RCA (1998) is provided in **Appendix D: Volume 2** of this document.

3.5.1 Previous Studies

3.5.1.1 Acid Sulfate Potential

The Beresfield 1:25,000 Acid Sulfate Risk map (HCMT and DLWC 1993) shows the probability of encountering acid-sulfate soils in the study area. Hexham Swamp lies almost entirely within an area described as having "high probability of occurrence of acid-sulfate soil materials within the soil profile".

However, additional studies and soil profile testing carried out in the study area in relation to acid sulfate soils obtained different results. These studies include the following:

- Geotechnical Investigation Report: Tarro to Shortland Pipeline Chichester Pipeline Replacement (1999) prepared by Robert Carr & Associates for Hunter Water Australia;
- EIS for the Maryland to Shortland Rising Main by CH2M Hill (1997);
- Department of Land and Water Conservation (DLWC 1996) sampling and testing in August and September 1996 along Ironbark Creek; and
- DWLC Newcastle Acid Sulfate Soil Survey (Murphy 1998).

The locations of the boreholes from these surveys are shown in Figure 3.13.

The results of these studies indicate generally high oxidisable sulfur levels below the water table, though many samples were buffered by carbonate derived from shell fragments. Buffering capacity varied with depth and location, which may be associated with a variable carbonate content distribution within the soils. Samples from above the water table generally had a low oxidisable sulfur content, indicating oxidation in the past. The results of these studies indicate that, in general, the soils around Ironbark Creek were neither actual nor potential acid sulfate soils, (Robert Carr and Associates, 1999).

3.5.1.2 Soil Properties

The results from ICTCMC (1996) indicates that soil profiles within the swamp range from loam to clay with typically a clayey loam topsoil to about 0.2 m to 0.3 m over a light to medium clay that becomes sandier (sandy clay loam to sandy loam) at depths of about 1m. Other soil materials noted in the swamp area include brown fibrous peat comprising a surface layer of organic material and loose pale sand which often contains shell fragments and may underlie the surficial clay layers. The soils were typecast as the "Hexham Swamp soil landscape", which covers the whole of Hexham Swamp.

Soil data collected by CH2M Hill (1997) for the Maryland to Shortland Rising Main can be summarised as:

- Topsoil comprising low to medium plasticity clay about 0.2m thick; overlying
- Clay, high plasticity, variable strength ranging from stiff to soft, strength decreasing with depth, to 0.8m to 1.4m, with a groundwater table at about 1m depth; overlying
- Shelley clay, high plasticity, soft to depths in excess of 2m; and
- Fill was encountered in two of the bores.

Additional data from a study of the two dominant soil horizons in Hexham Swamp indicates that the soils ranged from silty clays (clays) with a variable sand content through to silty clayey sands (loams) (DLWC, undated). Some of the clays found within the swamp are partially dispersive.

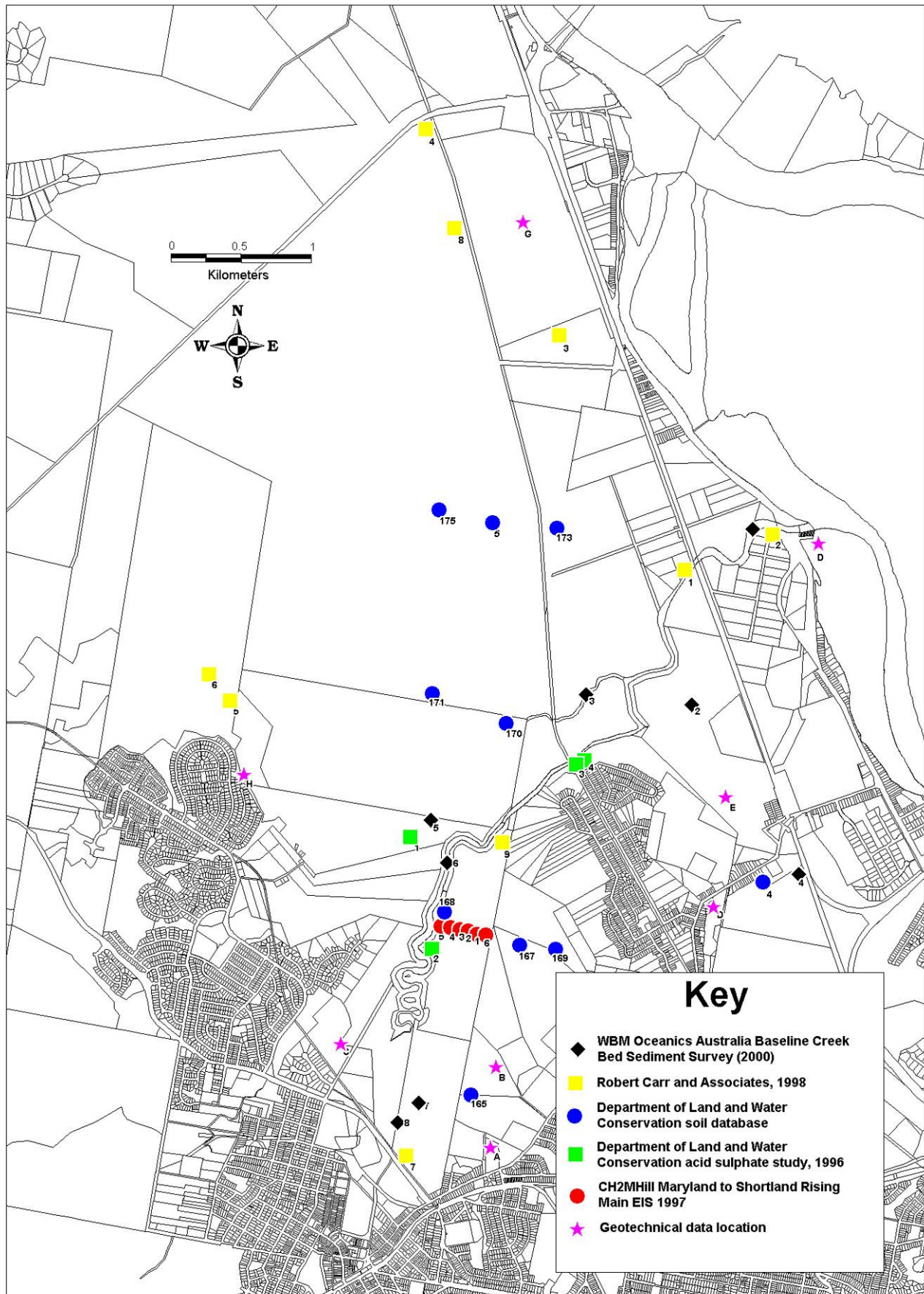


Figure 3.13 Soil and Groundwater Test Locations

3.5.1.3 Groundwater Properties

The position of the groundwater table relative to the ground surface has been noted on some DLWC soil profiles as well as the borelogs along the proposed route of the Maryland to Shortland rising main. In general the groundwater table is noted to occur between 0.5 and 1.5m below ground level. Fluctuations in the ground water level can be expected depending on climate and hydrology.

3.5.1.4 Soil Erosion

ICTCMC (1996) concluded that no significant erosion was occurring in Hexham Swamp and that the area was in a period of siltation. The sediment load entering the swamp greatly exceeds the sediment discharge into the Hunter River.

Soil profile mapping by the DLWC (undated) indicates that the surface soils within the swamp area generally have only a slight erosion hazard.

The incidence of scour erosion has been noted in the west of the swamp and this has been attributed to high run-on from the surrounding cleared slopes and the effects of lowered water tables due to drainage of the swamp. The paths taken by catchment run-on cause the localised formation of scour channels resulting in redistribution of sediments to lower gradient areas of the swamp away from the margins.

3.5.1.5 Geotechnical Data

A number of geotechnical investigations have been undertaken for road, industrial and communication projects around the perimeter areas of Hexham Swamp (Robert Carr and Associates, undated).

The approximate locations of these investigations are shown in Figure 3.13. The soils encountered in Hexham Swamp are characterised by the presence of saturated low strength clays typically of soft to firm consistency with a surface crust of variable thickness. These clay soils are prone to consolidation settlement on loading. Observation of the fill pads for the transmission easement along Ironbark Creek indicates settlements of approximately 0.3m to 0.5m for 1m to 1.5m high fill embankments. The settlement is relative to the pile supported concrete foundations.

This settlement has implications for the design and construction of bund walls. Bunds constructed on these soils would undergo consolidation settlement with the rate and magnitude dependent on the depth and geotechnical properties of the soil and the applied load (i.e. bank height). Therefore, maintenance works on any bunds would be necessary in the future to ensure that crest heights are maintained at design levels.

3.5.2 Additional Works carried out for this Study

Fieldwork undertaken by Robert Carr & Associates (1998) involved:

- Drilling of 9 hand auger bores (up to 1.7m depth) for soil profile identification and to provide samples for physical and acid sulfate testing and groundwater quality assessment;

- Installation of three 50mm PVC standpipe piezometers for groundwater sampling and quality assessment;
- Field measurement of groundwater and surface water pH and electrical conductivity (E.C.);
- Mapping of soil profiles, creek bank erosion and site features.

Laboratory testing was undertaken to characterize site conditions and supplement existing data. The laboratory testing involved:

- Acid sulfate testing on 8 samples to assess oxidisable sulfur levels, total actual acidity, total potential acidity, soil buffering capacity and net acid generating potential;
- Emerson crumb dispersion testing on 2 samples using saline site water;
- Particle size distribution analysis on 2 samples for erosion susceptibility analysis;
- Water quality testing of 3 groundwater samples recovered from the piezometers.

The locations of the bores are shown on Figure 3.13 with standpipe piezometers installed in bores 1, 2 and 7. Engineering logs of the bores are presented in RCA (1998), which can be provided upon request.

Results of the additional works are presented in the following Section of this document (Section 3.5.3).

3.5.3 Field and Laboratory Test Results

3.5.3.1 Groundwater Quality

All the groundwaters tested by the laboratory were Na-Cl type waters and were found to be slightly acidic. Nutrient (nitrate) levels were low. Borehole GW1 (upstream) and GW2 (downstream) were highly saline as would be expected given they were taken from bores situated near the floodgates. Water taken from GW7 in the southern corner of the swamp was found to be fresh.

Additional field results indicate the presence of highly saline ground water over most of the swamp area with fresh water recharge over the higher areas at the northern corner (Bore 4) and along Ironbark Creek from the Wallsend area.

A confined aquifer in sandy soils appears to occur across the eastern part of the swamp at a shallow depth (about 1m) beneath surface clay layers. The aquifer appears to be saline indicating marine deposition. Fresh water recharge appears to be occurring around the margins of the aquifer, however the confined nature of the aquifer and the clayey nature of the surface layers suggest that the rate of fresh water recharge is slow. The lowering of ground water levels associated with the construction of the floodgates and cessation of tidal flushing is likely to have increased the rate of fresh water recharge into the saline aquifer, however, the aquifer still maintains a strong saline signature.

3.5.3.2 Acid Sulfate Test Results

Results indicate that, apart from Bore 9, none of the samples tested would be classified as actual or potential acid sulfate soils, thus confirming previous studies. The soil profile at Bore 9 (located adjacent to Ironbark Creek, upstream of Morris Jetty) had well developed jarosite nodules between

0.3m and 0.6m depth and a pH of 3.6, indicative of actual acid sulfate soil conditions. Estuarine clay from 1.0m depth had a total potential acidity of 1.5, indicating potential acid sulfate soils.

The levels of oxidisable sulfur from all samples tested, except location 9, were less than 0.03% which is less than the action criteria threshold of 0.05% outlined by the Department of Environment and Conservation (DEC) (formerly EPA), Department of Infrastructure, Planning and Natural Resources and the Acid Sulfate Soils Management Advisory Committee (1997) for sandy loams and light clays. The tested POSA values are less than the threshold of 1.54 Kg H_2SO_4 / tonne of soil used by the EPA (1995) for soils having a high risk of acid generation. The TPA values are less than 0.1 H_2SO_4 / tonne indicating limited potential for acid production.

The high sulfur content encountered in Bore 1 at 1.6m depth indicates the presence of potential acid sulfate soils at depth at this location.

Very high sulfur and oxidisable sulfur levels were encountered in Bore 9 with a total potential acidity of 178kg H_2SO_4 /tonne of soil. A neutralising requirement of in excess of 100kg of lime per cubic metre of soil would be required if the soil were oxidised at this location.

These results differ somewhat to the later ASS investigations carried out for the Tarro to Shortland Pipeline Replacement EIS (Robert Carr and Associates, 1999). The pipeline replacement investigation sampled soils to 3 metre depths at 100 metres spacings along the existing pipeline route. The results indicated that potential acid sulfate soils were present along much of the pipeline route, with only 14 of the 73 sites containing no potentially acid producing soils.

3.5.3.3 Soil Profiles

The surface soils over most of the swamp appear to have derived through alluvial soil deposition associated with the Hunter River and the catchment creeks entering the swamp. The terrestrially derived alluvial soils are usually not associated with acid sulfate soil conditions and this has been confirmed by test results in these areas. Estuarine soils may occur in these areas below the surface alluvial soils.

The occurrence of estuarine mud (clay and silt) deposits at shallow depth appears to be localised around the Ironbark Creek area. The marine deposition of these mud deposits is conducive to the formation of acid sulfate soil conditions.

3.5.3.4 Physical Soil Test Results and Properties

Physical testing on soil samples recovered from the bores confirmed the results of previous studies. In general, the clay soils encountered in the swamp appear to be non-dispersive, although there is a localised occurrence of some partially dispersive soils. Clays exposed in the creek banks along the waterways do not exhibit erosion characteristics that would be associated with dispersive soils.

The moisture content of the clay soils increases with depth and will fluctuate depending on climatic conditions and the groundwater level. During the summer months, a thin surface crust of higher strength soil will develop over the low strength saturated clays. Depending on the clay type, surface fissuring or cracking of the clays may occur on desiccation. The clay soils within the swamp are generally saturated with moisture contents well in excess of that required to achieve compaction

specification for earthworks such as bunds and levees. Significant drying of these soils would be required before they could be utilised for engineered structures.

3.5.4 Erosion and Sedimentation

ICTCMC (1996) noted that Hexham Swamp traps sediment derived from its catchment, with little of the sediment transported through the Swamp to the Hunter River, due to a low gradient and a mass of filtering vegetation. The study estimated an annual sediment load of about 8,500 tonnes of delivered sediment with an output of about 400 tonnes into the Hunter River. The sediment load is noted to be variable, depending on climatic variation and development activities.

The areas surrounding the swamp comprise residual clay soils and weathered rock associated with the Tomago Coal Measures. These clay soils are highly susceptible to sheet and rill erosion particularly where the topsoil has been removed or disturbed.

Creek bank erosion within the study area was noted at several locations. This appears to primarily occur in areas where:

- Native vegetation has been cleared to grass pasture;
- Cattle have accessed the creek banks;
- Fill has been placed along the banks to form bunds; or
- Concentration of runoff has occurred through low fill embankments associated with tracks and easements or drains.

The susceptibility to erosion of the surface soils in Hexham Swamp is considered to be low on the basis of soil properties, vegetative cover and very low surface gradients. The swamp is periodically inundated with significant runoff of surface waters occurring to the drainage paths. Under these general sheet flow conditions, the erosion hazard appears to be slight, however, under concentrated flows the risk of erosion is high.

Some localised sheet and rill erosion is occurring along the margins of the swamp where urbanisation has resulted in increased and concentrated runoff. The erosion appears to be predominantly occurring along the foot slopes of the surrounding residual soil hillside areas. The boundary between the hillside areas and the low gradient swamp areas is generally marked by a sharp break of slope, suggesting past erosion from estuarine processes.

3.6 Former Landfill and Other Contaminated Sites

3.6.1 Astra Street Landfill

The Astra Street landfill site (refer Figure 3.1) was decommissioned in 1995. Prior to this, the site was an active waste disposal depot operated by Newcastle City Council. It is considered unlikely that the site is fully lined and hence restoration of tidal inundation could impact on the landfill. The surface soils in the vicinity of the Astra Street Landfill are sandy (to about 6m below surface level), underlain by clay, with rock underlying the site at approximately 35m. The landfill is elevated above the surrounding ground level. A leachate evaporation pond is located at the downstream end of the landfill.

As discussed in Section 3.4.1.16, surface water and groundwater within the landfill has been monitored by Council since 1990, and shows elevated concentrations of a number of heavy metals. On-going groundwater monitoring by RCA Australia (2003) has shown that significant and consistent exceedances of ANZECC (2000) guidelines have been recorded for the following parameters:

- Arsenic;
- Cobalt;
- Chromium (total as Cr III);
- Copper;
- Nickel;
- Zinc;
- Phenanthrene;
- Anthracene;
- Free Cyanide; and
- Ammonia.

The Astra Street Landfill has recently (December 2003) been declared an Investigation Area under the Contaminated Lands Management Act 1997. The Department of Environment and Conservation (formerly EPA) made this declaration as they believe that the land is contaminated in such a way as to present a significant risk of harm because:

- The land was used as a municipal landfill between 1974 and 1995;
- Groundwater quality has been degraded by heavy metals, PAHs and ammonia contamination;
- Concentrations of heavy metals, PAHs and ammonia in groundwater at the land boundary exceed ANZECC guideline trigger values;
- Contaminated leachate may potentially migrate from the land into Ironbark Creek and the adjacent SEPP-14 Hexham Swamp wetlands, with heavy metals and ammonia already detected in Ironbark Creek above ANZECC trigger values;
- Leachate contaminated groundwater may continue to migrate into Ironbark Creek if left unchecked, and potentially impact on aquatic ecosystems; and
- Heavy metals, some PAHs and ammonia are toxic to aquatic organisms and can bioaccumulate in plants and animals, including aquatic organisms.

Newcastle City Council is in the process of formulating a long term remediation strategy for the Astra Street landfill that will consider the impacts of opening the floodgates (pers comm.. Paul McMurray, NCC, 2004).

3.6.2 Lorna Street Landfill

A former landfill site is located off Lorna Street, Sandgate, known as the Shortland Refuse Tip. The site of the landfill is roughly located between the main northern rail line and the Shortland Waters Golf Club / University of Newcastle sites, adjacent to the Newcastle Wetlands Reserve. Several earlier references cite water quality impacts from Shortland Refuse Tip leachate, and later references

indicate a leachate collection and evaporation system was put in place to mitigate water quality impacts from this leachate.

The Shortland Tip was decommissioned following the commissioning of the Astra Street landfill in about 1972. This tip was in operation before the floodgates were installed. Therefore, the tip level is likely to be well above the level at which would experience tidal inundation and negligible impacts from this tip would be expected when the gates are opened.

3.6.3 North Limited Land off Maitland Road, Sandgate

A storage handling facility owned by North Limited, located off Maitland Road, Sandgate, is also listed in Section 60 of the Contaminated Lands Management Act 1997. This site is known as the Toll Bulk Services Site (Sandgate), and contains an impervious liner and containment cell to prevent the escape of contaminants to the surrounding environment.

3.6.4 Night Soil Disposal behind Wallsend Cemetery

Newcastle City Council has indicated that there is a former night soil disposal site located adjacent to Wallsend Cemetery. This site is situated on higher ground adjacent to Hexham Swamp, and as such, should not be affected by increased tidal inundation associated with opening of the floodgates.

3.6.5 Dark Creek Informal Disposal Site

Dark Creek is an artificially dredged channel that was originally constructed to drain the surrounding urbanised catchment area to Ironbark Creek. An informal disposal site for rubbish and other typical urban pollutants was identified adjacent to Dark Creek on land currently owned by Council (refer Figure 3.14).

A geochemical investigation of the informal disposal site was carried out by Robert Carr and Associates (2003). This investigation involved collection and analysis of soil and groundwater samples from sites within and around the visible disposal area. Robert Carr and Associates (RCA) found that sections within the site contained low to moderate contamination of Polyaromatic hydrocarbons (PAH), with concentrations up to six (6) times guideline values. The contamination was generally confined to the near surface sediment. PAH was not detected in the groundwater, and for this reason, RCA concluded that leaching of the contamination was not occurring at the time of the investigation.

RCA (2003) postulated that the source of the elevated PAH concentrations at the site may include:

- Illegal fuel / oil / lubricant disposal;
- Deposition of either free contaminants or contaminated sediment from upstream sources (however, this scenario fails to explain the apparent variation in PAH concentrations across the site).

RCA considers that the site is a minor health risk, and does not warrant remediation given its remoteness and lack of groundwater leaching.



Figure 3.14 Location of Contaminated Soils Adjacent to Dark Creek, Shortland

3.7 Vegetation

3.7.1 Previous Studies of the Hexham Swamp Vegetation

The vegetation of Hexham Swamp has been described previously in a number of studies. These are briefly summarised below.

3.7.1.1 DPW (1972)

DPW (1972) provided a brief description of the vegetation as part of an environmental assessment for the construction of the drainage works near the mouth of Ironbark Creek. Only dominant species were recorded and no vegetation map was provided.

3.7.1.2 Briggs (1978)

The first detailed vegetation description of the site is provided by Briggs (1978). Using aerial photograph interpretation with some field observations, the vegetation was mapped into four zones, based on hydrological and salinity conditions. The zones consisted of intertidal wetlands (tidally inundated), reed communities dominated by *Fimbristylis ferruginea* (brackish), fresh meadow and

seasonal fresh swamp (mostly fresh), and grass swamp and other freshwater communities (fresh, regularly inundated).

3.7.1.3 Pressey (1981)

A survey of the non-tidal wetlands of the Lower Hunter floodplain by Pressey indicated that Hexham Swamp represented approximately 37% of the total non-tidal wetland area within the floodplain. Vegetation communities characterised by common reed, cumbungi, *Schoenoplectus littoralis* and *Bolboschoenus caldwellii*, were well represented within Hexham Swamp relative to other habitats in the Lower Hunter floodplain. Based on its extent, Pressey considered Hexham Swamp to be an 'outstanding' wetland in a regional context.

3.7.1.4 Conroy and Lake (1992)

A vegetation assessment of the Hexham Swamp area was also carried out by Conroy & Lake (1992) using similar methodology to that of Briggs (1978), whereby, broad vegetation communities were delineated on aerial photographs (February 1989) and field studies were carried out to confirm vegetation community types and their extent. Considerable differences between the vegetation maps of Briggs (1978) and Conroy and Lake (1992) are apparent, most notably, a reduction in the area of tidal wetlands. This is likely to be the result of the installation of the floodgates at Ironbark Creek and associated works. In addition, there was a major expansion of common reed (*Phragmites australis*), which replaced virtually all of the *F. ferruginea* community mapped by Briggs (1978).

3.7.1.5 Winning (1996)

The most recent description of the swamp as a whole is by Winning (1996) which included a vegetation assessment of the Kooragang and Hexham Swamp Nature Reserves and adjoining land. The assessment was based on aerial photography (1992/1993, 1966, and 1954) and field survey. Vegetation information from circa. 1850 was also obtained from various historical land survey maps.

The analysis indicates that large parts of Hexham Swamp were originally covered with swamp oak (*Casuarina glauca*) dominated communities, most of which was cleared by 1954, presumably for grazing. Areas of freshwater reed/sedge land and intertidal wetland present in 1850 were essentially unchanged in 1954 and 1966. However, based on the vegetation mapping of Briggs (1978) and Conroy and Lake (1992), there was a reduction in the extent of these intertidal wetlands between 1966 and 1992/3.

By 1992/3 much of the area formerly occupied by intertidal wetlands consisted of perennial and transient fresh/brackish marsh/meadow. Furthermore, areas covered by common reed land expanded from a few small, isolated stands in 1966 to an area covering most of the central portion of Hexham Swamp in 1992/3.

Winning (1996) concluded that the extensive areas of *F. ferruginea* mapped by Briggs (1978) were incorrectly typed, and that these areas were most likely a brackish swamp dominated by *Schoenoplectus littoralis*.

3.7.1.6 *Winning (1997)*

This study was part of the EIS prepared by CH2MHill (1997) for the Maryland to Shortland Rising Main. It describes the vegetation of a relatively small area in the southern part of Hexham Swamp, based on field survey. No significant plant species or communities were recorded during this work.

3.7.1.7 *Winning (1999) and Winning & King (2002-2003)*

Winning (1999) and Winning & King (2002-2003) have collected baseline quantitative data on vegetation in Hexham Swamp since 1997 as part of an ongoing study for Hunter-Central Rivers Catchment Management Authority (previously Hunter Catchment Management Trust). The study has expanded in scope since its inception in 1997, and currently comprises data collected every three months along 53 transects in Hexham Swamp and at several control and reference sites outside of Hexham Swamp. The abundance of plant species is recorded at intervals along each transect to provide a description of the vegetation at that sample site.

While many new sample sites have been added to the survey (as previously privately owned land became accessible), a number of sites have been sampled more or less continuously since 1997. A detailed analysis of the data from these sites presented in Winning & King (2002) using non-metric multidimensional scaling (MDS) showed that the vegetation at a number of sites noticeably shifted between 1997 and 2002 from vegetation dominated by salt tolerant species (i.e. relic and degraded saltmarsh) to vegetation dominated by species less tolerant of salt (e.g. *Paspalum vaginatum*). Other sites were evidently invaded by *Phragmites australis* during the period between 1997 and 2002.

The data from this ongoing baseline study demonstrate that the vegetation in Hexham Swamp is still changing in response to the cessation of tidal inundation resulting from the construction of the floodgates.

3.7.1.8 *King (1999)*

King (1999) mapped the vegetation of Hexham Swamp as it occurred in 1999 based on aerial photograph interpretation and detailed ground-truthing. No quantitative analysis was undertaken.

3.7.1.9 *Morrison (2000)*

Morrison (2000) undertook a GIS analysis of historical changes in vegetation in Hexham Swamp using aerial photography from 1938, 1954, 1966, 1976, 1986, 1994 and 2000. This analysis quantified previous observations of a substantial decrease between 1938 and 2000 in intertidal communities and an increase in reed swamp. Morrison (2000) also attempted to model the likely distribution of mangroves and saltmarsh in Hexham Swamp should the floodgates be opened. This modelling was simplistically based on elevation alone, and Morrison (2000) concluded that the lack of microtopographical data for Hexham Swamp substantially limited the models such that she could only conclude that mangrove and saltmarsh communities will re-establish in Hexham Swamp if tidal flow is reinstated.

3.7.1.10 MacDonald (2001)

In a study of historical changes to a number of estuarine wetlands in the Hunter River estuary, MacDonald (2001) looked at a small part of Hexham Swamp east of Ironbark Creek and north of the suburb of Shortland. The analysis of change between 1969 and 1993 showed similar changes to that of Morrison (2000) albeit at a smaller scale (i.e. substantial decrease in mangroves and saltmarsh, and increase in *Casuarina* and *Phragmites*).

3.7.2 Description of the Existing Vegetation

3.7.2.1 Methods and Results

The following description of the existing vegetation is based on the mapping undertaken by Morrison (2000). Morrison's objective was to compare vegetation for several different points in time using aerial photograph interpretation, including early black and white photography. As a consequence, Morrison (2000) needed to adopt broad vegetation map units that could be identified and delineated for all of the aerial photograph units, regardless of whether they were monochrome or colour, and without the benefit of ground-truthing.

Of the eleven map units used by Morrison (2000), nine relate to vegetation present in Hexham Swamp in her interpretation of 2000 aerial photography. These nine vegetation map units or vegetation communities are described below, with the basic definition adopted by Morrison being augmented by field observations, particularly as described by Winning & King (2002), Winning & King (2003) and Winning (pers. obs.). The map of existing vegetation (2000) is presented in Figure 3.15 and the extent of the vegetation communities is summarised in Table 3.19.

Vegetation structural descriptions are based on those of Specht (1981). A list of plant species encountered within Hexham Swamp is presented in **Appendix E: Volume 2**. Plant nomenclature follows that of Harden (1990-1993). *Environmental weed* refers to any plant that survives in a natural area where its presence is undesirable, harmful or troublesome to the existing land use. A *noxious plant* means a declared plant under the *Noxious Weeds Act 1993*.

On 1 June 1999, the Commonwealth Government declared 20 weeds to be *Weeds of National Significance* (WONS). The endorsement of a weed species as a WONS, by definition, requires that national action is needed to effectively manage the weed by restricting its spread and/or eradicating it from parts of Australia.

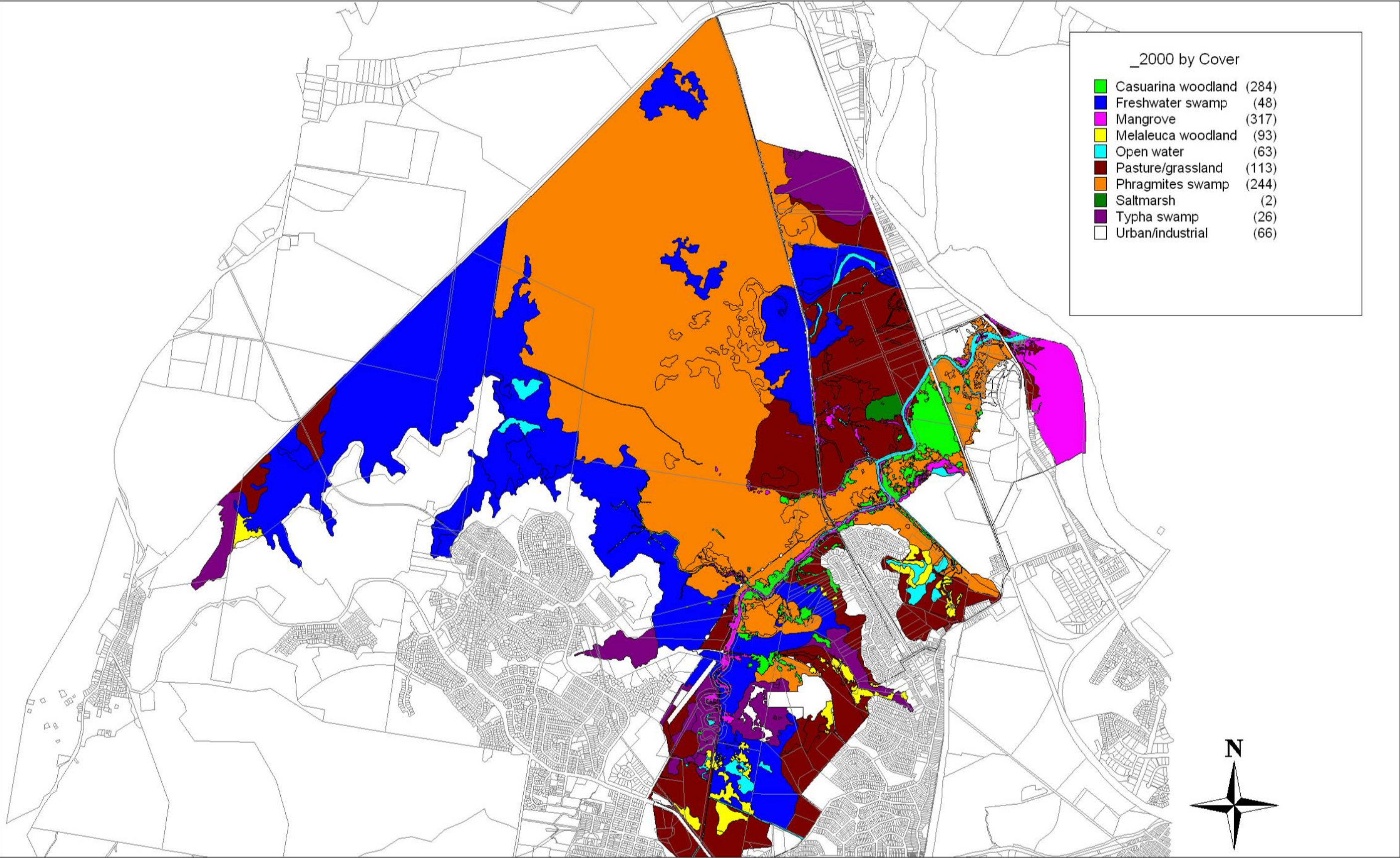


Figure 3.15 Vegetation communities of Hexham Swamp (Source: Morrison, 2000)

Table 3.19 Vegetation Communities in Hexham Swamp 2000

Vegetation Community	Description	Area (ha)	% of Total
1	Mangrove	22	1
2	Saltmarsh	6	0
3	Open water	38	2
4	Freshwater swamp	575	27
5	Common Reed (Phragmites swamp)	918	43
6	Broad-leaved Cumbungi (Typha swamp)	110	5
7	Swamp She-oak (Casuarina glauca woodland)	47	2
8	Paperbark (Melaleuca woodland)	31	1
9	Pasture/grassland	369	17
Total		2116	

Source: Morrison (2000)

3.7.2.2 Descriptions

Vegetation Community 1: Mangroves

This community comprises areas of land covered by canopies of mangroves, and is relatively easily distinguished on aerial photography due to it generally comprising one species - grey mangrove (*Avicennia marina* var. *australasica*). While mangroves were once historically extensive in Hexham Swamp, they are now generally restricted to the edges of creeks that continue to have some tidal flow, as scattered remnant patches.

Structurally, they occur as low closed (70-100 % foliage projective cover [FPC (based on visual estimates according to Specht1981) and open mangrove forest (30-70 % FPC) along the banks of Ironbark Creek, Fishery Creek, and Shelley Creek and other drainage lines, and as low woodland (10-30 % FPC) and low open woodland (< 10% FPC) some distance away from the drainage lines.

The predominant species is Grey Mangrove, averaging heights of 4 m away from the drainage lines, to 10 m along Ironbark Creek. River mangrove (*Aegiceras corniculatum*) occurs in the understorey at some creek locations to a height of 2m. While mangroves along the drainage lines were apparently healthy, most of those away from the drainage lines were dead or dieing. Swamp she-oak (*Casuarina glauca*) often occurs among the mangroves as an emergent species, particularly along the landward edge adjacent to major drainage lines. The ground layer is variable. In areas where tidal inundation still occurs, ground cover is generally sparse and comprises saltmarsh species, mainly saltmarsh

couch (*Sporobolus virginicus* var. *virginicus*). In remnant patches removed from the existing tidal inundation, species with a lower salt tolerance, especially common reed (*Phragmites australis*) are common.

Alligator weed (*Alternanthera philoxeroides*) occurs among mangrove roots in the upper reaches of Ironbark Creek. Alligator weed is a W3 category noxious weed in the Newcastle area, and is listed as a WONS.

Vegetation Community 2: Degraded Saltmarsh

These are relic areas of previous tidal saltmarsh. As Morrison's (2000) analysis shows (discussed below in Section 3.6.3.1), most of the original saltmarsh vegetation has been displaced by vegetation with a lower salt tolerance, especially common reed. Morrison (2000) mapped an area of saltmarsh in the eastern part of Hexham Swamp. Smaller areas of saltmarsh persist west of the Chichester pipeline, which were presumably not mapped by Morrison (2000) because of their limited extents. Areas of saltmarsh vegetation also still persist in parts of the Morrison's (2000) "freshwater swamp" community on the western edge of Hexham Swamp.

Typical saltmarsh species samphire (*Sarcocornia quinqueflora*) and saltmarsh couch persist in these relic saltmarsh areas. Along the margins of these areas the saltmarsh species occur mixed with species adapted to lower salinities such as water buttons (*Cotula coronopifolia*), water couch (*Paspalum vaginatum*) and blown grass (*Lachnagrostis filiformis*).

Structurally, this community varies from a closed grass/herb land (70-100 % FPC) to scattered plants. The height is generally low, approximately 0.1 m.

Vegetation Community 3: Common Reed

This community was the most widespread vegetation type within the study area, and has expanded considerably in the recent past (see Section 3.6.3.1). In its pure form it is a tall (up to 2m) closed grassland (70-100 % FPC) of one species, common reed. As mapped by Morrison (2000), it includes relatively small areas of low open grassland of common reed and water couch, patches of broad-leaved cumbungi (*Typha orientalis*), as well as relatively small areas of degraded saltmarsh (historical saltmarsh communities in the process of being displaced by species with a lower salt tolerance).

Vegetation Community 4: Open Water

Morrison's (2000) map shows larger ponds and channels which appear on aerial photography as open water. Those areas within larger creeks support little aquatic vegetation, due mainly to the high turbidity of the water, and the edge vegetation varies depending on prevailing salinity conditions. Within the swamp proper, there are many ephemeral ponds and channels. When inundated, the water is generally fresh with an open (10-30 % FPC) to very open (< 10 % FPC) sedge and herb land of up to 0.5 m height emerging from the water surface. The most prominent species is coastal club rush (*Bolboschoenus caldwellii*). Other important species include water couch, broad-leaved cumbungi and *Schoenoplectus littoralis*.

Vegetation Community 5: Freshwater Swamp

This vegetation community is extensive in the western part of the swamp, particularly towards Minmi. It comprises an intermittently inundated grass/sedge/herb land (30-70 % FPC) to closed grass/sedge herb land (70-100 % FPC) of approximately 0.1-0.5 m height. Common species include coastal club rush, water couch, water ribbons (*Triglochin microtuberosum*) and knotweeds (*Persicaria* spp.). In prolonged droughts, the community can be gradually colonised by species that are less tolerant of waterlogged soils, such as common couch (*Cynodon dactylon*) and fireweed (*Senecio madagascariensis*).

Vegetation Community 6: Broad-leaved Cumbungi

This closed community (70-100 % FPC), with a height of 1-2 m is dominated by broad-leaved cumbungi. It is mostly associated with edge parts of the swamp receive runoff from large catchments. However, as noted above, cumbungi also occurs in patches in extensive stands among common reed and in ephemeral ponds and channels.

Vegetation Community 7: Swamp She-oak

Small stands of swamp she-oak occur throughout the edges of Hexham Swamp. The community is particularly common along the banks of Ironbark, Fishery and Shelley Creeks, with a large stand occurring adjacent to the main northern railway, on the southern bank of Ironbark Creek. Individuals of Swamp Oak also occurred as widely dispersed juveniles among the common reed communities in the southern parts of Hexham Swamp, suggesting the commencement of a new seral stage. The structure of swamp she-oak communities vary from woodland (10-30 % FPC) through to closed forest (70-100 % FPC) on the banks of Ironbark Creek. Heights vary from 3 m for juveniles to 10-15 m for the closed forest along Ironbark Creek. A shrub layer occurs in some patches, with the most common species being lantana (*Lantana camara*) and boobialla (*Myoporum acuminatum*). The ground layer usually consists of species similar to adjoining communities, although in denser patches the ground layer is virtually absent.

Vegetation Community 8: Paperbark

Patches of vegetation dominated by *Melaleuca* species occur in the upper edges of the swamp. The dominant species varies with soil type, with broad-leaved paperbark (*Melaleuca quinquenervia*) dominating on sandy soils near Shortland, and narrow-leaved paperbark (*Melaleuca linariifolia*) and prickly-leaved paperbark (*Melaleuca styphelioides*) dominating on soils with a higher clay content near Minmi. Most patches form a closed forest (70-100 % FPC) with a height of 10-15 m. Ground layer vegetation generally comprises freshwater herbs and grasses.

Vegetation Community 9: Pasture / Grassland

These are areas that fall within the Hexham Swamp geomorphic unit but are of high enough elevation not to be inundated, except for major flood events. Historical grazing of these areas has maintained a low (0.1-0.3m) closed grass/herb land (70-100 % FPC) or pasture. Common species include common couch, kikuyu (*Pennisetum clandestinum*), fireweed, paspalum (*Paspalum dilatatum*) and plantain (*Plantago lanceolata*).

3.7.3 Conservation Values

3.7.3.1 Vegetation Change

As noted in the above discussion, the vegetation of Hexham Swamp has been subject to considerable change in the last century. While freshwater swamp forests were cleared early on, probably for agricultural pursuits, much of the recent change has been due to the construction of the Hunter River levee and the installation of the floodgates at the mouth of Ironbark Creek, resulting in extensive changes in the hydrology of the swamp. Development of the residential estates within the catchment would have altered erosion and run-off characteristics, thus also contributing to vegetation change within the swamp.

While there would have been short-term oscillations in vegetation community boundaries as the result of variation in climatic conditions from year to year, the major change during the last few decades has been the decrease in tidally inundated wetlands and the concurrent expansion of reed and sedge lands.

The most comprehensive analysis of changes in vegetation in Hexham Swamp was undertaken by Morrison (2000) who mapped broad vegetation communities using aerial photography and compared changes in area of those communities. Morrison (2000) concluded that there had been a substantial decrease between 1938 and 2000 in mangroves (-75%), saltmarsh (-99%) and open water (-63%), and a substantial increase in *Phragmites* swamp (+2861%), *Typha* swamp (+328%) and *Casuarina* woodland (+900%). Other changes were also noted, including the loss of 207ha of swamp to urban and industrial development since 1938. Copies of Morrison's maps for 1938, 1954, 1966, 1976, 1986 and 1994 are reproduced, with permission, as Figure 3.16 to Figure 3.21, while the 2000 vegetation map was presented previously as Figure 3.15.

Table 3.20 Changes in Vegetation Communities in Hexham Swamp 1938-2000
(Source: Morrison, 2000)

Cover	1938	1954	1966	1976	1986	1994	2000	Change 1938-2000 (ha)	Change 1938-2000 (%)
Mangrove	86	148	173	125	53	23	22	-64	-75
Saltmarsh	904	825	761	544	238	23	6	-898	-99
Open water	105	103	105	87	66	25	38	-66	-63
Freshwater swamp	866	857	820	870	689	605	575	-291	-34
Common Reed (<i>Phragmites</i> swamp)	0	31	24	137	699	859	918	887	2861
Broad-leaved Cumbungi (<i>Typha</i> swamp)	26	19	19	94	56	95	110	84	328
Bare earth	6	16	8	0	0	0	0	-6	-100
Swamp She-oak (<i>Casuarina</i> woodland)	5	9	11	14	18	25	47	42	900
Paperbark (<i>Melaleuca</i> woodland)	29	38	24	22	27	26	31	2	8

Cover	1938	1954	1966	1976	1986	1994	2000	Change 1938-2000 (ha)	Change 1938-2000 (%)
Urban/industrial	66	93	202	279	328	343	339	273	411
Pasture/grassland	364	316	309	284	282	431	369	5	1
Total	2455	2455	2455	2455	2455	2455	2455		

Note that the mapping carried out by Morrison extended beyond the Project Boundary defined for this project, thus the total area mapped (2455 ha) exceeds the area defined by the Project Boundary (1948 ha – refer Section 3.1.1).

3.7.3.2 Existing Vegetation Communities in Regional Context

An examination of regional vegetation surveys indicates that none of the vegetation communities occurring within Hexham Swamp can be considered to be rare or threatened. Similar communities occur elsewhere within the region, including the Hunter Valley (Pressey 1981), Port Stephens and Myall Lakes area (McNair 1992), the Lake Macquarie-Gosford area (Benson 1986), and the Hawkesbury River estuary (Benson and Fallding 1981). However, Hexham Swamp is mapped as SEPP14 Wetland No. 840 and is large by regional standards.

A survey of the non-tidal wetlands of the Lower Hunter floodplain by Pressey (1981) indicated that Hexham Swamp represented approximately 37% of the total non-tidal wetland area within the floodplain. Based on its extent, Pressey considered Hexham Swamp to be an “outstanding” wetland in a regional context. Vegetation communities well represented within the Swamp included common reed, cumbungi, *Schoenoplectus littoralis* and *Bolboschoenus caldwellii* communities (Table 3.21).

Most of Pressey’s data would no longer be valid, given the changes that have occurred within Hexham Swamp in the last two decades. Many of the communities delineated by Pressey no longer occur and as discussed, common reed has expanded considerably at the expense of cumbungi and sedge communities. Assuming that the area of common reed outside Hexham Swamp has remained constant since Pressey’s (1981) study (i.e. 47.9 ha, see

Table 3.21), the proportion of the regional common reed resource located within Hexham Swamp is now 95.0%.

Mangrove communities in the study area have always been small by regional standards. Hexham Swamp accounted for approximately 10% of the Lower Hunter’s mangrove communities in 1966. By 1994, this was reduced to approximately 1%. With regard to saltmarsh, however, Hexham Swamp historically supported a large proportion of the total saltmarsh in the Lower Hunter (approximately 30%), being reduced by 1994 to approximately 3%. The loss of virtually all saltmarsh and mangroves (other than for gallery mangroves along creeks) in Hexham Swamp since installation of the floodgates has therefore contributed considerably to the decline of this community in the Lower Hunter (see Table 3.22).

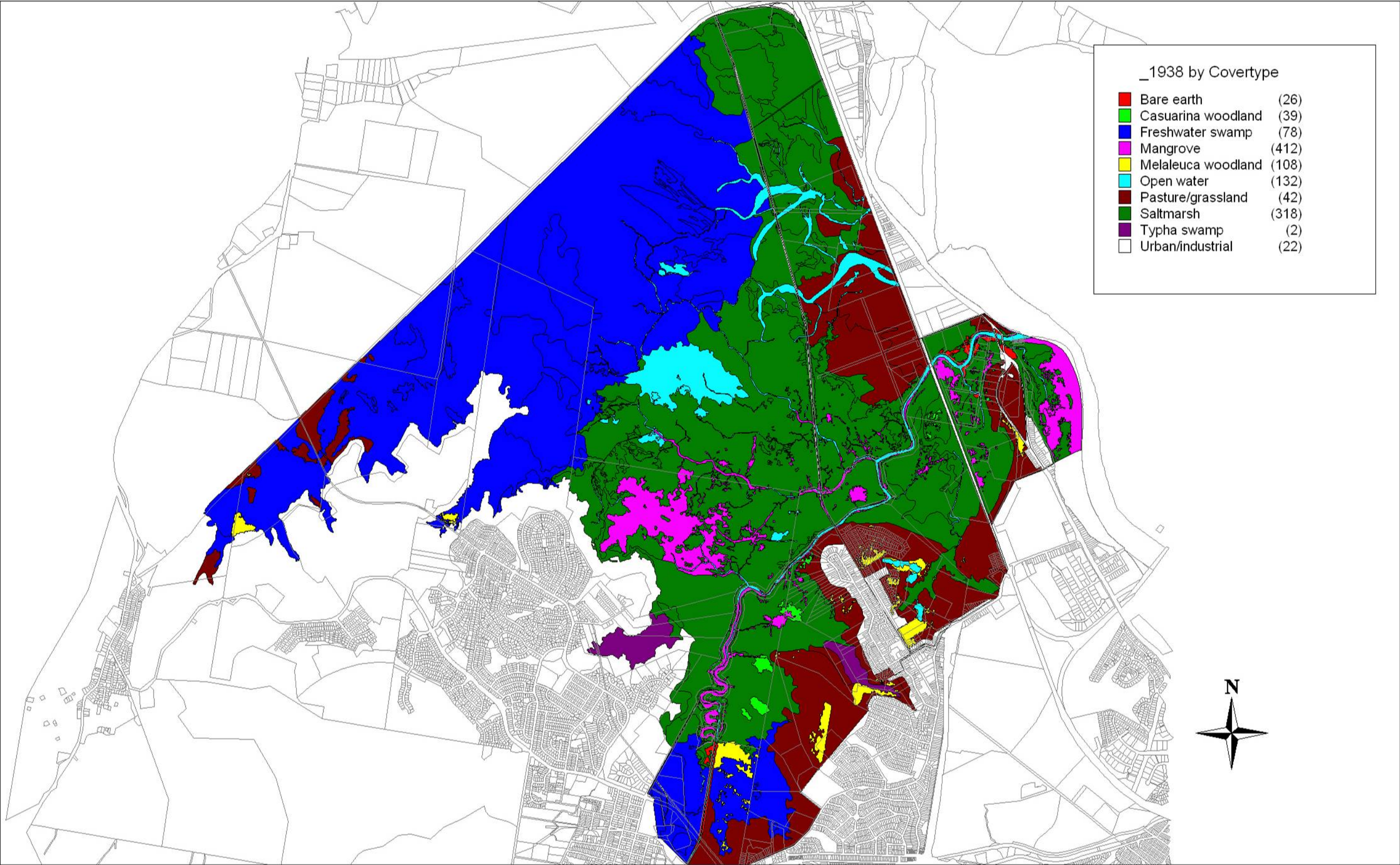


Figure 3.16 Vegetation Map of the Study Area 1938 (Source: Morrison 2000)

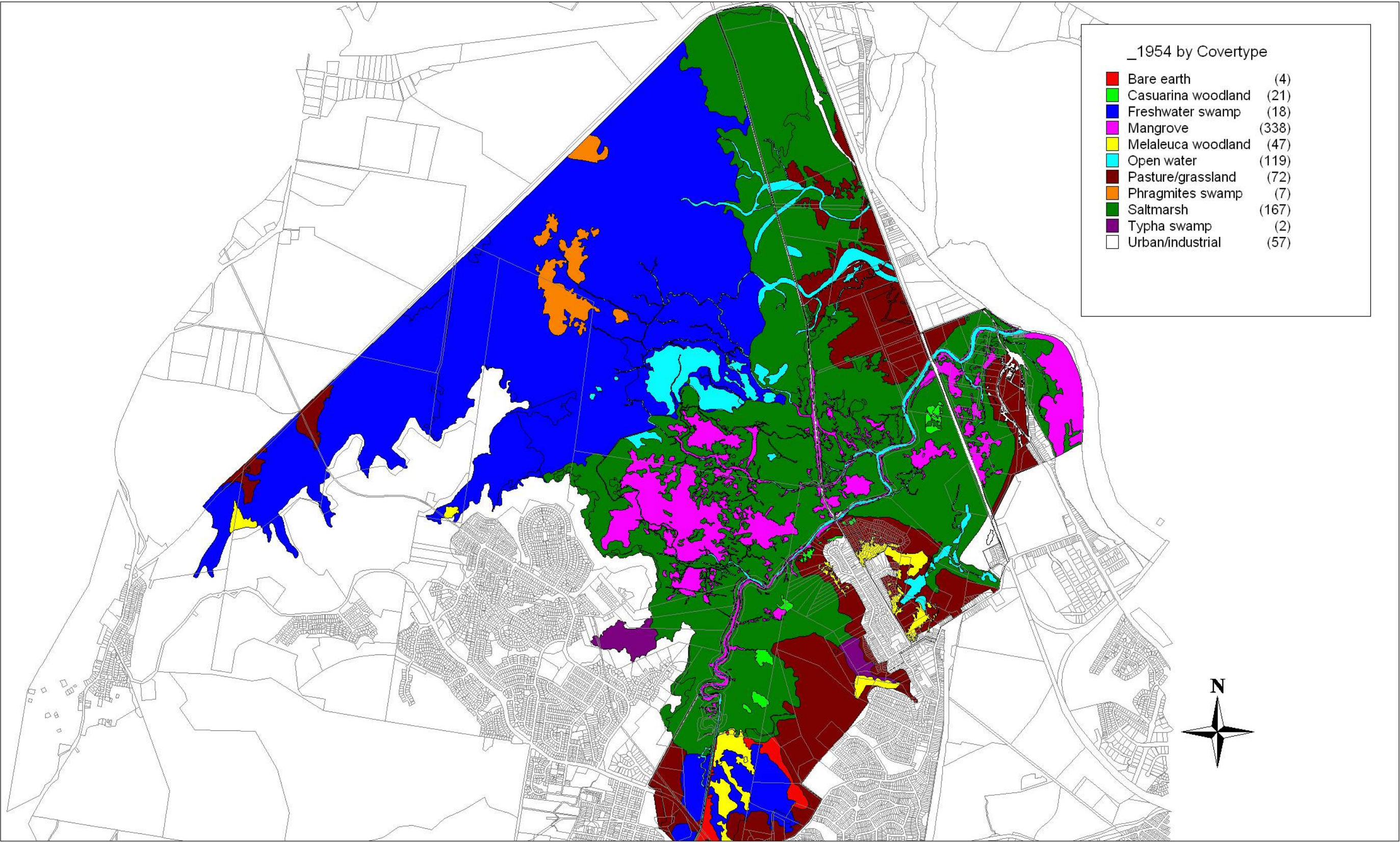


Figure 3.17 Vegetation Map of the Study Area 1954 (Source: Morrison 2000)

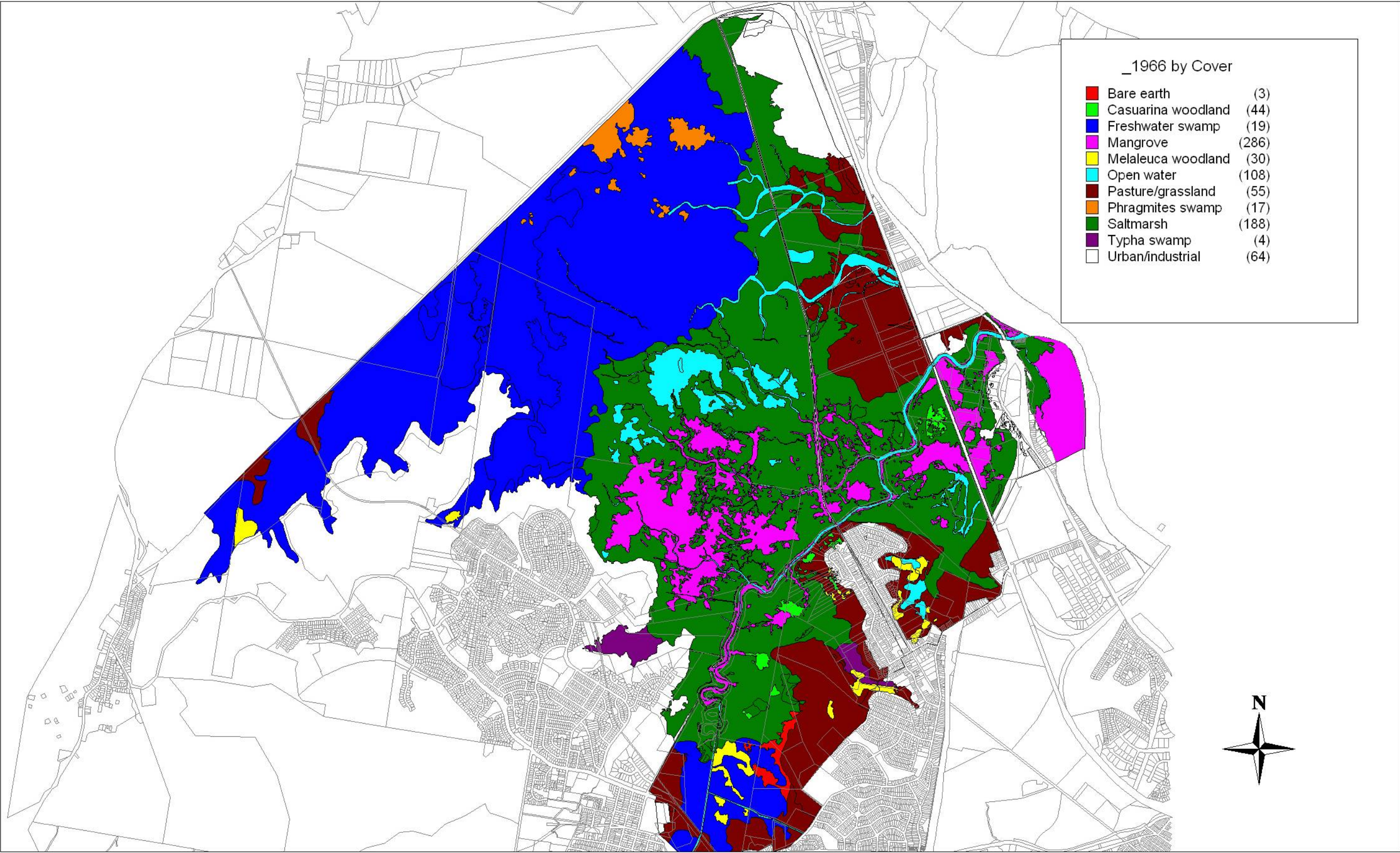


Figure 3.18 Vegetation Map of the Study Area 1966 (Source: Morrison 2000)

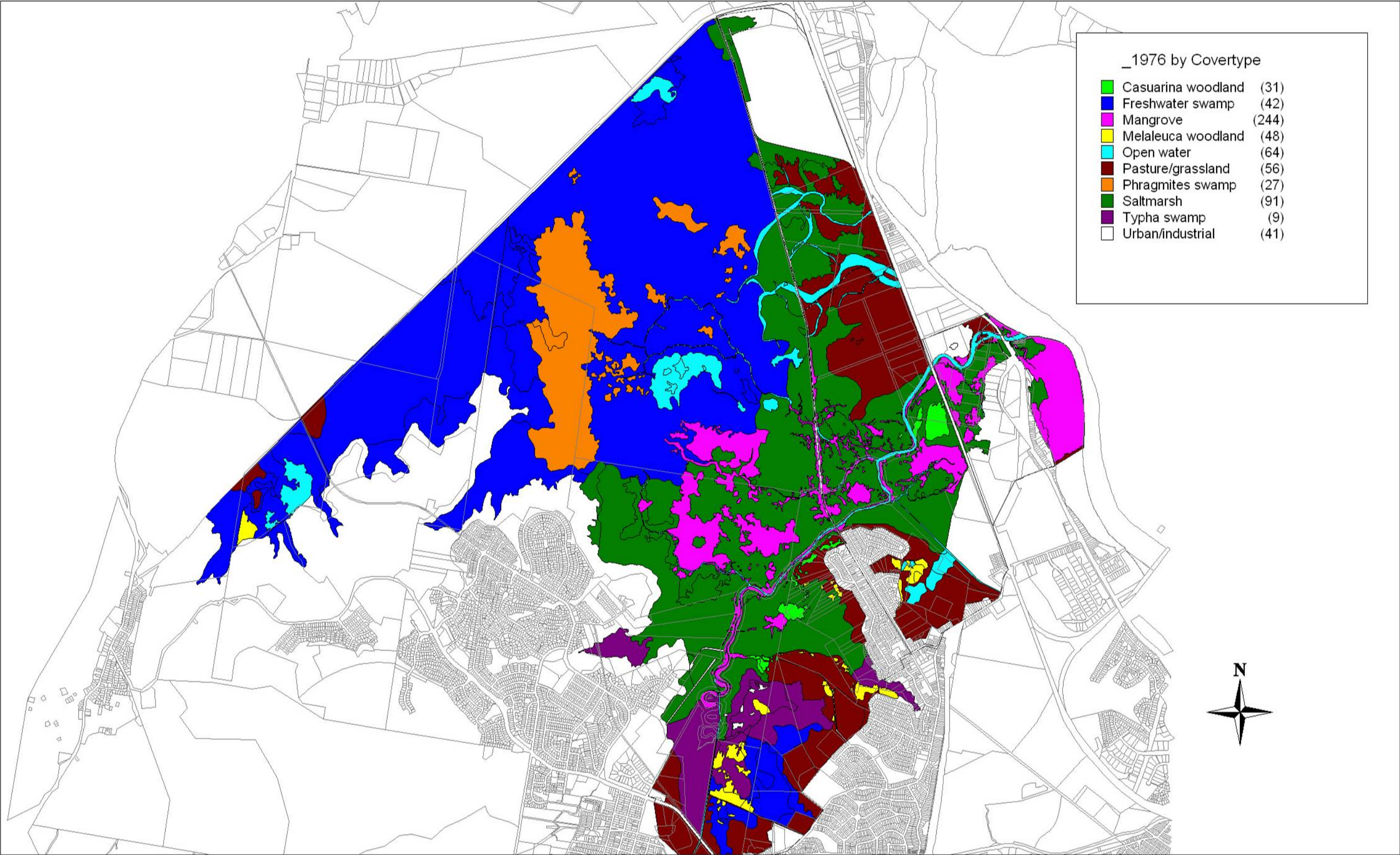


Figure 3.19 Vegetation Map of the Study Area 1976 (Source: Morrison 2000)

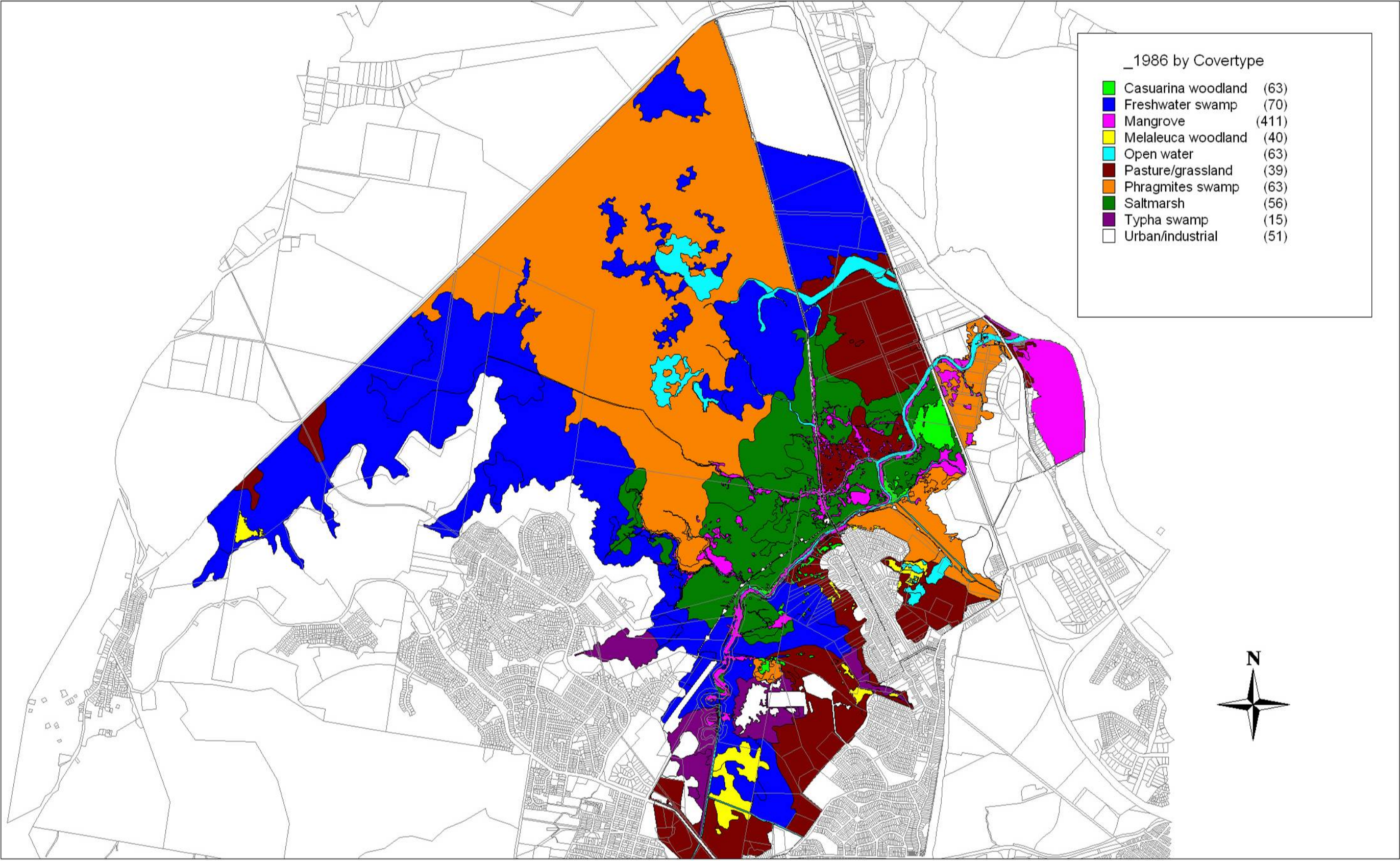


Figure 3.20 Vegetation Map of the Study Area 1986 (Source: Morrison 2000)

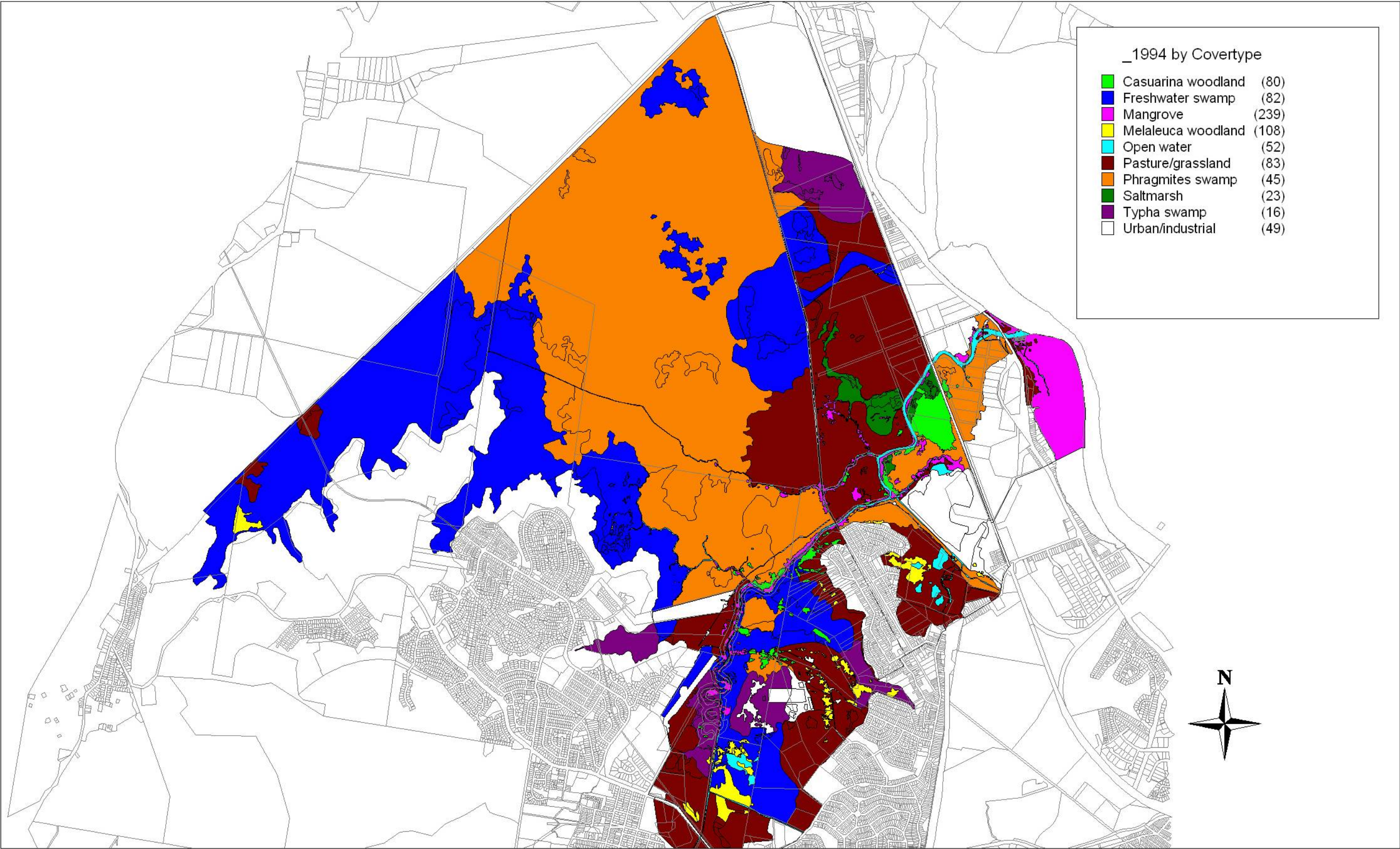


Figure 3.21 Vegetation Map of the Study Area 1994 (Source: Morrison 2000)

Table 3.21 Vegetation of the Study Area in Spatial Context

Community type	Total Area in Lower Hunter Floodplain (ha)*	Area at Hexham Swamp (ha)	Percentage of Total Area in Hexham Swamp
<i>Casuarina glauca</i>	115.6	20	17.3
Narrow-leaved Paperbark	104.2	10	9.6
<i>Melaleuca quinquenervia</i>	29.1	10	34.4
<i>Phragmites australis</i>	592.9	545	91.9
<i>Typha orientalis</i>	128.1	105	82.0
<i>Schoenoplectus littoralis</i>	35.2	35	99.4
<i>Juncus sp.</i>	624.9	88	14.1
<i>Eleocharis spp.</i>	268.2	88	32.8
<i>Bolboschoenus caldwellii</i>	203	175	86.2
<i>Triglochin procera</i>	122.5	30	24.5
<i>Lidwigia peploides</i>	52	18	34.6
<i>Paspalum paspalodes</i>	1249.9	526	42.1
Shallow open water	967.2	105	10.9

* Adapted from Pressey (1981) and assumes no change in vegetation extents in the Lower Hunter Floodplain beyond Hexham Swamp since 1981.

Table 3.22 Changes in Intertidal Wetlands in Lower Hunter 1966-1994 (Source: Williams et al., 1998 & Morrison, 2000)

Community	Area in 1966 (ha)	Area in 1994 (ha)
Mangrove		
Lower Hunter (excl. Hexham)	1541	1711
Hexham	173	23
Total Mangrove (% in Hexham)	1714 (10)	1734 (1)
Saltmarsh		
Lower Hunter (excl. Hexham)	1803	705
Hexham	761	23
Total Saltmarsh (% in Hexham)	2564 (30)	728 (3)

3.7.3.3 Existing Vegetation Communities in National Context

A recent assessment of the conservation status of vegetation communities on a national basis is provided by Specht *et al.* (1995). Table 3.23 shows the vegetation communities found in Hexham Swamp together with the approximate equivalent communities used by Specht *et al.* (1995). Equivalent communities listed by Specht *et al.* (1995) were considered to be reasonably to adequately protected on a national level.

Table 3.23 National Conservation Status of Vegetation Communities

This Assessment Community	Description	Specht et al (1995) Description	National Conservation Status
1	Mangroves	<i>Avicennia marina</i> - <i>Aegiceras corniculatum</i> (Map Number 791)	Adequate
2	Degraded Salt Marsh	<i>Halosarcia pergranulata</i> - <i>Sarcocornia quinqueflora</i> / <i>Sporobolus virginicus</i> (Map Numbers 792/793)	Adequate/Adequate
3	Common Reed (<i>Phragmites australis</i>)	<i>Phragmites australis</i> - <i>Typha</i> spp. (Map Number 754)	Reasonable
4	Ephemeral Ponds and Channels	No Equivalent	
5	Fresh Water Swamp	No Equivalent	
6	Broad-leaved Cumbungi (<i>Typha orientalis</i>)	<i>Phragmites australis</i> - <i>Typha</i> spp. (Map Number 754)	Reasonable
7	Semi-Permanent and Permanent Ponds	No Equivalent	
8	Swamp She-Oak (<i>Casuarina glauca</i>)	<i>Casuarina glauca</i> (Map Number 794)	Adequate

3.7.3.4 Significant Plant Species

One plant species found in Hexham Swamp, *Zannichellia palustris*, is listed as 3R+ in the Rare or Threatened Australian Plants (ROTAP) list by Briggs and Leigh (1996) (see Table 3.24), and as Endangered (Schedule 1) under the New South Wales *Threatened Species Conservation Act 1995*. The species is not currently listed under the federal *Environment Protection and Biodiversity Conservation Act 1999*.

Zannichellia palustris is an aquatic halophyte that occurs in eutrophic lakes, rivers and estuarine areas in Europe and North America, where it occasionally requires control. It was first recorded in Australia near Murray Bridge in South Australia in 1887. Since 1971 it has been recorded in the Canoe Channel (a drain off Ironbark Creek), as well as near the Minmi Road bridge across Ironbark Creek, Black Creek at Cessnock, ponds on Kooragang Island, and near Belmont (Winning 1996; Winning 1999b). Its occurrence in the Lower Hunter has been known since the 1971 (pers comm.. Dr S. Skinner, Royal Botanic Gardens, 2005).

Given its worldwide distribution and its relatively recent discovery within the Hunter region, it is not clear whether the species is a recent introduction, possibly brought in on ballast water, or an indigenous species to NSW with a restricted range.

In a study of the ecology of *Zannichellia palustris* in the Lower Hunter, Greenwood (2001) suggested that the species is introduced, based mainly on its occurrence in estuaries near major sea ports in Australia. However, the current view in the botanical literature is that *Zannichellia palustris* is a native species (i.e. present before 1788) and, in any case, it is listed as an endangered species in New South Wales.

Further information on this species is provided in the Eight Part Test in **Appendix H: Volume 2** of this document.

Table 3.24 ROTAP Status of *Zannichellia palustris*

Symbol	Meaning
3	Range > 100 km within Australia, but occurs only in small populations which are mainly restricted to highly specific, localised habitats.
R	Rare in Australia but not considered Endangered or Vulnerable. May occur as a relatively large population in a restricted area, or as smaller populations spread over a wider range, or some intermediate combination of these patterns.
+	Overseas occurrence

3.7.3.5 Significant Ecological Communities

Coastal Saltmarsh

In addition to the listing of threatened species, the New South Wales *Threatened Species Conservation Act 1995* lists ecological communities (assemblages of plant and or animal populations) considered to be threatened in New South Wales. The ecological community *Coastal Saltmarsh in the NSW North Coast, Sydney Basin and South East Corner Bioregions* (Coastal Saltmarsh), was listed as endangered (Schedule 1) in June 2004, and occurs in the vicinity of Hexham Swamp.

Coastal Saltmarsh is described in the final determination for its listing as an endangered ecological community (EEC) as occurring in the intertidal zone on the shores of estuaries and lagoons including when they are intermittently closed along the NSW coast. Characteristic vascular plant species of

Coastal Saltmarsh are listed as: *Baumea juncea*, *Isolepis nodosa*, *Juncus kraussii*, *Samolus repens*, *Sarcocornia quinqueflora*, *Selliera radicans*, *Sporobolus virginicus*, *Suaeda australis*, *Triglochin striata* and *Zoysia macrantha*.

Small areas of communities dominated by some of the above-listed plants species (*Juncus kraussii*, *Sarcocornia quinqueflora*, *Sporobolus virginicus*, *Triglochin striata*) remain in Hexham Swamp, and represent highly degraded coastal saltmarsh communities. Tidal restriction, due to the construction of the floodgates, has dramatically reduced the extent of coastal saltmarsh in Hexham Swamp, as well as the rest of the Lower Hunter estuary. Artificial restriction of tidal flows, by structures such as floodgates, is listed in the determination as one of the key degrading influences on this endangered community.

Rehabilitation of Hexham Swamp through re-introduction of tidal waters to the wetland will result in substantial improvements to the existing coastal saltmarsh communities, although benefits are at this stage, mostly unquantifiable.

Swamp Oak Floodplain Forest

The ecological community *Swamp Oak Floodplain Forest of the NSW North Coast, Sydney Basin and South East Corner Bioregions* (Swamp Oak Floodplain Forest) was listed as endangered in December 2004. This ecological community occurs within Hexham Swamp, with the largest area adjacent to Ironbark Creek between the main northern rail line and the former Astra Street dump (refer Figure 3.15). This community is expected to experience some die-back with increased tidal inundation as a result of opening the floodgates, and would be replaced by mangroves, saltmarsh and saline ponds. Clause 15 of the determination for this endangered community recognises that the distribution and composition of floodplain communities may change as a result of rehabilitation works to restore more natural hydrological regimes within floodplain, but that coordinated planning and management approaches across the whole catchment is required to address and resolve priorities between different management objectives.

Coastal Floodplain Wetlands

The ecological community *Freshwater Wetlands on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner Bioregions* (Coastal Floodplain Wetlands) was also listed as endangered in December 2004, and also occurs within Hexham Swamp. This ecological community, which includes *Phragmites australis*, has established within Hexham Swamp at an increasing rate on areas that previously supported mangroves, saltmarsh and saline ponds. The Coastal Floodplain Wetlands endangered ecological community will die back with increased tidal inundation of the swamp subsequent to the managed opening of the floodgates, and would be replaced by the communities previously lost, including mangroves, saltmarsh and saline ponds. While extensive areas of the freshwater wetland community would be lost, they would be replaced by arguably more important estuarine communities, including the EEC Coastal Saltmarsh. As for the Swamp Oak Floodplain Forest determination, Clause 15 of the determination recognises that there is a dynamic response of this community to changes in hydraulics and hydrology. Accordingly, consideration has been given to the need for restoration of natural hydrological regimes within coastal floodplain wetlands, and the likely change in distribution and composition of communities that would result.

3.8 Fauna

There is a large body of information describing the fauna assemblages of the Ironbark Creek catchment. This existing information was of sufficient scope and detail to provide the description of the existing environment for this EIS, although some aspects were confirmed through additional field inspections.

3.8.1 Methods

The methodologies used in this study are outlined below.

3.8.1.1 Literature and database search

Information on the faunal assemblages and habitats within the study area was compiled and reviewed. Most relevant information was sourced from Pacrim (1998) including:

- scientific publications, reports undertaken for Local Authorities in the region and previous environmental planning and environmental impact studies;
- database records of the Australian Museum, Royal Australasian Ornithological Union (RAOU), local and recreational fishing association records, and NPWS and Fisheries records; and
- work by local universities and amateur naturalists.

Additional information was sourced from liaison with relevant government departments and local authorities. The following persons were contacted as part of the fauna assessment studies: Mr. Scott Carter (NSW DPI: Fisheries), Mr. Dennis Hirst and Mr. John Hewitt (commercial fisherman).

3.8.1.2 Field inspections

Site inspections were undertaken on the 3-4 August 1998 and 12 February 2002 to ground-truth information collated in the literature review. The purpose of these site inspections was to provide descriptions of the habitat types within the study area, particularly in regard to their condition, extent and the species likely to occur in these areas. Particular emphasis was placed on identifying the suitability of these habitats to species of high fisheries/conservation value.

3.8.1.3 Nomenclature

Unless otherwise noted, the nomenclature used for fauna in this study follows Strahan (1995) for mammals, Christidis and Boles (1995) for birds, Cogger (2000) for reptiles and amphibians, and McDowell (1996), Allen *et al.* (2000), and CSIRO CAAB database for fish.

3.8.2 Fauna habitats

3.8.2.1 Habitat Types

The installation of floodgates has severely modified the flow regimes and the diversity of habitats previously found in Ironbark Creek. In summary, the floodgates form a barrier to normal tidal flow, which has resulted in:

- the infilling and closure of some tributaries and deep water holes through siltation¹;
- the absence of tidal inundation of shallow saltmarsh habitats; and
- extensive losses of shallow estuarine habitats (mangroves and saltmarshes).

There are now two broad habitat types (containing a range of micro-habitat types) within the Ironbark Creek catchment. These are:

- Channel habitat, comprised of Ironbark Creek and its major tributaries; and
- Wetland habitat, comprised of the shallow, seasonally inundated freshwater wetland areas of Hexham Swamp.

The sections below describe each of the broad habitat types.

3.8.2.2 Channel Habitat

The channel habitat is the predominant habitat type in the four main creeks of the Ironbark Creek catchment, i.e. Ironbark Creek, Shelley Creek, Fishery Creek and the Canoe Channel.

The physical characteristics of each creek showed considerable variation. Within Ironbark Creek, the channel width increased with distance downstream (i.e. channel width is approximately 30 m in some downstream reaches compared to 2-5 m in upstream areas). Channel depth was typically between 1.5 to >2 m along most of its length, but was relatively shallow in far upstream reaches (i.e. near Minmi Road).

The two major tributaries of Ironbark Creek (Fishery and Shelley Creeks) were also deep in places (up to 1.5 m), but relatively narrow (8 to 10 m) compared with adjacent sections of Ironbark Creek. The Canoe Channel, located adjacent to Marist Park and the former Astra Street tip, was approximately 15 m wide and shallow (<1m) along its entire length. The Canoe Channel was historically dredged to facilitate drainage of lands at Sandgate.

Bank structure also varied within and among creeks. The banks immediately upstream of the gates were steep in places, but narrow intertidal fringes containing saltmarsh, mangrove and bare mud-banks were also present. These intertidal fringes supported small shore crabs and a range of other macroinvertebrate species. By contrast, the channel upstream of the gates (including Fishery and Shelley Creeks, and the Canoe Channel) had a steeper profile with no shallow intertidal fringe. Undercutting occurred along most of the banks, and a thick layer of fine black detrital matter, probably comprised of silt and decaying *Phragmites* sp., covered the bed in places.

The riparian fringe along all creeks was comprised almost entirely of common reed and other grasses, with occasional stands of mangroves (*Avicennia marina* and *Aegiceras corniculatum*) and she-oak

¹ The most significant closure is Muckeye Creek, located approximately 300m upstream of the floodgate, which prior to floodgate installation was approximately 5 - 10 m wide and 0.5-1.5 m deep. The creek is presently infested with common reed and is almost completely infilled;

(*Casuarina glauca*). Submerged macrophytes were generally absent from Ironbark, Shelley and Fishery Creeks, although some *Potamogeton pectinatus* was found in the Canoe Channel.

3.8.2.3 Wetland Areas

The shallow, seasonally inundated freshwater wetland areas (i.e. non-channel habitats) within the study area comprise a significant component of Hexham Swamp. These wetland areas drain into Ironbark Creek, but are not currently subject to tidal inundation. Maximum depth of these wetland areas is unlikely to be greater than 1 m for most of the year.

In general, the wetland areas are covered almost entirely by freshwater vegetation (particularly *P. australis* and reed species), herbs and grasses, and patches of degraded saltmarsh. There are only limited areas of open-water present in the swamp.

The wetland is covered by numerous small (<1 m wide), shallow (<0.5 m) drainage channels that flow into Ironbark Creek. At the time of field inspections, several of the drainage channels contained a thin layer of filamentous green algae, with limited accumulation of sediments. These channels may form important corridors to fish movements throughout the swamp.

3.8.2.4 Fauna Conservation Value of SEPP14 Wetlands

The SEPP14 listing of sections of the Ironbark Creek catchment indicates that the study area has relatively high conservation values at regional and state-wide scales. However, the importance of the study area as a habitat is largely dependent on the fauna assemblages under consideration, as outlined below.

3.8.2.5 Conservation value of available habitats to estuarine fauna

The absence of tidal inundation in shallow wetland areas precludes the use of these areas by estuarine macroinvertebrates and fish. Consequently, these groups are limited to (predominantly deep) channel habitats.

Overall, the Ironbark Creek catchment habitat values for estuarine fauna are greatly reduced in quality as:

- heavy siltation, *Phragmites* infestation and lack of tidal inundation has resulted in a reduction in the area of shallow brackish waters;
- all creeks have steep banks and are relatively deep (except the Canoe Channel), and therefore have limited structural diversity and habitat value;
- the presence of a narrow fringe of mangrove pneumatophores along some banks would provide a suitable habitat for some macroinvertebrates. However, the small area and poor condition of these mangroves limits their use by estuarine fauna;
- the channel habitat is well represented elsewhere in the Hunter River (eg. Moscheto Creek, Throsby Creek, areas around Fullerton Cove); and
- poor water quality (due to occasionally excessive nutrient levels sourced from catchment run-off) limits the value of Ironbark Creek as a viable estuarine habitat.

3.8.2.6 Conservation value of available habitats to freshwater fauna

The following habitat values for freshwater macroinvertebrates and fish fauna have been identified for the Ironbark Creek catchment:

- Habitat diversity can be considered as moderate, as both Channel and Wetland habitats are available to these groups;
- Structural diversity of the Channel habitat is relatively low, comprised almost entirely of only two micro-habitat types (i.e. deep channels with a narrow mangrove fringe). None of the creeks contain shallow protected areas, aquatic vegetation or riffle sequences. Some upstream sections of Ironbark Creek contain shallow waters, although these areas are degraded and suffer from high levels of weed infestation, litter and urban run-off;
- Structural habitat diversity of the Wetland habitat is relatively high;
- The available habitat types are well represented elsewhere in the Hunter region, but to a far lesser extent than those in the Ironbark Creek catchment (eg. Beresfield, Thornton etc.);
- The available wetland areas are in relatively good condition; and
- Poor water quality (due to occasionally excessive nutrient levels) limits the value of Ironbark Creek channel as a freshwater habitat.

3.8.3 Aquatic Macroinvertebrates

3.8.3.1 Taxonomic Composition

The aquatic macroinvertebrate assemblages of Ironbark Creek have been investigated in several studies, most of which have concentrated on species of direct fisheries value. **Appendix F: Volume 2** provides a preliminary list of the macro-invertebrate taxa recorded in Ironbark Creek since the installation of the floodgates, while **Appendix K: Volume 2** provides the most recent summary report for macroinvertebrate monitoring that is currently underway within the Swamp as part of the baseline sampling for the Hexham Swamp Rehabilitation Project (Bio-Analysis, 2005).

Estuarine macroinvertebrates are being sampled at a number of spatial and temporal scales along the length of Ironbark Creek and reference creeks (Bio-Analysis, 2005). A distinct trend in the estuarine macroinvertebrate assemblages has been observed compared to the reference creek, which is reasonably consistent from time to time, this being that both richness and abundance is smaller in Ironbark Creek. At times, however, the locations closer to the floodgates have greater richness and abundance than locations further upstream.

Current monitoring has also found very few freshwater species in the upper estuarine sections of Ironbark Creek and other reference creeks. Previous surveys of Hexham Swamp have indicated that both freshwater and estuarine organisms typically co-occur throughout the creek, from areas adjacent to the floodgates to areas upstream of the Chichester pipeline. This suggests that the composition of aquatic (estuarine and freshwater) macroinvertebrates does not follow a strong salinity gradient, at least along the length of the creek investigated by previous surveys.

Unfortunately there are few available data on the composition, distribution and/or abundance of macroinvertebrates that inhabit the shallow wetland areas. Preliminary observations made during

field inspections recorded numerous freshwater insects (see **Appendix F: Volume 2**) that are typical of shallow freshwater wetland areas.

3.8.3.2 Conservation Values

The benthic macroinvertebrate assemblages in the study area are typical of those found in slightly brackish to fresh-waters. Almost all macroinvertebrate families recorded in the study area have been recorded elsewhere in the Hunter River system (eg. Shepherd 1994, Chessman *et al.* 1997), and are widespread and common throughout temperate Australia (Williams 1980; Hutchings 1984; Dakin and Bennett 1987).

The macroinvertebrate communities within the study area would form an important part of the diet of most fish species that inhabit Ironbark Creek, its tributaries and the adjacent wetlands. Macroinvertebrates have many other important ecological roles, including the cycling of nutrients, conversion of energy in estuarine food webs, and modifications of benthic habitats.

3.8.4 Fish

3.8.4.1 Community Composition

A list of fish species recorded from Ironbark Creek since the installation of floodgates is presented in **Appendix F: Volume 2**. Overall, a total of 25 families comprising 50 species have been recorded from upstream of the Ironbark Creek floodgates. Note that this figure includes species which were unidentified, and therefore may have been counted twice (i.e. “Juvenile Eleotridae”, “*Gobiomorphus* spp”, “Juvenile flathead” and “Juvenile Toadfish” may be a species where a Latin binomial has been provided).

Of the 61 species, 39 are primarily estuarine/saltwater species, 19 are known to occur in both fresh and estuarine waters at some stage in their life-history and 3 are primarily freshwater species, according to classifications in Merrick and Schmida (1984), Grant (1985), Hutchins and Swainston (1986), Allen (1989) Wager (1993), McDowall (1996) and Allen (2002). It is recognised however that all of the freshwater species are occasionally found in brackish water and most of the estuarine/saltwater species are occasionally found in fresh water. Fifteen species are harvested primarily by the commercial fishery, one species is harvested primarily by the recreational fishery and seven species are important in both the commercial and recreational fisheries.

The most specious families were gobies (Gobiidae; 14 or 16 species), gudgeons (Eleotridae; 6 or 8 species), herrings (Clupeidae; 4 species) and mullet (Mugilidae, 3 species). Under taxonomic classifications suggested by Larson and Hoese (1996), the families Gobiidae and Eleotridae may be [not recognized by primary taxonomic schemes] merged into a single family (Gobiidae), thus the total number of species under this new family classification is 15 or 18 (depending on whether the unidentified species have been counted twice).

Shepherd (1994)

Shepherd (1994) examined the distribution and abundance of fishes at Ironbark Creek. The most common species recorded throughout the creek were: Striped Gudgeon (*Gobiomorphus australis*; 30% of the total catch); Empire Gudgeon (*Hypseleotris compressa*; 15%); Flat-headed Gudgeon

(*Philypnodon grandiceps*; 11%); Sea Mullet (*Mugil cephalus*; (10%); and Dwarf Flat-headed Gudgeon (*Philypnodon* sp.; 8%). Sea mullet were the most abundant commercial species, followed by yellow-finned bream (*Acanthopagrus australis*; 3%) and flat-tailed mullet (*Liza argentea*; 0.3%). The numerical dominance of species that are found in freshwater at some time in their life-history led Shepherd (1994) to conclude that Ironbark Creek was essentially a freshwater creek system.

Shepherd (1994) compared the fish fauna of Ironbark Creek with that of the similar sized, but non-gated Moscheto Creek (Kooragang Island), using the same sampling effort and procedures. While recognising that there were large differences in the catchment areas and impacting processes within each location Shepherd (1994) demonstrated that Moscheto Creek had a higher:

- species richness of saltwater species;
- species richness, abundance and biomass of commercially important species; and
- overall biomass of fish species.

Shepherd (1994) suggested that the abundances of many species, particularly the adult stages of commercial species, appear to be limited by floodgates in the Ironbark Creek catchment. Unfortunately, the sampling design only incorporated a single control location (Moscheto Creek), hence it could not be determined whether differences were due to the impacts of floodgates or other factors.

Shepherd (1994) did find, however, that while many small juveniles of some commercial saltwater species, such as the yellowfin bream, were captured in Ironbark Creek, few adults were recorded. This result was not surprising given that for much of the time only one of the eight floodgates was open, and then only to 150 mm. These results demonstrated that Ironbark Creek is rarely utilised by adult commercial saltwater fish, consistent with results obtained by McGregor (1979).

Gibbs *et al.* (1999)

More recent studies (Gibbs *et al.* 1999) examined the effects of barriers (floodgates) on the utilisation of estuaries by juvenile fish and mobile crustaceans (*Utilisation of Restored Wetlands*, NSW Fisheries Project 95/150). The sampling methodologies used by Gibbs *et al.* (1999), which differed from Shepherd (1994), tended to focus on smaller fish. No attempt was made to directly compare the results of this with Shepherd's (1994) study.

Gibbs *et al.* (1999) found that fish communities were dominated (numerically) by the following six most common species:

- Blue-spot Goby (*Pseudogobius olorum*) – 19.38 %
- Port Jackson Glassfish (*Ambassis jacksoniensis*) – 18.40 %
- Largemouth Goby (*Redigobius macrostoma*) – 17.24 %
- Glass Goby (*Gobiopertus semivestitus*) – 11.14 %
- Tamar River Goby (*Afurcagobius tamarensis*) – 10.66 %
- Flathead Gudgeon (*Philypnodon grandiceps*) – 3.78 %

The five most common species of commercial significance were:

- Yellowfin Bream (*Acanthopagrus australis*) – 3.37 %
- Common Silver Biddy (*Gerres subfasciatus*) – 1.28 %
- Sea Mullet (*Mugil cephalus*) - 0.73 %
- Sandy Sprat (*Hyperlophus vittatus*) – 0.16 %
- Sand Mullet (*Myxus elongatus*) – 0.13 %

Gibbs *et al.* (1999) found the community structure in Ironbark Creek was comparable to the main channel of the Hunter River, but supported greater numbers of juvenile Sea Mullet (*Mugil cephalus*), Yellowfin Bream (*Acanthopagrus australis*) and school prawns (*Metapenaeus macleayi*) than the main channel. However, the main channel is a different type of habitat which was sampled as part of a larger study of multiple estuaries and there is no means of comparing the results from Ironbark Creek with similar tidal creek habitats that are unaffected by floodgates. It was concluded that Ironbark Creek (most importantly the lower reaches) provided a functional nursery habitat for a range of economically important fish and prawn species. While recognising that juvenile fish and prawns utilise many parts of Ironbark Creek, this does not necessarily mean that fish communities have not been altered through the installation of floodgates. As discussed below, fisheries values would be diminished by poor water quality (see Section 3.4) and degraded habitat conditions (sedimentation of tributaries, degraded estuarine wetland communities). Anecdotal evidence based on discussions with commercial fishers suggests that fish productivity has shown a marked reduction since the installation of the floodgates.

3.8.4.2 Exotic Fish Species

At least three introduced fish species occur in the wider study area: Eastern Gambusia (*Gambusia holbrooki*), European Carp (*Cyprinus carpio*) and Oriental goby (*Acanthigobius flavimanus*). Advice from Dr Bruce Pease of NSW DPI Fisheries indicates that goldfish (*Carassius auratus*) may also be present in the catchment, although collected specimens require further taxonomic analysis for confirmation of species identification.

Mosquito Fish

The mosquito fish (*Gambusia holbrooki*), an introduced species of fish, is a key threatening process against the long-term conservation of native fish species in the study area. The low salinity and absence of flow in the study area provides optimal habitat conditions for this species. Mosquito fish occur in large numbers in most of the fringe waterholes such as those located on both sides of Leneghans Drive and in lesser numbers in the isolated waterholes along the northern end of the Chichester pipeline.

A native to South America, the mosquito fish was deliberately introduced into waterways during the last century as part of a program to control mosquito larvae. This highly fecund freshwater species has the capacity to tolerate a wide range of aquatic conditions (e.g. high-low water temperatures, low dissolved oxygen levels, high levels of salinity and pollutants) (Arthington 1986). As a result, the species is now known to occur in permanent inland and coastal waterways throughout Australia except Tasmania (Merrick and Schmida 1984, McDowell 1996).

The mosquito fish has been implicated in the decline of native fish species (Lloyd 1989, Arthington 1989) and threaten native species by predation on their eggs and fry, and by competition for food and space. They are well known for their aggressive behaviour and the habit of nipping fins of other species, which may lead to fungal infections and death. "Predation by *Gambusia holbrooki* Girard, 1859 (Plague Minnow or Mosquito Fish)" was gazetted as a Key Threatening Process under Schedule 3 of the *Threatened Species Conservation Act* 1995. The NSW Scientific Committee considered that predation by this species was a serious threat to the survival of threatened species including the Green and Gold Bell Frog (*Litoria aurea*) and the New England Frog (*L. castenau*), and a range of other frog species (NSW NPWS 2002). This species is not currently declared as a noxious species under the *Fisheries Management Act* 1994.

European Carp

Recently (post 1998), the introduced Carp (*Cyprinus carpio*) has been recorded in the upper freshwater reaches of the wetland. The ornamental Koi strain is reportedly the parent stock of carp populations in the Hunter River catchment.

This species can have serious deleterious effects on native freshwater ecosystems. This species reverts to bottom feeding when there are insufficient supplies of their preferred food in the water column. This can lead to increased turbidity, releases of sediment nutrients, and disturbance of benthic substrates and aquatic vegetation. This species can also reach plague densities resulting in impacts to food-webs, increased nutrient loads (from wastes), and algal blooms (including blue-green algae). Increased prevalence of disease in native fish populations have also been observed in areas where this species occurs in high numbers.

The low flows and low salinities of the study area provide suitable habitat for this species. Although this species is a predominantly freshwater species, it can tolerate brackish water conditions. Experimental studies have demonstrated reduced feeding and growth rates in this species at higher salinities (Wang *et al.* 1997). Experimental studies demonstrate an LC₅₀ at salinities of 7,300 mg/L in unacclimated fish (references cited in Hart *et al.* 1991). Salinities in parts of the study are presently within the salinity tolerance range of this species.

Oriental Goby

The oriental or yellowfin goby is native to brackish estuarine and sheltered inshore coastal waters of Japan and the adjacent mainland of northeastern Asia (Matsuda *et al.* 1984). It lives in a wide range of salinities, from coastal marine to fresh waters at the upper tidal limits (Pollard and Hutchings 1990). In Australia, it was first reported from Sydney Harbour in 1971 (Hoese 1973). It is believed to have arrived in the ballast water of ships from Japan and has since been reported in the Hunter, Hawkesbury, Sydney Harbour, Botany Bay and Port Kembla estuaries (Bell *et al.* 1987; Pollard and Hutchings 1990). This introduced species probably competes with native gobies and juvenile whittings, flatfish and flatheads (Middleton 1982). Dr Bruce Pease (DPI Fisheries) recently recorded this species at Kooragang Island, and it is likely also to inhabit Ironbark Creek.

3.8.4.3 Habitat Requirements of Fish

The fish species that inhabit Ironbark Creek utilise a range of micro-habitats, as shown in **Appendix F: Volume 2**. For descriptive purposes, micro-habitats are broadly defined as either pelagic (fish not

generally associated with the substrate), demersal (fish generally associated with the substrate), or pelagic/demersal in cases where fish generally move between both habitats. Demersal species are further arbitrarily divided into hard (including rocks, snags and logs) and soft bottom dwellers.

3.8.4.4 Conservation Values

The fish assemblages in the study area have the following ecological values:

- the fish assemblages that are typical of those found in slightly brackish to fresh-waters. All fish recorded are relatively common and widespread throughout New South Wales;
- no endangered species, populations, ecological communities, or vulnerable fish species as currently listed under *Fisheries Management Act 1994* or the *Environmental Protection Biodiversity Conservation Act 1999*, have been recorded or are likely to occur in the study area;
- the Purple Spotted Gudgeon (*Morgunda adspersa*), which is classified as Restricted by the Australian Society of Fish Biologists, has been recorded from Ironbark Creek. This classification was given due to serious decline in distribution and abundance of this species in the Murray-Darling Drainage, particularly in South Australia (Extinct) and Victoria (Presumed Extinct) (Wager 1993). Electrophoretic studies (South Australian Department of Fisheries, cited in (Wager 1993)) indicate that the Murray-Darling stock is considerably different from east coast stocks, and therefore warrants classification as a separate taxon (species). For this reason, IUCN and ANCA only classify the Murray-Darling stock as Endangered (ANCA) and Critical (IUCN), and does not apply to east coast stocks (Wager 1993), which are considered as relatively common;
- no species (but see *Morgunda adspersa*) listed as Endangered, Threatened, Potentially Threatened, Critical or Vulnerable by the ANCA (Wager 1993) or the IUCN have been recorded, or are likely to occur, within the study area;
- provides a functional nursery habitat for a range of economically important species; and
- many species (eg. *Pseudomugil signifier*, *Hypseleotris compressa*, *H. galii*) prey on mosquito larvae, restricting adult mosquito population sizes;

Native fish communities are currently affected by a range of impacting processes, including:

- poor water quality;
- reduction in the area of important estuarine wetland habitat;
- competition/predation by mosquito fish and oriental gobies (the impacts of Carp in this system are not known); and
- physical barriers formed by the flood-gates, and vegetation encroachment in several of the tributary creeks.

3.8.5 Fisheries

3.8.5.1 Habitats

Habitat Changes in a Historical Context

Prior to floodgate installation, large areas of Hexham Swamp would have been inundated by tides, however there are no empirical data to determine the past extent of tidal inundation. Using the extent of estuarine vegetation (mangroves and saltmarsh) as a coarse indicator of the degree of tidal inundation, it is estimated that approximately 965 ha of the floodplain would have been inundated by king tides prior to floodgate/levee bank installation. This figure excludes tidally flushed channels.

The installation of floodgates and associated levee banks at the mouth of Ironbark Creek modified tidal flushing processes as follows:

- a lowering of the water table behind the gates to below mean water levels (during dry conditions);
- restricted saline waters entering the swamp area; and
- general stagnation of water behind the floodgates (although the one partially open gate prevents complete stagnation of the water).

At present, tides are essentially restricted to the waterway channels, resulting in negligible overbank tidal inundation of the adjacent floodplain. Floodgate/levee bank construction has resulted in the loss of approximately 900-965 ha of estuarine habitat.

There was a dramatic shift in vegetation community structure within Hexham Swamp over time, most likely as a result of changes in tidal hydraulic regimes. As discussed in Section 3.7.1.9, Morrison (2000) mapped the vegetation communities of Hexham Swamp for three times prior to the construction of floodgates (i.e. 1938, 1954 and 1966), and four times following the construction of gates in 1970-71 (i.e. 1976, 1986, 1994 and 2000). The area of major community types for each time period is shown in Figure 3.22.

In the period prior to floodgate construction, the numerically dominant vegetation community types in Hexham Swamp were saltmarsh (average cover in ha = 830 ± 71.63 S.D.) and freshwater swamp (average cover in ha = 848 ± 24.39 S.D.), each accounting for approximately 34% of the total area of Hexham Swamp. Saltmarsh cover during this period was in a general state of decline, whereas there was no clear temporal trend in the extent of freshwater swamp. Prior to floodgate construction, the average cover of mangroves was 136 ha (± 44.79 S.D.), and showed a general increase in extent between 1938 and 1966. Open water habitats had an area of 104 ha (± 1.15 S.D.), and displayed little variation over time.

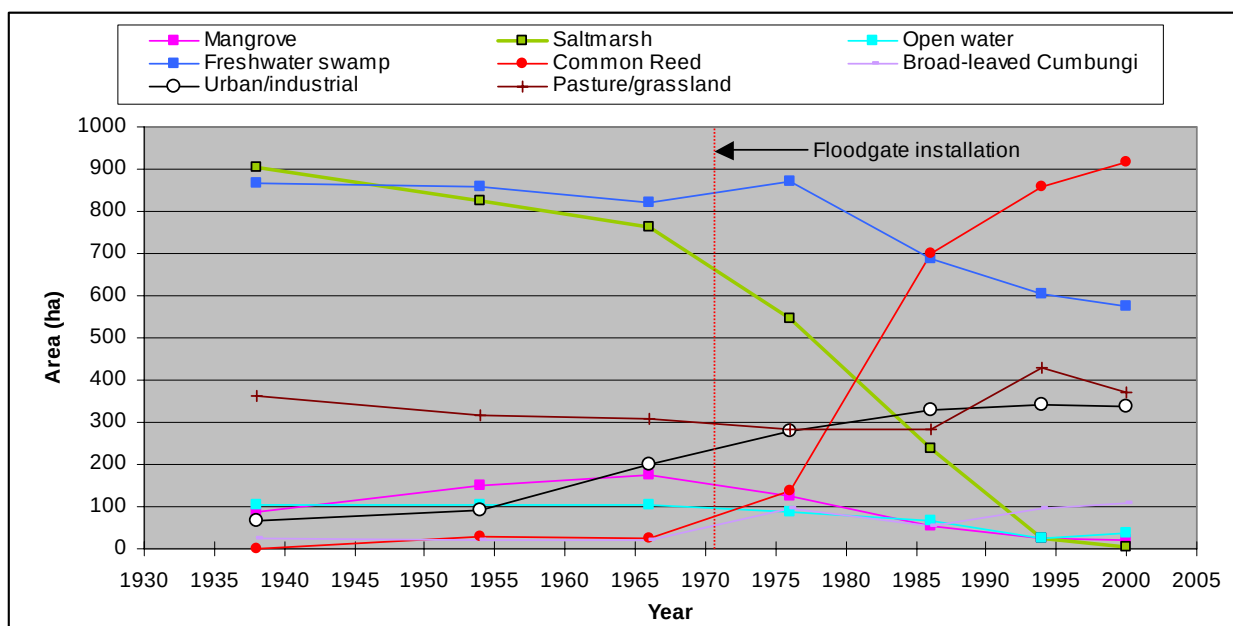


Figure 3.22 Extent of major vegetation community types in Hexham Swamp between 1938 and 2000 (Data source: Morrison, 2000)

There were marked changes in the extent of vegetation communities in the period following the construction of floodgates in 1970/71. The following notable changes occurred to estuarine habitats of potential fisheries value:

- The extent of mangroves declined over time, reversing the general temporal trend observed between 1938 and 1966. The average cover declined from 136 ha (± 44.79 S.D.) observed prior to gate construction, to 125 ha in 1976, 53 ha in 1986, 23 ha in 1994, and 22 ha in 2000. This represents a change in extent of -113.7 ha (-84%) between pre-gate construction (average cover for 1938-1966) and 2000.
- The general trend of declining saltmarsh area observed between 1938 and 1966 continued, but greatly accelerated following floodgate installation. The average cover declined from 830 ha (± 71.63 S.D.) prior to gate construction, to 544 ha in 1976, 238 ha in 1986, 23 ha in 1994, and 6 ha in 2000. This represents a change in saltmarsh extent of -824 ha (-99.27%) between pre-gate construction (average cover for 1938-1966) and 2000.
- The extent of open water habitats was stable prior to floodgate installation, but showed a marked decline post floodgate construction. The average extent of open water declined from 104ha (± 1.15 S.D.) prior to gate construction, to 87 ha in 1976, 66 ha in 1986, 25 ha in 1994, and 38 ha in 2000. This represents a change in extent of -66 ha (-64%) between pre-gate construction (average cover for 1938-1966) and 2000.

In addition to estuarine habitats, there were marked changes in the extent of freshwater habitats following floodgate installation. The extent of freshwater swamp declined from 848 ha (± 24.39 S.D.) prior to floodgate installation, increasing to 870 ha in 1976, but declining to 689 ha in 1986, 605 ha in 1994 and 575 ha in 2000. This represents a 32% reduction in freshwater swamp between pre-gate construction (average cover for 1938-1966) and 2000. The decline in estuarine habitats and

freshwater swamp was accompanied by an increase in the extent of *Phragmites* and *Typha* dominated communities.

The temporal changes in tidal flushing regimes and associated changes in vegetation communities would be expected to have reduced the fisheries habitat values of Hexham Swamp. The following impacts would have occurred:

Reduction of tidally inundated floodplain habitat

As discussed above, it is estimated that up to 965 ha of tidally inundated floodplain habitat was lost as a result of floodgate/ levee bank installation/operation. It is believed that the full 965 ha area of floodplain would only have been inundated infrequently (once or twice per year, during king tides), whereas a comparatively smaller area of floodplain habitat would have been inundated during frequent spring tides.

These tidally inundated floodplain habitats may have once provided important habitats and food resources for many species of direct fisheries value (e.g. Moussalli and Connolly 1998; Saintilan and Rogers 2002). In the absence of tidal inundation, these floodplain habitats are currently unavailable to most commercially significant fish species, with the possible exception of freshwater eels (e.g. *Anguilla reinhardtii*, *A. australis*), and possibly mud crabs (*Scylla serrata*) in low-lying areas close to the main channel.

Habitat simplification

As discussed above, Hexham Swamp once supported a wide variety of estuarine habitats, most notably large areas of mangroves, saltmarsh, and channel habitats of variable depth. The installation of floodgates/bunds has resulted in the loss of most of these habitat types, leading to the simplification of structural habitats important to many species of commercial and recreational value.

The channel areas form the only available habitat for estuarine invertebrates and fish of commercial value. These channel areas provide a relatively uniform depth and longitudinal profile along most of their length, and therefore provide little structural habitat diversity. Minor maintenance dredging of the channel at Maryland and near Chichester pipeline (pers. comm.. Vicki McBride, DIPNR, March 2005) would further reduce micro-habitat diversity in these channel areas, albeit on a relatively small spatial scale.

High quantities of silty sediments occur within the main channel and tributaries of Ironbark Creek. Sedimentation is particularly severe at Muckeye Creek, which has almost completely infilled and is now covered in *Phragmites australis*. This sedimentation has resulted in further simplification of channel habitats.

The banks of the channel are lined by mangroves, whose pneumatophores, trunks and associated snags offer micro-habitats for a range of macroinvertebrates and juvenile fish (Bell et al. 1984; Morton 1990; Chapman and Underwood 1995; Laegdsgaard and Johnson 1995). At present, the area of mangroves in the Ironbark Creek catchment is small (approximately 22 hectares; see Section 3.7.2.1), and likely to be of relatively limited fisheries habitat value. Sections of the Ironbark main channel and most of the smaller creeks draining into Ironbark are lined with *Phragmites*, which may also provide some shallow micro-habitats.

Degraded water quality

Channel and wetland areas are periodically subjected to poor water quality associated with algal blooms (and potentially acid sulfate soils), reducing their viability as fisheries habitats. For example, Shepherd (1994) reported large decreases in fish abundance following two algal blooms within the creek system in a single year.

3.8.5.2 Crustaceans

Anecdotal evidence suggests that Ironbark Creek was once an important prawn habitat and fishing area prior to floodgate installation. For example, NSW Fisheries (DLWC, 1996) cites anecdotal reports of large quantities of prawn shells (moult) present along the banks of Ironbark Creek. John Hewitt, who was one of seven commercial prawn fishers that previously fished Ironbark Creek since the 1950's (pers. comm.. D. Hurst, commercial fisherman, January 2005), suggested that numbers of prawns in the area are now too small to support a viable fishery. He attributed the decline in prawn numbers to the absence of suitable habitat types and a decline in habitat quality since the installation of the floodgates (pers. comm.. J. Hewitt, community member, January 2005).

Shepherd (1994) undertook an investigation of the distribution and abundance of prawns (Family Penaeidae) over a one-year period at Ironbark Creek, and recorded three species of commercial importance (*Metapenaeus bennettiae*, *M. macleayi* and *Penaeus plebejus*). A fourth commercially important prawn species (*Penaeus esculentus*) and the blue-swimmer crab (*Portunus pelagicus*) have also been recorded in Ironbark Creek by NSW Fisheries (unpublished data in DLWC 1996; Gibbs et al. 1999). Shepherd (1994) demonstrated that the school prawn (*M. macleayi*) was by far the most abundant of the prawn species in Ironbark Creek, consistent with McGregor (1979) and NSW Fisheries (unpublished data in DLWC 1996, Gibbs et al. 1999).

The juveniles of all prawn species occur at very low abundances in the study area, possibly due to the absence of good quality nursery habitat (McGregor 1979, Shepherd 1994). All prawn species recorded at Ironbark Creek utilise shallow coastal estuaries and rivers during their juvenile stage (Kailola et al. 1993), and are typically more abundant in areas with extensive seagrass cover (Coles and Lee Long 1984, Halliday 1995). It is recognised however, that seagrass is not a obligatory micro-habitat for all prawn species, and that other juvenile school and greasy back prawns occur in a range of micro-habitat types.

Despite the presence of prawn species and blue-swimmer crab in the study area, Ironbark Creek is unable in its currently degraded state to support a viable commercial fishery for these species.

3.8.5.3 Fish

Appendix F: Volume 2 lists the commercially important fish species that have been recorded in Ironbark Creek since the installation of floodgates. A total of 23 of these are commercially and recreationally important fish species. As discussed in Section 3.8.4, the most common commercially important fish species in Ironbark Creek are Sea Mullet (*Mugil cephalus*), Bream (*Acanthopagrus australis*) and Flat-tailed Mullet (*Liza argentea*) and eels (*Anguilla reinhardtii* and *A. australis*). Other commercially and recreationally important freshwater and estuarine species, such as Australian Bass (*Macquaria novemaculeata*) and Freshwater Herring (*Pomatoschistus richmondia*) are also known to occur in the creek, but in low abundance. As is the case with prawns, Ironbark Creek is fished only

very occasionally for mullet, and then only a few kilograms are collected in any year (pers. comm.. John Hewitt, community member, January 2005). According to John Hewitt, Ironbark Creek does not support sufficient numbers of adult fish to form a viable fishery. Furthermore, previous 'prime' fishing areas identified by Mr. Hewitt have either silted completely over (i.e. Muckeye Creek), or are no longer inundated by tidal waters (i.e. most of the Hexham swamp), limiting the fisheries habitat value of Ironbark Creek.

3.8.5.4 Summary of Current Fisheries Values

Ironbark Creek presently has low fisheries values at regional scales as:

- there are few habitat types of direct fisheries value in Ironbark Creek;
- mangroves, which constitute one of the most important micro-habitat types to commercial fisheries species, cover only a small area of Ironbark Creek catchment and are highly degraded (Section 3.7.2);
- water quality is typically poor and unsuitable for many species of fisheries importance;
- the abundance of commercially important prawn species in the Ironbark Creek is relatively low. Ironbark Creek is not directly fished for prawns, however it is likely that the prawns that do use this waterway would contribute to a large part of the commercial prawn catch in the Hunter River, and possibly other areas along the New South Wales and Queensland coasts; and
- with the exception of sea mullet and longfinned eels, Ironbark Creek does not presently support significant adult populations of commercially important fish.
- Some shallow channels lined with Phragmites may provide limited nursery function for juvenile sea mullet, flat-tail mullet, bream, silver biddies, sandy sprat and longfinned eels.

3.8.6 Birds

3.8.6.1 Community Composition

A total of 188 species of birds have been previously recorded from the NPWS Atlas grid square (Eastings 371000, 38100 and Northings 6359000, 636900) in which Hexham Swamp is located (DEC, 2004). This species diversity represents 142 genera from 55 families.

Approximately 17% (32 species) of the avifauna recorded within the NPWS Atlas areas containing Hexham Swamp are heavily dependent on freshwater and brackish wetland systems (eg. open water, saltmarsh, shallow seasonal freshwater swamps, wet reed communities, ponded pastures) to complete their life cycle. The majority of the species recorded that are listed under the NSW *Threatened Species Conservation Act* 1995 are species that are heavily dependent on wetland environments that are of high habitat value and integrity.

A further 41 species utilise freshwater and brackish wetland environments as one of several preferred habitats (eg. Little Egret, *Egretta garzetta*). ICTCMC (1996) noted that approximately 60% of the bird species recorded from the Ironbark Creek catchment utilise wetland habitats.

The avifauna records from the NPWS Atlas area accounts for approximately 91% of the total number of species (207 species) known to occur within the Ironbark Creek Catchment (ICTCMC 1996). A list containing all these species is contained in **Appendix F: Volume 2**.

As previously described, the vegetation of Hexham Swamp has been subject to considerable changes resulting from a variety of disturbance factors including the operation of the floodgates (see Section 3.7). Changes to the diversity, extent and quality of these habitats are likely to have resulted in a decline in the diversity and abundance of the current avifauna community of Hexham Swamp. Of particular concern, is the expansion of the common reed (*Phragmites australis*) dominated community at the expense of the formerly extensive saltmarsh.

Historically, Hexham Swamp's wetland habitats, such as the saline grasslands and saltmarsh, were likely to have supported a diversity of birds, particularly migratory wader species. Keane (1983) considered that wet grassland and flooded pasture communities supported significantly higher densities of *Anatidae*, *Ardeidae*, and Snipe (*Gallinago hardwickii* & *Rostratula benghalensis*), with the lowest densities of birds occurring within the reed swamps.

Saltmarsh habitats support favoured feeding and roosting habitats for a range of migratory and resident waders, known to occur within the lower Hunter including Red-necked Stint (*Calidris ruficollis*), Sharp-tailed Sandpiper (*Calidris acuminata*), Red-capped Plover (*Charadrius ruficapillus*), Marsh Sandpiper (*Tringa stagnatilis*), Pacific Golden Plover (*Pluvialis fulva*), Black-winged Stilt (*Himantopus himantopus*) and Red-necked Avocet (*Recurvirostra novaehollandiae*).

Mangroves are known to provide important roosting habitat for both Whimbrel (*Numenius phaeopus*) and Grey-tailed Tattler (*Heteroscelus brevipes*). The muddy substrate which supports mangroves adjacent to Ironbark Creek would support a range of wader species, particularly the Common Sandpiper (*Actitis hypoleucos*).

The flooded grasslands, semi-permanent and permanent waterbodies provide important habitat for a range of waterfowl and wetland species (Families *Anatidae*, *Ardeidae*, *Threskionithidae* and *Rostratulidae*). The remaining species known to occur within the Hexham Swamp area are primarily associated with the drier grasslands (eg. Chestnut-breasted Mannikin (*Lonchura castaneothorax*)), forest and woodland cover (eg. Rufous Whistler (*Pachycephala rufiventris*)), and species such as raptors which prey on birds within all of the habitats of the area.

There were evidently no systematic surveys of the avifauna of Hexham Swamp prior to the construction of the floodgates. Since the construction of the floodgates, Waterhouse (1978) recorded waterbirds using the seasonal swamp northwest of the old Stockrington rail line during 1977 and 1978; this area is outside of the present proposal area. Winning (1999) and Winning & King (2002-2003) have compiled baseline data on avifauna assemblages at several locations within Hexham Swamp as well as at reference sites. These records have been incorporated into the list presented at **Appendix F: Volume 2**.

3.8.6.2 Conservation Values

Of the species known to occur within the NPWS Atlas grid square in which Hexham Swamp is located, one species (Black-necked Stork (*Ephippiorhynchus asiaticus*)) is listed as Endangered under the NSW *TSC Act*, while a further seven species are listed as Vulnerable under the *TSC Act*. These

are the Magpie Goose (*Anseranas semipalmata*), Blue-billed Duck (*Oxyura australis*), Freckled Duck (*Stictonetta naevosa*), Black Bittern (*Ixobrychus flavicollis*), Australasian Bittern (*Botaurus poiciloptilus*), Painted Snipe (*Rostratula benghalensis*) and Comb-crested Jacana (*Irediparra gallinacea*). In determining whether the proposal will have a significant effect on these species, an assessment (i.e. an Eight Part Test) of the significance of the potential impacts is presented in **Appendix H: Volume 2**.

Sixteen species listed under CAMBA² and/or JAMBA³ were identified through literature review and/or the search of the NPWS Atlas database are considered known and/or likely to occur in Hexham Swamp.

Hexham Swamp has previously been considered to be of regional importance for large numbers of birds, particularly waterfowl (NPWS 1981), supporting approximately 45% of remaining Hunter wetlands habitat for Black Swan (*Cygnus atratus*), Pacific Black Duck (*Anas superciliosa*), Australasian Shoveler (*Anas rhynchos*), Grey Teal (*Anas gracilis*) and Chestnut Teal (*Anas castanea*) (DPW1988). In excess of 10 000 waterfowl were recorded on Hexham Swamp during the 1970's, however numbers have declined since then possibly due to flood mitigation works and the increase in the dominance of common reed (*Phragmites australis*.) over large tracts of Hexham Swamp (NPWS 1996a), as the reed has no value for migratory birds and only limited value for waterbirds. By comparison, baseline ecological surveys undertaken bi-monthly from March 1997 – March 1999, indicate that the introduced Common Starling (*Sturnus vulgaris*) is currently the most numerous recorded bird species in Hexham Swamp, with records of up to 1000 individuals recorded during one sampling day (Winning 1999a).

Kingsford and Levy (1996) list 103 species of waders, waterbirds and seabirds that have been recorded within the Hunter River estuary complex. Of these, 32 species are migratory waders (Families *Charadriidae* and *Scolopacidae*) and are listed under international bilateral agreements between Australia, Japan and China (JAMBA and CAMBA).

Nine of the 32 wader species were not recorded within the lower Hunter between 1986 and 1996 with significant declines in the population of a further 11 species. Declines and absences of the wading species have been attributed to significant changes in feeding and roosting habitats as estuarine islands were removed by dredging and amalgamated with the mainland (Kingsford and Levy 1996).

Loss of saltmarsh and freshwater wetlands within the lower Hunter Valley has also been implicated in these declines, especially of the smaller wader species (Geering 1995). Red-necked Stint (*Calidris ruficollis*), Sharp-tailed Sandpiper (*Calidris acuminata*) and Red-capped Plover (*Charadrius ruficapillus*) are species that exhibit preference for shallow wetlands and saltmarsh habitats, which were formerly extensive within Hexham Swamp (see Section 3.7.3.2). Since 1971, within the Hunter estuary area, numbers of Red-necked Stint have declined by approximately 60%, whilst Sharp-tailed Sandpiper numbers have declined by up to 90% (Kingsford and Levy 1996).

Both Wood Sandpiper (*Tringa glareola*) and Pectoral Sandpiper (*Calidris melanotos*) are two species which Kingston and Levy (1996) identified as absent from the Hunter estuary between 1986 and

² CAMBA - the Agreement between the Government of Australia and the Government of The Peoples Republic of China for the protection of migratory birds and their environment 1976.

³ JAMBA - the Agreement between the Government of Australia and the Government of Japan for the protection of migratory birds in danger of extinction and their environment 1974.

1996. Both species are likely to have occurred within the formerly extensive saltmarsh of Hexham Swamp.

3.8.7 Herpetofauna

3.8.7.1 Community Composition

The NPWS Atlas (grid square in which Hexham Swamp is located), together with records from previous studies within the area indicate that 13 reptile species representing, eleven genera and five families are known or considered likely to occur within Hexham Swamp (see **Appendix F: Volume 2**) (DEC, 2004). ICTCMC (1996) lists twelve species for the Ironbark Creek catchment including one species Blind Snake (*Ramphotyphlops nigrescens*), which is not included in the summary above, and may occur within Hexham Swamp.

Whilst the reptile fauna has been poorly surveyed, it is considered that a few additional species are likely to occur within Hexham Swamp and this should be clarified with appropriate targeted field surveys.

Those species with strong wetland affinities include Eastern Long-necked Tortoise (*Chelodina longicollis*), Black-bellied Swamp Snake (*Hemiaspis signata*) and the Red-bellied Black Snake (*Pseudechis porphyriacus*). The Eastern Long-necked Tortoise inhabits permanent water bodies from lakes to billabongs and within the slower moving sections of waterways. Both snake species feed principally on frogs with reptiles and small mammals also taken, either as encountered and or sought during declines in frog populations (Wilson and Knowles 1988).

Eleven species of amphibians (four genera and two families) have been recorded from Hexham Swamp. An additional three species have been recorded within the NPWS Atlas grid square in which Hexham Swamp is located (see **Appendix F: Volume 2**). One species, the Green and Golden Bell Frog (*Litoria aurea*) is listed as *Endangered* under the *TSC Act*.

The most comprehensive study of the frog fauna of Hexham Swamp was undertaken by Markwell (1984). This seven month, biogeographic study identified eleven frog species, (including the Green and Golden Bell Frog) which represented approximately 30% of the frog species known or likely to occur within the Hunter region (Markwell 1984).

The study also noted that the operation of the Ironbark Creek floodgates may have produced beneficial conditions for the expansion of frog distribution in the south-east of the swamp as a result of changes from saline to freshwater conditions and subsequent vegetation community changes (e.g. saltmarsh to freshwater reed swamps).

Other primary findings of the study included the following:

- The most widely distributed species were the Spotted Grass Frog (*Limnodynastes tasmaniensis*), Brown striped Frog (*Limnodynastes peronii*) and Common Eastern Froglet (*Crinia signifera*);
- An apparent preference by all eleven species for the margins of wetland areas west of the Richmond-Pelaw Main railway line was identified;

- A notable absence of frogs within the central sector of Hexham Swamp, east of the Richmond-Pelaw Main railway line which corresponded with an extensive area of wetland dominated by *Phragmites australis* was observed; and
- Only one species, the Green and Golden Bell Frog, was recorded from vegetation communities dominated by *Phragmites australis*, where it was found only to occur on the margins of this vegetation type.

The study also noted widespread occurrence of the introduced Eastern Gambusia (*Gambusia holbrooki*). This species is an adaptable, fecund fish that has been implicated in the decline of local populations of native frogs and fish (Morgan and Buttemer 1996, Arthington 1989, NPWS 2002).

Opportunistic observations recorded by Winning (1999) and Winning & King (2002-2003) during vegetation and avifauna surveys have confirmed a number of frog and reptile species as still being common in Hexham Swamp, including Red-bellied Black Snake, Black-bellied Marsh Snake, Eastern Water Skink (*Eulamprus quoyii*), Spotted Grass Frog, Brown Striped Frog, Common Eastern Froglet, Green Tree Frog (*Litoria caerulea*), Bleating Tree Frog (*Litoria dentata*) and Eastern Dwarf Tree Frog (*Litoris fallax*).

Winning & King (2002-2003) have also undertaken targeted surveys for Green & Golden Bell Frog in Hexham Swamp but have not recorded this species in Hexham Swamp, apart from the known population in the “2HD swamp” at Sandgate which was historically part of Hexham Swamp but is now hydrologically separated.

3.8.7.2 Conservation Values

Of the herpetofauna recorded from Hexham Swamp, one species, the Green and Golden Bell Frog (*Litoria aurea*), is listed as an Endangered species under the TSC Act. In determining whether the proposal will have a significant effect on this species, an assessment (i.e. Eight Part Test) of the significance of the potential impacts is presented in **Appendix H: Volume 2** of this document, while a summary of the eight part test is also provided in Section 4.6.2.2.

3.8.8 Mammals

3.8.8.1 Community Composition

A total of 26 species of mammals (twelve genera, twelve families) have been recorded from the NPWS Atlas grid square (Eastings 371000, 38100 and Northings 6359000, 636900) in which Hexham Swamp is located (DEC, 2004). Ten species, including two native species, have been previously recorded from studies within Hexham Swamp. The two native species (Northern Brown Bandicoot (*Isodon macrourus*) and Water-rat (*Hydromys chrysogaster*)) provide additional native mammal records to those of the NPWS Atlas listing for the area in which Hexham Swamp is located (CH2M Hill 1997). A list of mammal species is provided in **Appendix F: Volume 2**.

There is a relatively small number of mammals of the region which are dependent on wetland environments for their existence. Of the species known or likely to occur in Hexham Swamp, only the Water-rat (*Hydromys chrysogaster*) and Swamp Rat (*Rattus lutreolus*) are considered to be dependent or heavily reliant on inundated or damp environments.

3.8.8.2 Conservation Values

Of the species identified in the NPWS Atlas search and those recorded from studies within Hexham Swamp, five species are listed as Vulnerable under the TSC Act. These are the Koala (*Phascolarctos cinereus*), Squirrel Glider (*Petaurus norfolcensis*), Little Bentwing-bat (*Miniopterus australis*), Common Bentwing-bat (*Miniopterus schreibersii*) and Greater Broad-nosed Bat (*Scoteanax rueppellii*). Eight Part Tests are presented in **Appendix H: Volume 2** for those species known or considered likely to occur in the Hexham Swamp area.

Whilst both Koala and Squirrel Glider are known from the vicinity of Hexham Swamp, the paucity of suitable habitat trees, sparse tree cover, lack of records and indirect evidence of presence (e.g. trunk scratchings and scats) within Hexham Swamp indicate that the site is unsuitable for the species. The records of Koala are most likely to relate to observations of the species in more suitable and extensive habitats (e.g. forested foothills to the west) which are included within the ten square kilometre grid within which Hexham Swamp is located.

The three microbat species identified from database searches are hollow or cave dependant for roost and breeding requirements. They forage for insects beneath and within the canopy of woodlands and forests (Churchill 1998). The habitats supported by Hexham Swamp are considered to be, at best, sub-optimal for these species, providing few resources for roosting/breeding, but these bats may drink from the swamp prior to nocturnal foraging. NPWS Atlas records for these species were most likely sourced from more suitable treed habitats that occur to the west of the swamp.

3.8.9 Threatened Species

Table 3.25 provides an assessment for those threatened species that are known or considered likely to occur within habitats contained within the 10 square kilometre grid (used for searching the NPWS Atlas) containing Hexham Swamp (accessed April 2004). Those species identified from database searches and literature reviews that are known or considered likely to occur within Hexham Swamp, and hence potentially affected by the proposal, are assessed in accordance with the requirements of Section 5A of the *Environmental Planning and Assessment Act 1979* (i.e. Eight Part Tests) (see **Appendix H: Volume 2**).

Table 3.25 Threatened Fauna Species Assessment

Species and Information Source(s)	TSC Act Status	Habitat & Resource Requirements	Suitability of Habitat and likely occurrence within Hexham Swamp	Likely Occurrence Within Hexham Swamp Test Undertaken
Green and Golden Bell Frog (<i>Litoria aurea</i>) Source: a, b, c	E	Originally known from semi-permanent /permanent waterbodies and marshes ± dense reed beds (<i>Eleocharis</i> or <i>Typha</i> sp.) and no Mosquito fish (<i>Gambusia holbrooki</i>). More recently, also located within disturbed sites (eg. disused industry sites).	Suitable habitat exists within Hexham Swamp, though presence of <i>Gambusia holbrooki</i> reduces habitat suitability considerably.	Previously recorded from the Hexham Swamp, although recent targeted surveys have not identified any individuals except in the 2HD ponds.
Magpie Goose (<i>Anseranas semipalmata</i>) Source: a, b, c	V	Extensive wetlands and open waterbodies (eg. dams) surrounded by dense beds of rushes or sedges, flooded pastures and grasslands. Requires dense reed beds for breeding, roosting trees over water.	Suitable habitat exists within Hexham Swamp, though suitable roosting trees are scarce.	Known to breed within the Wetlands Centre, Shortland

Species and Information Source(s)	TSC Act Status	Habitat & Resource Requirements	Suitability of Habitat and likely occurrence within Hexham Swamp	Likely Occurrence Within Hexham Swamp Test Undertaken
Blue-billed Duck (<i>Oxyura australis</i>) Source: a, b, c	V	Almost wholly aquatic, prefers permanent deep water wetlands with abundant aquatic vegetation and tall dense fringing vegetation. May occur on saline wetlands where seasonal freshwater intrusions reduce salinity.	Marginally suitable habitat may be supported when area is flooded, providing large areas of deeper water.	Highly unlikely to occur within Hexham Swamp. Not recorded within the Hunter Valley since 1989 (HBOC 1997).
Freckled Duck (<i>Stictonetta naevosa</i>) Source: a	V	Essentially aquatic, a filter feeder of shallow (< 0.5m deep) areas of natural, permanent or seasonal open waterbodies and wetlands. Prefers nesting amongst reed beds, particularly lignum or dense shrubs.	Marginally suitable habitat may exist, particularly during flood conditions.	Highly unlikely to occur within Hexham Swamp. Not recorded in the Hunter Valley (HBOC 1997).
Black Bittern (<i>Ixolorychus flavicollis</i>) Source: c	V	Coastal terrestrial wetlands, estuarine and littoral habitats with densely vegetated margins with trees overhanging water for nesting.	Limited areas of suitable habitat present in Hexham Swamp.	May occur within limited areas of Hexham Swamp.
Australasian Bittern (<i>Botaurus poiciloptilus</i>) Source: a, b, c	V	Shallow, freshwater or brackish wetlands supporting extensive reed beds and/or dense bands of vegetation fringing open water.	Limited areas of suitable habitat present in Hexham Swamp.	Occurs within limited areas of Hexham Swamp, recorded by Winning and other
Black-necked Stork (<i>Ephippiorhynchus asiaticus</i>) Source: a, c	E	Shallow, terrestrial wetlands, estuarine and littoral habitats. Prefers open freshwaters which form shallow flooded grasslands.	Limited areas of suitable habitat present in Hexham Swamp.	Occur within limited areas of Hexham Swamp, recoded by Winning and others
Osprey (<i>Pandion subcristata</i>) Source: a, c	V	Marine and littoral habitat (including bays, estuaries and rivers) and terrestrial wetlands, with occasional records along large rivers inland from coast.	Limited areas of suitable habitat present in Hexham Swamp. Lack of suitable feeding and/or perching platforms (eg. large dead trees, logs) and nesting resources (eg. tall dead or live trees) reduces suitability.	May occur within limited areas of Hexham Swamp.
Square-tailed Kite (<i>Lophoictinia isura</i>) Source: c	V	Predator of small birds within canopy of coastal and sub-coastal tall open forests and woodlands. Requires large areas of undisturbed habitat for foraging and breeding.	Hexham Swamp represents sub-optimal habitat for both foraging and breeding.	Unlikely to occur within Hexham Swamp. Accidental occurrence possible, incidental to movements between foraging coastal hinterland habitats. No previous area records exist (HBOC 1997).
Painted Snipe (<i>Rostratula benghatensis</i>) Source: b, c	V	Shallow grassy wetlands, marshes, flooded grasslands. Feeds for invertebrates on exposed mud. Requires shallow water surrounded by grasses and reeds for nesting.	Suitable habitat exists within Hexham Swamp.	Likely to occur within Hexham Swamp.
Comb-crested Jacana (<i>Irediparra gallinacea</i>) Source: a, b	V	Broad, shallow wetlands supporting abundant areas of floating aquatic macrophytes (eg. waterlilies). Forages for invertebrates on mats of floating vegetation.	Very limited, patchily distributed areas of suitable habitat occur within Hexham Swamp	May occur within limited areas of Hexham Swamp Previously recorded from southern Hexham Swamp area. Regarded as more abundant in northern Hunter region. – not assessed
Wompoo Fruit-Dove (<i>Ptilinopus magnificus</i>) Source: c	V	Frugivore species of large undisturbed areas of lowland and adjacent highland rainforest with adjoining wet sclerophyll forest.	Hexham Swamp does not support the extent and quality of suitable habitat.	Highly unlikely to occur within Hexham swamp.
Rose-crowned Fruit-Dove (<i>Ptilinopus regina</i>) Source: c	V	Fruit-eating species of denser rainforests or sclerophyll forest with rainforest understorey.	Hexham Swamp does not support the extent and quality of suitable habitat.	Highly unlikely to occur within Hexham swamp. No confirmed records for the area (HBOC 1997).

Species and Information Source(s)	TSC Act Status	Habitat & Resource Requirements	Suitability of Habitat and likely occurrence within Hexham Swamp	Likely Occurrence Within Hexham Swamp Test Undertaken
Glossy Black Cockatoo (<i>Calyptorhynchus lathami</i>) Source: c	V	Upland forests, coastal woodland and open forest with abundant food resources of she-oak (<i>Allocasuarina</i> spp.).	Hexham Swamp does not support the extent or quality of suitable habitat (eg. preferred food tree species <i>Allocasuarina littoralis</i> .)	Highly unlikely to occur within Hexham swamp.
Powerful Owl (<i>Ninox strenua</i>) Source: b, c	V	A large, obligate tree hollow nesting owl of extensive eucalypt forest and woodlands with low levels of habitat disturbance. Requires a large home range (>500ha).	Limited forest cover, lack of suitable hollow bearing trees and possible low abundance of medium to large-sized prey (arboreal marsupials, flying-foxes) reduces Hexham Swamp habitat suitability.	Unlikely to occur within or adjacent to Hexham Swamp.
Masked Owl (<i>Tyto novaehollandiae</i>) Source: c	V	Requires large tree hollows for roosting and nesting. Forages within eucalypt forest and woodland with limited use of adjacent cleared areas.	Limited forest cover and lack of suitable hollow bearing trees significantly reduces habitat suitability of Hexham Swamp. Abundance of small to medium-sized ground dwelling prey may be limiting the occurrence of this species.	Unlikely to use Hexham Swamp. Considered rare in Hunter Valley (HBOC 1997).
Grass Owl (<i>Tyto capensis</i>) Source: d	V	Forages and breeds within taller wet heathlands, grasslands, dense reed beds, cane-grass pastures. Requires abundant populations of small ground mammals.	Limited areas of potentially suitable habitat present within Hexham Swamp.	Highly unlikely to occur within Hexham swamp. Not previously recorded in the Hunter Valley (HBOC 1997).
Regent Honeyeater (<i>Xanthomyza phrygia</i>) Source: b, c	E	Temperate eucalypt forest and woodlands (principally western slopes of GDR in NSW) dominated by box or ironbark; riparian forests dominated by she-oak (<i>Casuarina glauca</i>). Known, regularly used sites support tall, mature flowering trees with a taller shrub layer than adjoining unoccupied sites. Has been recorded in autumn, feeding in swamp mahogany (<i>Eucalyptus robusta</i>) at sites on NSW coast.	Hexham Swamp does not support the quality or extent of suitable habitat.	Highly unlikely to occur within Hexham swamp. Regarded as a vagrant on coast. Known from regular sightings in Upper Hunter Valley (HBOC 1997).
Koala (<i>Phascolarctos cinereus</i>) Source: b, c	V	Dry eucalypt forest and woodlands. Highly dependent on a limited range of locally favoured food trees.	Very limited number of suitable habitat trees exist, either as isolated individuals or small stands within Hexham Swamp. No records (sightings, scratchings, scats)	Unlikely to use Hexham Swamp.
Squirrel Glider (<i>Petaurus norfolcensis</i>) Source: b, c	V	Requires a combination of Acacias as understorey dominants and mixed-aged eucalypts as canopy of dryer coastal/subcoastal sclerophyll forests and woodlands. Forages on insects, exudates, pollen and nectar depending on availability.	Very limited areas of marginally suitable habitat occurs within Hexham Swamp.	Unlikely to use Hexham Swamp.
Yellow-bellied Sheathail Bat (<i>Saccolaimus flaviventris</i>) Source: b, c	V	A microbat which forages above canopy of dryer eucalypt forest and woodland. Roosts and nests in tree hollows.	Very limited areas of marginally suitable habitat occurs within Hexham Swamp. Roost and breeding habitat are scarce.	Unlikely to use Hexham Swamp.
Eastern Freetail Bat (<i>Mormopterus norfolkensis</i>) Source: b, c	V	Rainforest, wet sclerophyll forest and dry forest. Roosts and nests in tree hollows, and also recorded roosting in buildings.	Very limited areas of marginally suitable habitat occurs within Hexham Swamp. Roost and breeding habitat are scarce.	Unlikely to use Hexham Swamp.
Little Bentwing-bat (<i>Miniopterus australis</i>) Source: b, c	V	Forages beneath canopy within a range of well forested habitats, including sclerophyll forest, rainforest and Melaleuca wetlands. Requires maternity caves. Roosts in caves, old mines and tunnels, frequently sharing these sites with colonies of <i>M. schreibersii</i> .	Potentially suitable foraging habitat exists within Hexham Swamp, though scarcity of suitable roosting/maternity sites likely to restrict use. Use of Hexham Swamp likely to be reliant on availability of suitable roosting/maternity site in adjoining local habitat.	Likely to use Hexham Swamp as foraging habitat, though occurrence dependent on the availability of suitable roosting and maternity sites within close proximity of Hexham Swamp.

Species and Information Source(s)	TSC Act Status	Habitat & Resource Requirements	Suitability of Habitat and likely occurrence within Hexham Swamp	Likely Occurrence Within Hexham Swamp Test Undertaken
Common Bentwing-bat (<i>Miniopterus schreibersii</i>) Source: b, c	V	Forages within a range of well timbered habitats. Roosts in caves, old mines, tunnels and structures of similar form. Nursery caves are required by females.	Potentially suitable foraging habitat exists within Hexham Swamp, though scarcity of suitable roosting/maternity sites influences may restrict use. Use of the Swamp likely to be reliant on availability of suitable roosting/ maternity sites in adjoining/local habitat.	Likely to use Hexham Swamp as foraging habitat, though occurrence dependent on the availability of suitable roosting and maternity sites within close proximity of Hexham Swamp.
Greater Broad-nosed Bat (<i>Scoteanax ruepellii</i>) Source: b, c	V	Forages for insects within the open understorey of a variety of habitats including open forest and woodland. It is also known to forage low along waterway corridors and over treeless habitats including pastures. Prefers to roost in tree hollows but also known to use ceiling space within houses and buildings. Females known to congregate in suitable tree hollows to breed.	Potentially suitable foraging habitat exists within Hexham Swamp, though scarcity of suitable roosting/maternity sites influences may restrict use. Use of the Swamp likely to be reliant on availability of suitable roosting/ maternity site in adjoining/local habitat.	Likely to use Hexham Swamp as foraging habitat, though occurrence dependent on the availability of suitable roosting and maternity sites within close proximity of Hexham Swamp.
Large-footed Myotis (<i>Myotis adversus</i>) Source: b, c	V	Forages over waterbodies within vegetated wetlands and along timbered waterways. Roosts communally in caves, under bridges, tunnels and similar structures. Roost and maternity sites usually located close to open waters.	Potentially suitable foraging habitat exists within Hexham Swamp, though scarcity of suitable roosting/maternity sites influences may restrict use. Use of the Swamp likely to be reliant on availability of suitable roosting/ maternity sites within adjoining/local habitat.	Likely to use Hexham Swamp as foraging habitat, though occurrence dependent on the availability of suitable roosting and maternity sites within close proximity of Hexham Swamp.

Information sources:

- a: Threatened species records of the Atlas of NSW Wildlife (10km grid square containing study area)
- b: Threatened species records of the Ironbark Creek Total Catchment Strategy (Vol II, 1993)
- c: Threatened species known or likely to occur within the region which have been considered as part of an impact assessment. Also includes species investigated as requested by State Government agencies. Relevant sources are WBM (1997), CH2M Hill (1997), FFS et al. (1997b), and PPK (1998).
- d: Threatened or significant species investigated for this study at the request of NSW NPWS
- E: Endangered status under Schedule 1, Part 1 of the Threatened Species Conservation Act 1995
- V: Vulnerable status under Schedule 2 of the Threatened Species Conservation Act 1995

3.9 Weeds and Pests

3.9.1 Weed Species

There are many weed species in the Hexham Swamp area, with the greatest concentration in the fields and paddocks around urbanised areas such as Wallsend, Maryland, and Shortland, as well as along transport corridors and around industrial sites, such as those near Sandgate.

Some environmental weed species are sufficiently aggressive that they outcompete native plants and become an economic liability for councils and other authorities. Noxious weeds require some form of control under the NSW *Noxious Weeds Act 1993*. Three noxious weeds common in the Hexham Swamp area are pampas grass (*Cortaderia selloana*), alligator weed (*Alternanthera philoxeroides*) and water hyacinth (*Eichhornia crassipes*). These are described briefly below. Giant reed (*Arundo donax*) (W4a3) and bitou bush (*Chrysanthemoides monilifera*) (W3) are also listed as noxious weeds, and also occur in the study area. The most significant weed species in terms of their abundance and/or threat to the natural ecology of the area are listed in Table 3.26.

Table 3.26 Major Weed Species of the Ironbark Creek Catchment

Common Name	Scientific Name	Status	Nature of Impact
Dryland species			
Lantana	<i>Lantana camara</i>	WONS ⁴	Smothers native species and inhibits success of native animals
Fennel	<i>Foeniculum vulgare</i>		Problem for roadside verges
Pampas grass	<i>Cortaderia selloana</i>	W2 ⁵	Spreading rapidly in the area; extremely difficult to remove established clumps; out-competes native species
Kikuyu grass	<i>Pennisetum clandestinum</i>		Smothers verge areas and outcompetes native grasses
Castor oil plant	<i>Ricinus communis</i>		Grows in large stands and outcompetes native plants
Blackberry	<i>Rubus vulgare</i>		Forms impenetrable clumps and is difficult to remove
Stinking roger	<i>Tagetes minuta</i>		Rapidly colonises disturbed areas; harmful to cattle
Bitou bush	<i>Chrysanthemoides monilifera</i>	W3 WONS	Colonises roadside verges and other disturbed areas, particularly on sandy soils (coastal species); outcompetes native species
Camphor laurel	<i>Cinnamomum camphora</i>		Well established small to large tree, tending to outcompete native species
Wild tobacco tree	<i>Solanum mauritianum</i>		Large clumps of this tall shrub are found in shadier areas, e.g. following creek lines, such as Blue Gum Creek
Wetland species			
Alligator weed	<i>Alternanthera philoxeroides</i>	W3 WONS	Becoming a major problem along the banks and flood plain of Ironbark Creek and its tributaries; beginning to invade the Hexham floodplain
Water hyacinth	<i>Eichhornia crassipes</i>	W3	Found in Newcastle Wetlands Reserve, and at the western edge of the Hexham Swamp alongside Lenaghan's Drive, at the pipeline; has the potential to spread into nearby wetlands and dominate water bodies

Alligator weed

Alligator weed is now recognised as being one of the most aggressive and costly weeds introduced into NSW, being almost impossible to eradicate. It is declared as a W3 category weed under the NSW Noxious Weeds Act 1993 and is a Weed of National Significance.

⁴ WONS- Weed of National Significance.

⁵ Category for control in Newcastle under the NSW Noxious Weeds Act 1993.

Alligator weed is believed to have been introduced into Australia from South America in ship ballast dumped in Newcastle and Botany Bay in the 1940's (Griffiths 1989).

The weed produces fibrous roots at the stem joints which attach to the soil or hang in the water. Each joint can develop into a new plant. Broken-off stems root easily and spread rapidly. Alligator weed grows rapidly in water and can form dense mats of hollow, interwoven stems that may extend many metres from the shore. During wet weather, when swamps and drains overflow it spreads to adjoining land. Once established it can spread very quickly, especially during wet seasons, crowding out most other pasture species. It is easily spread in hay and turf, in mud on earth-moving machinery, by vehicles or by stock. It does not produce viable seeds.

In the catchment, alligator weed was first sighted in 1979 in a drain below the Shortland Wastewater Treatment Plants (Le Messurier 1981). Here it responded well to the influx of nutrient-enriched effluent. In 1981, pockets of alligator weed were found in an unformed suburban drainage canal off Watkins Street, Elmore Vale and on an adjoining embankment. Also in 1981, alligator weed was found in a recently planted turf lawn at a home in Andretta Avenue, Elmore Vale. This infestation was unrelated to earlier infestations. In 1988, infestations of alligator weed were found spreading along Ironbark Creek downstream from Minmi Road. Here the nutrient-rich waters provided ideal conditions for its quick growth and spread. Herbicide applications have been applied in an attempt to prevent its spread in this location. Other major infestations occur in Dark Creek and the adjoining land. In 1992, new outbreaks were detected north of Fishery Creek on the western side of the water pipeline. It is likely that this infestation was spread to the swamp by cattle frequenting areas of infestations along Fishery Creek. In early 1993, a further outbreak was confirmed in a suburban lawn at Maryland.

Hockley (1974) stated that alligator weed will tolerate up to 10 per cent of salt water by volume and Burkhalter et al. (1972) indicated that it will tolerate 10 per cent of sea strength in still water and 30 per cent of sea strength in flowing water. There is therefore the potential for the weed to be widely dispersed from Hexham Swamp via tidal waters to other ecologically suitable areas in the Lower Hunter, notably the Ash Island end of Kooragang Island. However, surveys conducted in the Ironbark Creek system have indicated that alligator weed was considerably less plentiful in the lower, slightly more saline sections of Ironbark Creek than in the fresher sections, suggesting that increased salinity had inhibited the growth and spread of alligator weed (EAM Consultants 1991).

Biological control methods for Alligator Weed have had mixed success in the Ironbark Creek system in the past (EAM Consultants 1991). Physical control, such as hand pulling, is not very effective, as viable plant parts are easily broken off, resulting in further dissemination of the plant. Control is therefore usually carried out using herbicides registered for use on alligator weed, including glyphosphate for floating plants and dichlobenil for water less than 1 m depth.

Pampas grass

Under the NSW *Noxious Weeds Act 1993*, pampas grass is listed as a W2 category noxious plant within the Newcastle local government area. Infestations of the perennial pampas grass occur in various locations along the southern and eastern edges of Hexham Swamp. An extensive spraying effort by Newcastle City Council has decreased the infestation considerably. An on-going campaign for many years will be necessary to kill regeneration particularly around the Shortland garbage dump and around The Wetland Centre at Shortland.

Herbicide applications are the most satisfactory method of destroying large infestations of pampas grass as mechanical removal on a large scale will disturb the soil, creating opportunities for seed establishment.

Water hyacinth

Water Hyacinth is listed as a W3 category noxious plant in the Newcastle local government are under the NSW *Noxious Weeds Act* 1993. Water hyacinth is a perennial, mat-forming aquatic plant formerly from Brazil and now widely distributed in wetlands just outside the study area, west of the disused railway line.

During the operations of the former Newcastle Regional Abattoir the presence of water hyacinth was considered beneficial in being able to remove large quantities of nutrients from the waterways receiving abattoir effluent.

A campaign undertaken in 1988 by the owners of this land, now a residential area, has controlled water hyacinth in the wetlands alongside the Great Northern Railway Line.

Former extensive infestations found in the waterways east of The Wetlands Centre were also controlled by Newcastle City Council in 1991. This program was extended to an infestation below the regional markets at Sandgate. Small pockets of water hyacinth remain elsewhere in the catchment, and these do have the potential to spread to Hexham Swamp if not contained.

3.9.2 Exotic Pest Species

Exotic or introduced animals in the Project Area include domestic pets, domestic livestock, feral pets and livestock and those species either accidentally (e.g. Black Rat) or deliberately (e.g. Cane Toad) introduced. These are discussed below.

Domestic Livestock

Cattle and horses are of economic benefit to land holders but they also contribute to environmental degradation if allowed to graze extensively outside pasture areas in the following ways:

- Consumption of native plant species;
- Nutrient enrichment of soil and waterways;
- Physical damage to vegetation;
- Compaction of soil;
- Bank pugging and subsequent collapse and erosion; and
- Spreading of weed species e.g. alligator weed.

The main problem in the Hexham floodplain relates to livestock being responsible for weed dispersal and eutrophication problems (the latter assisting in larval growth of mosquitoes).

Other exotic/introduced species

The impact of domestic and feral pets and livestock is difficult to quantify, but there is little doubt that feral animals have the potential to effect arboreal and small ground dwelling mammals, reptile,

frog and bird populations through predation, competition for food and breeding resources and via habitat destruction.

The following introduced animals have been recorded within the Project Area and are discussed below:

- Pig (*Sus scrofa*);
- Fox (*Vulpes vulpes*);
- Rabbit (*Oryctolagus cuniculus*);
- Hares (*Lepus capensis*);
- Black Rat (*Rattus rattus*);
- Brown Rat (*Rattus norvegicus*);
- Indian Mynah (*Acridotheres tristis*);
- Starling (*Sturnus vulgaris*);
- Sparrow (*Passer domesticus*); and
- Cane Toad (*Bufo marinus*).

The Pig is an omnivore and causes considerable destruction and degradation to native vegetation in its search for food. Its diet includes the roots and bulbs of both native and introduced plants. Pigs also occasionally attack, kill and eat other animals, and include eggs in their diet. Perhaps their main adverse environmental effect is that of erosion, soil compaction and the muddying of waterways, together with their contribution to nutrient pollution of waterways and wetlands from faeces and urine. The presence of Pigs in the Hexham area has been documented since the 1890s. In 1988 a group of 15 feral Pigs were killed by trapping programs co-ordinated by Newcastle City Council. The population of Pigs within the catchment fluctuates with climatic conditions.

The Fox is an efficient carnivore and is known to prey on native fauna. Foxes are known to have considerable territory ranges and lairs may be situated large distances from hunting domains. Foxes are frequently sighted in the Ironbark Creek catchment area.

The impact of the Rabbit is well documented in Australia. Rabbits do not occur in large numbers within the catchment. Hares are also found in the area and, with Rabbits, can contribute to problems of soil erosion.

The Black Rat is known to occur in the area and is a competitor with native animals for food and breeding resources. It is typically a coloniser of disturbed and degraded areas. The piles of dumped rubbish near Wallsair aerodrome and other similar places are known to support Black Rat populations. In addition, the Brown Rat (or Ship Rat) is also present in the catchment.

The Indian Mynah, a territorial, gregarious hollow dependant species, is spreading throughout the State, displacing native hollow dependant species such as native birds (e.g. galahs, eastern rosellas, and nightjars) and mammals (e.g. Squirrel Gliders). The bird is a nuisance in urban areas, and could potentially assist in spreading avian diseases amongst other bird species.

The Starling is also a territorial and gregarious hollow dependant species. It occurs in large flocks in the area and is mainly a problem in urban areas where it competes with native species for food and hollow dependant species for space resources.

The English Sparrow is an insignificant problem in urban areas.

Of much greater potential harm in the area is the possibility of the spread of the Cane Toad from Queensland and northern NSW. Media reports (Newcastle Herald 1992) have noted sightings of Cane Toads in several Newcastle suburbs. It is thought that these are isolated instances where Cane Toads have travelled from Queensland in soil and plant nursery supplies, and it is possible that the area may be too far south (and therefore too cold) to allow for successful reproduction. Work by Van Beurden (1981) indicates however that it may be possible for the Cane Toad to become established in the area. Considering the currently large area of habitat available to amphibians in the Hexham Swamp area (albeit of moderate to low value), a southern range extension of the population and subsequent impacts to native amphibian predators (e.g. Red-bellied Black Snake, goannas) could be extensive. This range extension potentially threatens the survival of many native populations.

3.9.3 Mosquitoes

3.9.3.1 Previous Conditions

The hydrology and salinity characteristics of the Ironbark Creek system have been altered during the past 20 years with the floodgates influencing ecological changes in Hexham Swamp.

The result of the loss of tidal interchange in Ironbark Creek and its tributaries has brought about fundamental changes in the local mosquito populations. Knowledge of tidal conditions is relevant in the understanding of mosquitoes and their control in Hexham Swamp.

Prior to the installation of floodgates, the Swamp was subject to the semi-diurnal fluctuations of tides produced by two high and two low waters each day. With every new and full moon, periods of spring tides greater than average in their range filled the depressions on the higher elevations of Hexham Swamp. Excess waters then drained back to Ironbark Creek as the tide receded. Only the highest areas lost water completely between the highest tides on successive flooding days. The non-draining salt pans and marshes when overflowed by the higher high tides held water long enough to mature prolific broods of the pestiferous saltmarsh mosquito (*Ochlerotatus vigilax*, previously known as *Aedes vigilax*). The same natural phenomena still occurs in the higher parts of Kooragang Island and other estuarine areas.

Before the installation of floodgates, the saltmarsh mosquitoes were most prevalent between December and March when Hexham Swamp was inundated with salt water and particularly when the water was replenished in favourable seasons by rainfall. Throughout periods of drought and when maximum tides were not in existence, the breeding of saltmarsh mosquitoes was greatly reduced.

3.9.3.2 Species

Prior to the advent of the floodgates, the most common mosquitoes found in the Hexham Swamp wetlands were:

- Saltmarsh Mosquito (*Ochlerotatus vigilax*);

- Scotch Grey or Hexham Grey Mosquito (*Ochlerotatus alternans*);
- Common Banded Mosquito (*Culex annulirostris*);
- Saltwater Culex (*Culex sitiens*);
- Australian Anopheline (*Anopheles annulipes*).

Ochlerotatus vigilax

The Saltmarsh Mosquito is a vicious biter, and the predominant pest mosquito in Newcastle. Its capacity for long migration flights from its breeding source (up to 20kms) makes general mosquito control a difficult problem.

It breeds in saltmarshes when flooded by the highest monthly tides. It usually does not breed in tidal creeks, but prefers predator free, shallow depressions on the marsh, typically vegetated with salt couch and red samphire. Eggs are laid on plant stems or soil surfaces elevated above the base of a pool. When the pool floods during spring high tides the eggs hatch into larvae and if sufficient water remains in the pool, the larvae will pupate and complete their development to emerge as adults.

Adult populations of *Oc. vigilax* persist from 2 to 3 weeks, after which, populations decline. However, a new generation of mosquitoes will be produced following subsequent tidal, or rainfall, inundations of the wetland.

Larval control programs were instituted primarily against this species because it was responsible for most complaints, occurred in the highest numbers and hatches could be predicted from tide charts.

This species is a known vector of disease causing pathogens (eg. Ross River virus and Barmah Forest virus).

Ochlerotatus alternans

The Scotch Grey or Hexham Grey Mosquito deposits its eggs singly on saltmarshes in the same places as those of the saltmarsh mosquito. Unlike most other mosquito larvae, the large larvae of *Oc. alternans* are predatory, feeding almost exclusively on saltmarsh mosquito larvae.

Adult Scotch Grey Mosquitoes can be distinguished at a glance by their large size and distinctive sandy/orange colouring.

Culex annulirostris

The Common Banded Mosquito is a known vector of arboviruses that cause encephalitis and epidemic polyarthritis. The larvae are found in the well vegetated margins of marshes, freshwater ponds and freshly-inundated land. Breeding occurs beyond the reach of any tidal influence.

Characteristically, the Common Banded Mosquito is found during the summer months and is a real nuisance in urban and suburban areas. It breeds in association with a number of other freshwater pest mosquitoes including the Australian Anopheline. It is the most predominant species currently breeding in the Hexham Swamp.

Culex sitiens

The Saltwater Culex, unlike the other saltmarsh species, deposits eggs in raft-shaped masses in the water surface of stagnant brackish pools and marshes or more permanent water areas. Typically, this species is most abundant during the late Summer and early Autumn.

This species is not usually considered a major pest but may be responsible for some pest impacts close to the breeding habitats.

Anopheles annulipes

The Common Australian Anopheline breeds in shallow pools containing aquatic vegetation and exposed to sunlight. Seasonal conditions influence breeding and prolonged wet seasons will tend to encourage an increase in numbers. The female mosquito deposits single boat-shaped eggs on the surface of the water.

3.9.3.3 Present Conditions

Mosquitoes within Hexham Swamp and other nearby environments are currently being monitored by the Institute of Clinical Pathology and Medical Research at Westmead Hospital on behalf of the HCRCMA to establish a baseline dataset for future impacts assessment. The most recent progress report on the mosquito monitoring is provided as **Appendix M: Volume 2**.

Despite the loss of significant tidal ventilation in Ironbark Creek and salt water intrusion into Hexham Swamp, monitoring has found that the current mosquito breeding sources are variable and include former tidal channels and mudflats off Ironbark Creek and Fishery Creek. The continuity and free-flowing characteristics of the channels have been obstructed over the past 20 years by natural earth blocks and the accumulation of debris.

The major inputs of water to these hollows arise from periods of sustained rainfall or overtopping of levees caused by floods.

Water may stand for many weeks in some of the deeper ponds and allow breeding and larval development of mosquitoes. Common banded mosquitoes and *Cx. annulirostris* has been found breeding in some of the grassy pools. Estuarine Mosquitoes also breed in some of the shallow temporary pools of the old mudflats fringed by the remains of mangroves where the pools become brackish due to the remnant salt content of the substrate. A lack of drainage in these areas ensures a continuum of mosquito breeding.

Former tidal channels, now vegetated and holding semi-permanent water following rainfall, are also breeding sources. Larvae of the common banded mosquito have been identified breeding in these pools. These sources occur east of the water supply pipeline and previously supported populations of the Saltmarsh Mosquito. However, there are likely to be extensive breeding habitats for freshwater mosquitoes west of the pipeline but the thick growth of vegetation in this area has made mosquito surveys difficult.

In addition, sources include freshwater swamps, shallow water or water-logged areas located on the fringe of the swamp. Here the water may be temporary or permanent. These are distinct depressions vegetated by weeds and other plants and allow breeding of *Cx. annulirostris*. The breeding of the

Common Banded Mosquito and the Saltwater *Culex* has been detected in enormous numbers in the eutrophic waters of Fishery Creek beneath the water pipeline crossing.

Occasional algae blooms, aquatic plant and weed build-up, caused by high nutrient levels, have enhanced conditions for mosquito breeding by restricting the predation by larvivorous fish.

The results of adult light trapping programs at Shortland by Newcastle City Council also provide some guidance to the pest species present in the Ironbark Creek area. Large numbers of *Oc. vigilax* are often collected in the Hexham Swamp area. However, because of its long flight range this species is likely to arise from the natural tidal marshes on Kooragang Island or elsewhere rather than breeding on site. The presence of this species at Blackbutt Reserve indicates the well established dispersal ability of this mosquito from the estuarine saltmarshes.

From the monitoring results it is evident that *Cx. annulirostris* is now the predominant pest species breeding in the Ironbark Creek catchment. However, it should be noted that, even when populations of this species are high following summer rainfall, the populations are often overshadowed by populations of *Oc. vigilax* that are produced from the nearby estuarine wetlands.

There are often large numbers of the non-human biting mosquito *Culex australicus* present as both larvae and adults in Hexham Swamp but this species does not represent a significant pest threat.

In regard to predation, the most prolific populations of vertebrate and invertebrate predators occur in the major ponds at The Wetlands Centre, Shortland. Native fish species are likely to have a significant effect on mosquito larvae numbers, as are the introduced Eastern Gambusia (*Gambusia holbrooki*), and a range of insect predators including the larvae of *Oc. alternans* and beetles of the family Dytiscidae. However, temporary shallow pools and waterbodies that are otherwise inaccessible to predators provide refugia for mosquito larvae.

3.10 Acoustic Environment

The acoustic environment of Hexham Swamp was assessed by Global Acoustics (2004) (refer **Appendix I: Volume 2**). The assessment focussed on the likely impacts associated with the construction of the Marsden Street earthen bund at Shortland.

Background noise levels were monitored at two locations in Shortland between 7 December and 17 December 2004. The locations were 43 Mawson Street, and 170 Marsden Street, Shortland.

The results of the background noise level assessment are provided in Table 3.27. These results indicate that the background noise levels in the Shortland area range from approximately 38dB during the day and evening (up to 10pm) to about 33dB during the night.

Table 3.27 Background Noise Levels at Shortland

Receptor	Period	L_{Aeq} dB	L_{A10} dB	L_{A90} dB	RBL L_{A90} dB
43 Mawson Street	Day	47	49	41	38
	Evening	46	48	42	38
	Night	42	44	37	34
170 Marsden Street	Day	49	51	40	36
	Evening	50	52	43	37
	Night	40	43	35	33

Notes

L_A – the A-weighted root mean squared noise level at any instant

L_{Aeq} – the average noise energy during a measurement period

L_{A10} – the noise level which is exceeded for 10% of the time (which is approximately the average of the maximum noise level)

L_{A90} – the noise level which is exceeded for 90% of the time (which is approximately the average of the minimum noise level, and is often referred to as the “background” noise level)

RBL – Rating background level (derived generally in accordance with EPA guidelines)

Day: 7am to 6pm; Evening: 6pm to 10pm; Night: 10pm to 7am

3.11 Fire Management

Reed communities such as those which currently dominate Hexham Swamp typically have high fuel loads and provide conditions suitable for very high fire intensities (NPWS 1997b). Despite these characteristics, Hexham Swamp does not appear to have been affected greatly by fire. Records from DEC (formerly NPWS) and NSW Fire Brigades on fires in the swamp extending back to 1990 indicate that the majority of recorded fires were small spot fires.

Only two events over this time period could be considered to have had a significant impact, with both of these occurring in the eastern corner of the site. These events occurred in April 1991 and March 1993. The 1991 event affected areas on both sides of Ironbark Creek, while the 1993 event was limited to its eastern side. It is likely that both of these events would have had a significant effect on the remaining mangrove and saltmarsh communities found on the site.

Reeds recover quickly after fire, however, mangroves and saltmarsh are not fire tolerant and do not cope well with fire events. It is likely therefore that the 1991 and 1993 fires in Hexham Swamp would have further reduced the areas covered by these two communities.

Fire management in Hexham Swamp is not currently considered a priority, with few if any controlled burnings being undertaken. Moist conditions in the swamp tend to limit the potential for large scale fires, and there are no major structures under threat from any fires which do occur. The agricultural land which fringes the swamp also limits the ability of fires to spread and cause property damage.

The Plan of Management for Hexham Swamp indicates that fire will be managed within the Nature Reserve by DEC (NPWS) based on their statutory responsibilities, which include:

- Reducing the risk of bushfire damage to life and property;

- Protecting and conserving the natural, cultural, scenic and recreational features; and
- Cooperating with other organisations in fire management planning and implementation.

The Plan of Management also states that a specific fire management plan for the Kooragang and Hexham Swamp Nature Reserves will be developed by December 1998. It is understood that this fire management plan has not yet been prepared by DEC (NPWS).

3.12 Visual Landscape

3.12.1 General

Hexham Swamp is a shallow depression contained by the Hunter River to the north-east and by vegetated slopes and development on its sides. It presents a varied visual amenity ranging from natural areas and waterways to rural, industrial and residential zones. The visual catchment, adopting the Hunter River as a boundary, can be divided into five general visual landscape units. These units include;

- Waterways;
- Developed areas;
- Trees;
- Rush lands; and
- Swamp fringe.

The visual amenity of the study site is characterised by flat rush lands interspersed by waterways and forested sections. Large areas are covered by the swamp fringe zone, much of which is used as agricultural land. The amenity of the study area varies throughout the year, with large areas becoming inundated during the wet winter months and also during periods of heavy rain at other times of the year.

The dominant visual feature of the site is Ironbark Creek. The creek line and its tributaries stand out from the surrounding areas not only because of the water contained within them, but also because of the vegetation which grows surrounding its banks. This strip of vegetation consists of moderately sized trees which stand out against the regularity of the rush lands and swamp edge. The other significant features contained on the site are anthropogenic features, including the rail line and water pipeline. These features detract from the naturalness of the site, although they do not greatly affect its scenic value. Overall, the site portrays a naturally regular landscape contrasted by the passage of Ironbark Creek and its tributaries and by the soft edge of agricultural land.

3.12.2 Detailed Description

Waterways

This unit consists of the Hunter River which acts as a visual boundary to the site, and also of Ironbark Creek and its tributaries. The unit may also include temporary water bodies found on the site throughout certain parts of the year, especially during the winter months. A high value is placed on this unit, especially on those sections which are moving or which cover a wide expanse.

Developed areas

Including residential, rural and industrial areas, this zone exists all around the boundary of the site. These areas range from having little detracting from the natural character of the site (rural areas and sympathetic residential) to having a strong detracting (industrial areas).

Trees

This zone consists of the area immediately surrounding Ironbark Creek and its tributaries, as well as the undeveloped area on the slopes to the south and west. These areas have a high scenic value, which increases with the size and density of the forested clumps.

Reed lands

A mainly flat muted zone extending over much of the site. Its natural state is its main contributing factor to the visual amenity of the site.

Swamp fringe

This unit is covered mainly by agricultural land. It has been largely cleared of natural vegetation. Apart from the grazed paddocks, development is largely absent. The visual characteristics of this area therefore do not detract from those of the study area.

3.13 Infrastructure

Hexham Swamp is traversed by a range of major infrastructure, including:

- Buried and above ground water and wastewater pipelines;
- High voltage transmission lines;
- Railway;
- Radio towers; and
- Airstrip.

These infrastructure components are discussed further below.

3.13.1 Hunter Water Pipelines

There are three main Hunter Water pipelines that cross various sections of Hexham Swamp (refer Figure 3.1). The most obvious pipeline is the Chichester Water Supply pipeline, which runs north-south through Hexham Swamp, approximately parallel with the Hunter River. This pipeline is raised off the ground surface via a series of concrete saddles. The Chichester pipeline is serviced by an access road, which is located immediately adjacent to pipe. The pipeline was originally constructed in the 1920s, and is due for replacement within the next 5 – 10 years (pers. comm. G. de Redder, HWC, 2004).

A water supply pipeline is also located along the western margins of the swamp. This pipeline is buried below the surface of the Swamp.

A sewage rising main also traversed Hexham Swamp towards the upstream (southern) reaches of Ironbark Creek. The section of the rising main across the Swamp was constructed relatively recently (in 2000), and is used to transport sewage from Maryland to the Shortland WWTW. The rising main is located a minimum of 600mm below the ground surface, and is also located below the bed level of Ironbark Creek at its crossing.

3.13.2 Transgrid Transmission Lines

High voltage Transgrid transmission lines are located within Hexham Swamp (refer Figure 3.23). Stanchions holding the transmission lines are positioned on elevated earthen pads, which typically have a surface level in excess of RL 1.0m AHD. This level is about 0.7 metres higher than the surrounding swamp ground levels.

Maintenance of the transmission lines and stanchions is via an unsealed access road running adjacent to the transmission line route.



Figure 3.23 Location of Transgrid Transmission Lines across Hexham Swamp

3.13.3 Main Northern Railway

The Main Northern Railway runs mostly adjacent to the Hexham Swamp study area, forming a boundary to the area over some of its length. The railway is located fully inside the study area at the Ironbark Creek rail bridge and continues inside the study area for a distance of approximately one kilometre south of the bridge (refer Figure 3.1).

The railway is used by coal trains, which transport coal between the Hunter Valley coal mines and the Port of Newcastle. Goods and passenger trains also use the railway, including the regular passenger service between Scone and Newcastle.

A new bridge over Ironbark Creek was constructed recently (June 2004). This new bridge is located adjacent (to the south) of the previous old bridge, which was significantly structurally degraded.

Prior to commissioning of the new bridge, trains were required to slow to 40 km/hr when travelling over the old bridge. Replacement of the Ironbark Creek rail bridge was undertaken by Rail Infrastructure Corporation (RIC). An EIS was prepared prior to the construction of the bridge, which outlined predicted environmental impacts and proposed mitigation measures (URS, 2003).

An access track is located on the south side (down side) of the railway line between the Ironbark Creek crossing and Sandgate station. The elevation of this access track is generally lower than the level of the railway line, and may be susceptible to inundation as a result of local flooding.

3.13.4 Radio Towers

3.13.4.1 Broadcast Australia Limited

Broadcast Australia (formerly NTL) owns and operates two towers located immediately adjacent to the Ironbark Creek floodgates at Sandgate (refer Figure 3.24). The towers are located on low-lying ground, which is just within the study area.

The towers are surrounded by a network of earthen radial cables to assist in the reception of radio signals. The conductivity of the subterranean cables is maximised by the high groundwater level, hence the preferred positioning of these towers in low-lying swamp areas.

3.13.4.2 2HD Sandgate

A large telecommunication tower owned and used by 2HD is located adjacent to Hexham Swamp at Sandgate (refer Figure 3.25). The tower is surrounded by permanent ponds, which contain the endangered Green and Golden Bell Frog (refer Section 3.8.7).

The 2HD ponds would have originally formed part of the Hexham Swamp wetlands, however, they are now mostly disconnected hydraulically by culverts, and thus are considered to be outside the Hexham Swamp study area. However, the ponds are still able drain to Hexham Swamp following significant rainfall and a local increase in pond level. The ponds drain via culverts under the access road between R&H Transport and Unimin. The presence of small mangrove trees within the 2HD ponds indicates some residual salts in the soil and the pond waters, however, given the absence of mature trees, the lack of tidal flows in the pond is likely to be sub-optimal for mature development.

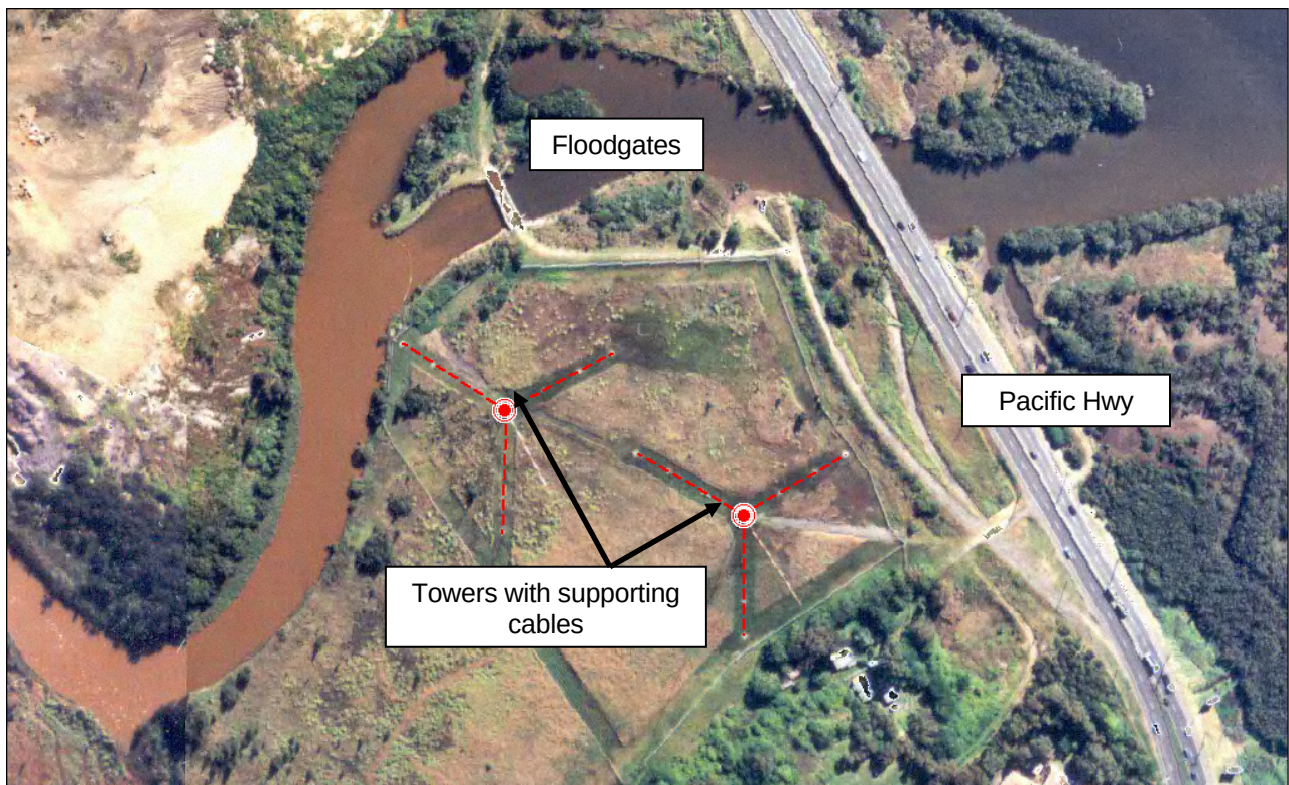


Figure 3.24 BAL Towers at Sandgate

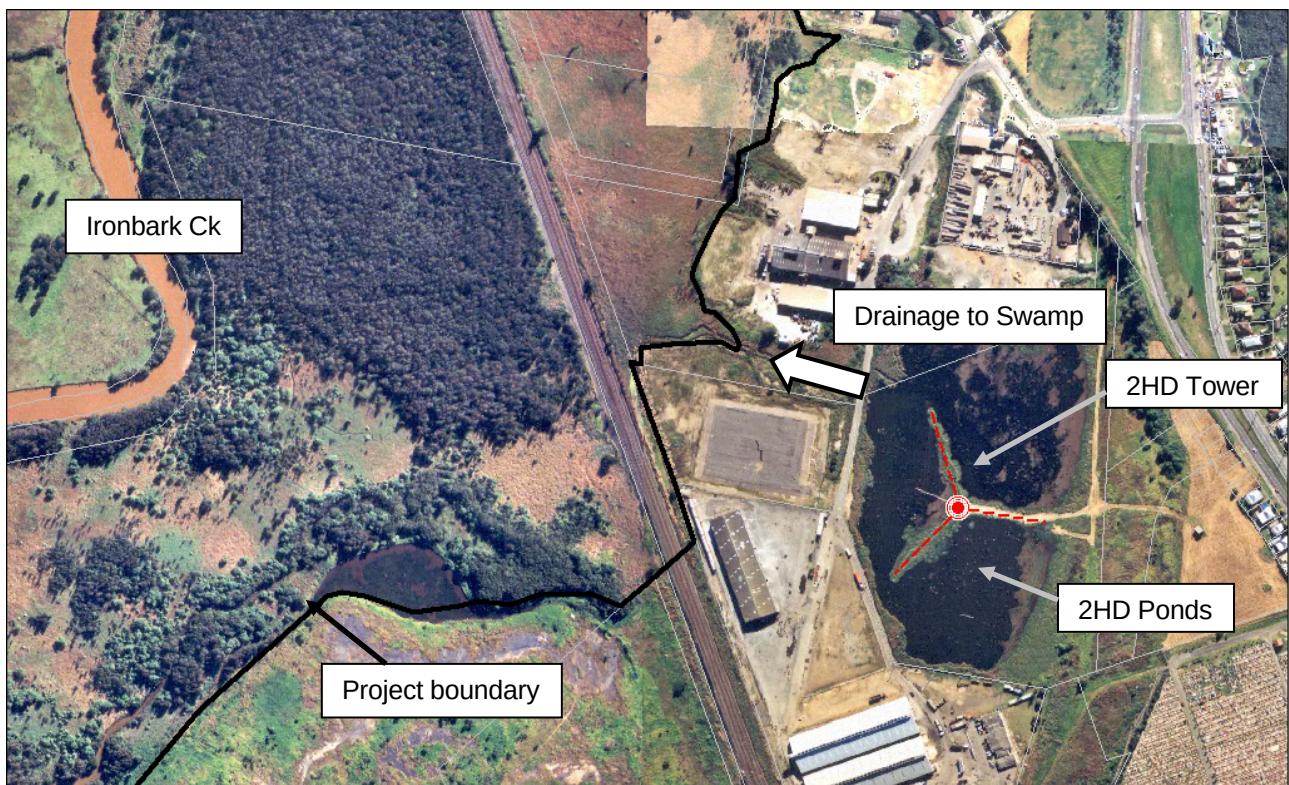


Figure 3.25 2HD Tower at Sandgate

3.13.4.3 2KY Shortland

Two radio towers are located on land owned by the TAB at Shortland (refer Figure 3.26). These towers are used by radio station 2KY. Access to the towers is via a narrow roadway to the south of the Wallsend General Cemetery.

Once again, the towers have been located on low-lying swampland to maximise conductivity for the associated subterranean infrastructure.



Figure 3.26 2KY Towers at Shortland

3.13.5 Wallsend Airstrip

Wallsend (Wallsair) airstrip is a small privately owned and operated light aircraft facility located adjacent to the upper tidal reaches of Ironbark Creek, on the edge of Hexham Swamp (refer Figure 3.27). The runway and taxiways are currently unsealed. A hangar is located adjacent to the runway, which houses approximately three light aircraft.



Figure 3.27 Wallsend Airstrip at North Wallsend

3.14 Heritage

Under Part 4 of the Newcastle LEP 2003, consideration must be given to Items of Environmental Heritage as listed under Schedule 6 of the LEP. There are a number of items listed under the LEP that occur within close proximity to Hexham Swamp. These items are listed in Table 3.28.

Table 3.28 Heritage Items in the Hexham Swamp Area

Suburb	Item	Level of Significance
Birmingham Gardens	Wallsend General Cemetery, 164 Sandgate Road	Local
Hexham	Railway Station Maitland Road	Local
Hexham	Former Travellers Rest Hotel 23 Maitland Road	Local

Suburb	Item	Level of Significance
Maryland	Glendor Thomas Family Grave, 79 Callan Avenue	Local
Maryland	"Styles Grove", Moreton Bay fig trees, former residence and farm buildings 256 Minmi Road	Local
Minmi	John Brown's Model Farm and Stone Ford 33 Leneghans Drive	Local
Minmi	Minmi to Hexham railway	State
Sandgate	Sandgate Cemetery, 108 Maitland Road	State
Sandgate	Sandgate Cemetery office 116 Maitland Road	Local
Sandgate	Sandgate Cemetery Railway Spur	Local

3.15 Archaeology

The southern part of the Hunter estuary and surrounding alluvial lands is considered to lie within the area formerly occupied by the Awabakal people (Gunson, 1974). To the north of the Hunter River, the Worimi people occupied the Williams and Patterson River valleys, as well as the coastline and coastal barrier systems of Newcastle Bight. Darkinjung and Wonnarua people lived further to the west (west of Sugarloaf Range and Maitland).

A full report on the archaeological status of Hexham Swamp is provided in Umwelt (2003), including correspondence from Awabakal LALC regarding this project. A brief summary of this report is provided below, while the full Umwelt (2003) document is provided as **Appendix G: Volume 2** of this document.

3.15.1 Native Title

The National Native Title Tribunal indicated that as of 14 July 2004, there were no registered Native Title Claims over the Hexham Swamp area.

3.15.2 Types of Sites around Hexham Swamp

No types of archaeological sites would be located within the wetland areas of Hexham Swamp itself. Rather, sites would be located around the margins of the swamp on the elevated lands. These sites include:

- Isolated artefacts;
- Artefact scatter or open campsite;
- Pre-contact burial sites;
- Stone arrangements;
- Shell middens;

- Grinding grooves;
- Stone quarries;
- Ceremonial grounds;
- Scarred and carved trees;
- Post-contact burial sites;
- Aboriginal fringe camps / reserves;
- Waterholes / wells; and
- Preservation of timber / fibre implements.

Based on ethnographic and archaeological research in the Hexham Swamp area, it is predicted that:

- Stone artefact scatters and isolated finds are the most likely evidence of former occupation;
- Occupation would have concentrated on lower gradient spurs and ridges bordering the wetlands, particularly in areas associated with major tributaries (eg Ironbark Creek); and
- It is unlikely that Aboriginal sites will be located in low lying wetland areas due to the persistent past inundation of these areas.

3.15.3 Community Views

The Awabakal Local Aboriginal Lands Council (LALC) and traditional owners of the Hexham Swamp area are supportive of the proposed rehabilitation of the environmental and ecological values of Hexham Swamp. They are keen to actively participate in future rehabilitation works, and would like to be kept informed of habitat restoration progress during the course of the staged gated opening. Restoration of former estuarine habitats is seen as the restoration of important cultural heritage values. These habitats and the rich plant resource of the swamp supported people with a rich and complex culture for thousands of years before the arrival of Europeans.

3.15.4 Survey of the Proposed Marsden Street Bund Route

One archaeological site containing stone artefact scatter was found along the proposed Marsden Street bund route. The site is likely to have been affected by cattle trampling, past earthmoving activities and cultivation. Therefore, the potential for intact subsurface occupation evidence to be conserved at this location was considered to be low.

The site would be destroyed (buried) if the bund was to be constructed. Considering the low complexity of the Aboriginal site, its level of disturbance and the overall positive values of the project, the Awabakal LALC considers that the construction of the bund should proceed, provided it is constructed with clean imported fill, and following receipt of a Consent to Destroy from the Department of Environment and Conservation (formerly NPWS).

3.16 Socio-Economic Context

3.16.1 Overview

The Lower Hunter Region's population was approximately 469,000 in 2001 and is projected to increase to approximately 540,000 by the year 2016 (HVRF, 2003). Newcastle City is approaching its growth ceiling due to land constraints. In 2001, its population was 136,000, and is expected to grow by less than 8,000 by the year 2016 (HVRF, 2003). Urban development around Hexham Swamp is restricted by environmental constraints. Currently, there are no households located within the potentially inundated area of the Swamp. However, there are many households located on the higher ground of grazing properties, hobby farms and rural residential properties, and residential lots. The main urban growth is occurring to the south west of Hexham Swamp in the Maryland-Minmi corridor.

Traditionally, the Hunter regional economy has been dependent on coal mining, exports of coal through the Port of Newcastle, and heavy industry based on steel, aluminium, zinc and lead production. Of these activities, coal exports and steel production have had the greatest impact on Hexham Swamp. There has been extensive development on Kooragang Island, immediately to the north east of Hexham Swamp on the northern side of the South Channel of Hunter River, for coal loading facilities and heavy industry. Associated works have included filling of small estuarine channels to amalgamate islands within the Hunter River, and broadscale dredging of the lower estuary for navigation of deep hulled transport vessels. These works have significantly impacted the estuarine environment and the hydrology of the lower Hunter River area. For example, farmers in Hexham Swamp observed that tidal flooding of Hexham Swamp increased significantly from the mid 1950s. This led to a loss of dairying land on the swamp, which had been worked since the mid 1920s and ultimately resulted to the decision to construct floodgates at the mouth of Ironbark Creek (pers. comm. J. Searles, local grazier, January 2005).

Since 1971, there has been strong diversification of manufacturing into value adding and high technology production and services. Also, substantial operations within manufacturing have been outsourced to various service industries. This has led to a significant increase in tertiary sector employment from 61.3% in 1971 to 79.2% in 1998, which has been mirrored by declines from 9.9% to 6.9% for primary industries, and 28.8% to 13.9% for secondary industries. More importantly for the Hexham Swamp project, planners are re-imaging Newcastle and the region as a location for high technology, environmentally sustainable industries, and strong environmental protection and rehabilitation standards. The Kooragang Wetland Rehabilitation Project on Kooragang Island and the proposed Hexham Swamp Rehabilitation Project are important initiatives for this new vision.

Within Hexham Swamp, the two main activities are cattle grazing (beef cattle) and passive recreation such as canoeing and bird watching. Recreation activities are largely sponsored by The Wetlands Centre at Shortland, which lies adjacent to the Hexham Swamp. Ironbark Creek and areas within the Hexham Swamp Nature Reserve (administered by the Department of Environment and Conservation, formerly National Parks and Wildlife Service) are utilised for passive recreation. If saline habitats were restored in Hexham Swamp, the area could also become an important nursery area for commercial and recreational fish species. This could be highly beneficial for fisheries in the Hunter River and some offshore areas. The regional context of these industries is briefly discussed below.

3.16.2 Beef Cattle Grazing

Approximately 1.5 million hectares of agricultural land is utilised in the Hunter Region. In 1993-94, the largest agricultural sub-sector was beef cattle, which accounted for 29% of gross agricultural production or some \$99 million. In Hexham Swamp, there were approximately 744 ha of productive grazing land (or 0.05% of the region's developed agricultural land). Swamp areas are used for seasonal grazing and integrated with farming systems on adjacent higher land areas mainly for growing out vealers and finishing adult cattle. The swamp land is also an important drought reserve. Adult cattle numbers in the swamp and associated areas averaged approximately 500 head, while total numbers may range to upwards of 1,000 head when young cattle are included. This equates to about 0.09-0.2% of the regional beef cattle herd.

3.16.3 Tourism

In 1999-2000, the total number of domestic visits to the Hunter region was 2.7 million, with an average length of stay of 2.8 nights. The main purpose of the visits was holidays or visiting friends and relatives (HVRF, 2003). In 1999 - 2000, about 56% of visitors were from Sydney, 32% from NSW Country Areas, 5% from Queensland and the remainder from other states. Information relating to international visitors was not available, but their numbers would have been relatively small.

In 2002, The Wetlands Centre at Shortland attracted about 20,000 visits, while the number increased to over 24,000 in 2003. The centre has serviced largely the local day trip market, and thus these numbers cannot be directly compared with regional tourism statistics which exclude day trippers. The centre estimated that about 20% of visits or approximately 4,000 visits were from people who lived outside the area. This indicates that the centre possibly attracted about 1% of visits to the region and about 2% of visits to the Lower Hunter (incorporating the Cessnock, Dungog, Maitland, Newcastle, and Port Stephens LGAs).

Rehabilitation of the Hexham Swamp could play an important role in increasing visitation to The Wetlands Centre in the future, providing the rehabilitation plan opens more opportunities for recreational activities in the area.

3.16.4 Fishing

The total value of the commercial fish catch within the Hunter River is about \$1 million per annum. This excludes the value of the commercial catch from offshore ocean fisheries, other rivers and aquaculture in the region. Recreational fishing also occurs in the area. However, information is not available regarding the quantities of fish caught or the extent of recreational fishing effort. Currently, the Ironbark Creek floodgates prevent significant quantities of commercial or recreational fish species from growing out in the swamp habitat, and consequently Hexham Swamp's contribution to the adjacent fishing areas is insignificant. Re-establishment of mangrove and salt marsh areas within Hexham Swamp should increase productive habitat areas within the Hunter River catchment by about 30%. This could lead to a similar increase in the commercial fish catch in benefited areas.

4 ASSESSMENT OF ENVIRONMENTAL IMPACTS

For the purposes of this assessment, the proposal incorporates the opening of all eight floodgates, along with the construction of bunds and other works to minimise the impacts on private lands. The 'do nothing' option has also been discussed, where relevant, to highlight the impacts of the proposed works in Hexham Swamp.

The following sections describe the anticipated environmental impacts due to the proposal. Where appropriate, the assessment of one gate open and four gates open has also been discussed as interim steps to the ultimate floodgate management regime (of eight gates open).

4.1 Hydrology

The hydrological impacts of any floodgate regime will dictate the impacts on a range of other factors including fisheries, flora, water quality, soils and groundwater as well as social and economic issues. Hence, an accurate prediction of the expected changes to the hydrological regime of Hexham Swamp is critical to an understanding of the wider impacts and benefits of the proposal. The primary change associated with altered hydrology will be the increased tidal flushing and saltwater inundation of the swamp.

The highly complex nature of the hydrological regime of Hexham Swamp limits the accuracy of the predictions of saltwater inundation. These limitations are due to:

- the mixing of ponded freshwater and tidal inflows;
- the wide range of tidal conditions (ie. tidal range and salinity of water) that could occur in the Hunter River, including tidal anomalies that result in greater than predicted tidal levels;
- the influence of meteorological factors such as wind dispersion;
- the limitations of the survey data available for hydraulic modelling (although considerable effort was given to collecting survey data around the swamp for the purposes of hydrologic modelling);
- numerical assumptions used in hydraulic modelling for shallow waterbodies; and
- the resolution of the hydraulic modelling.

Also, it needs to be understood that while gate opening will result in increased salinity of the waterbody behind the floodgates, there will still be significant spatial and temporal variations in this salinity. The degree of impact of opening the gates would vary over the entire swamp area, season and phase of the tide or flood.

All of the above factors make it difficult to accurately define the extent of influence of saltwater inundation following gate opening. This section of the EIS focuses on describing the impact of floodgate opening on the *hydrological processes* of Hexham Swamp, which can then be considered for a range of tidal and flood-related hydrological conditions.

Inundation of Hexham Swamp is dependent on a number of sources of inflows including:

- Tidal inflows through the floodgate structure when tides are elevated in the Hunter River;

- Floodwater inflows generated from the local catchment of Hexham Swamp (via Ironbark Ck, Wentworth Creek, Dark Creek, Minmi Creek);
- Floodwater inflows from the Hunter River when levels exceed the levee banks along the Pacific Highway (approximately RL 1.8m AHD, or a 1 in 10yr Hunter River flood);
- Combination of the above events.

Outflows from Hexham Swamp are directed to the Hunter River, and can only occur when water levels in the river are lower than levels in the swamp. Future management of the floodgates will see the floodgates closed when flood warnings are issues for the Hunter River. In this regard, the future management of the floodgates during flood times will be the same as under existing conditions, and will be the responsibility of the Department of Infrastructure, Planning and Natural Resources. Flood management of the gates will be in accordance with DIPNR's Lower Hunter Valley Flood Procedures Manual (DLWC, 2000). As discussed in Section 2.3, the HCRCMA is also a registered floodgate controller for the Ironbark Creek floodgates, and will be responsible for modifying the floodgates during non-flood periods in order to manage and manipulate the extent of tidal inundation within Hexham Swamp.

4.1.1 Past Investigations

Hydrological impacts of alternative gate configurations were first assessed by Lawson and Treloar as part of the Hexham Swamp Inundation Study (Lawson and Treloar, 1993). Lawson and Treloar used a one-dimensional hydraulic model (MIKE-11) to predict inundation extents for a range of floodgate configurations, from existing conditions to all eight gates open. Lawson and Treloar determined the impacts of the floodgates during local catchment flood events (1% AEP and 5% AEP) as well as under low flow (tidal) conditions. The impacts of the floodgates, as determined in the Hexham Swamp Inundation Study, are presented in Table 4.1.

Table 4.1 Inundation Study Results (Lawson & Treloar, 1993)

	5% AEP local flood		1% AEP local flood		Low flow conditions	
	Peak WL (m, AHD)	Maximum inundation (km ²)	Peak WL (m, AHD)	Maximum inundation (km ²)	Peak WL (m, AHD)	Maximum inundation (km ²)
Existing Conditions	1.61	23.4	1.77	26.9	0.00	0.56
1 gate open	1.61	23.4	1.76	26.7	0.32	1.02
8 gates open	1.56	23.4	1.73	26.3	0.87	3.45

Lawson and Treloar concluded that the floodgates have a significant impact on tidal levels in Ironbark Creek, but have less impact on flood levels. Opening the floodgates would increase mean water levels, tidal range and salinity within the swamp, while flood levels from local catchment runoff would not be seriously impacted.

4.1.2 Additional Assessments

4.1.2.1 Model Set-up

To confirm the results of the Lawson and Treloar (1993) investigation, a second numerical model of Hexham Swamp was developed by WBM for this EIS using the TUFLOW two-dimensional finite difference model package. The TUFLOW model was set-up to improve the confidence of predictions associated with likely inundation extents. The model was based on extensive survey data that was collected as part of this study, which covered the entire swamp area, particularly the swamp peripheries where ground levels were most variable.

A digital terrain model (DTM) of the swamp area was developed for Hexham Swamp from the available survey data, and used as bathymetric input to the TUFLOW model. The Hexham Swamp DTM is presented in Figure 4.1. This figure clearly shows the low-lying nature of the swamp, surrounded by steeper bedrock ridges that protrude into the alluvial floodplain.

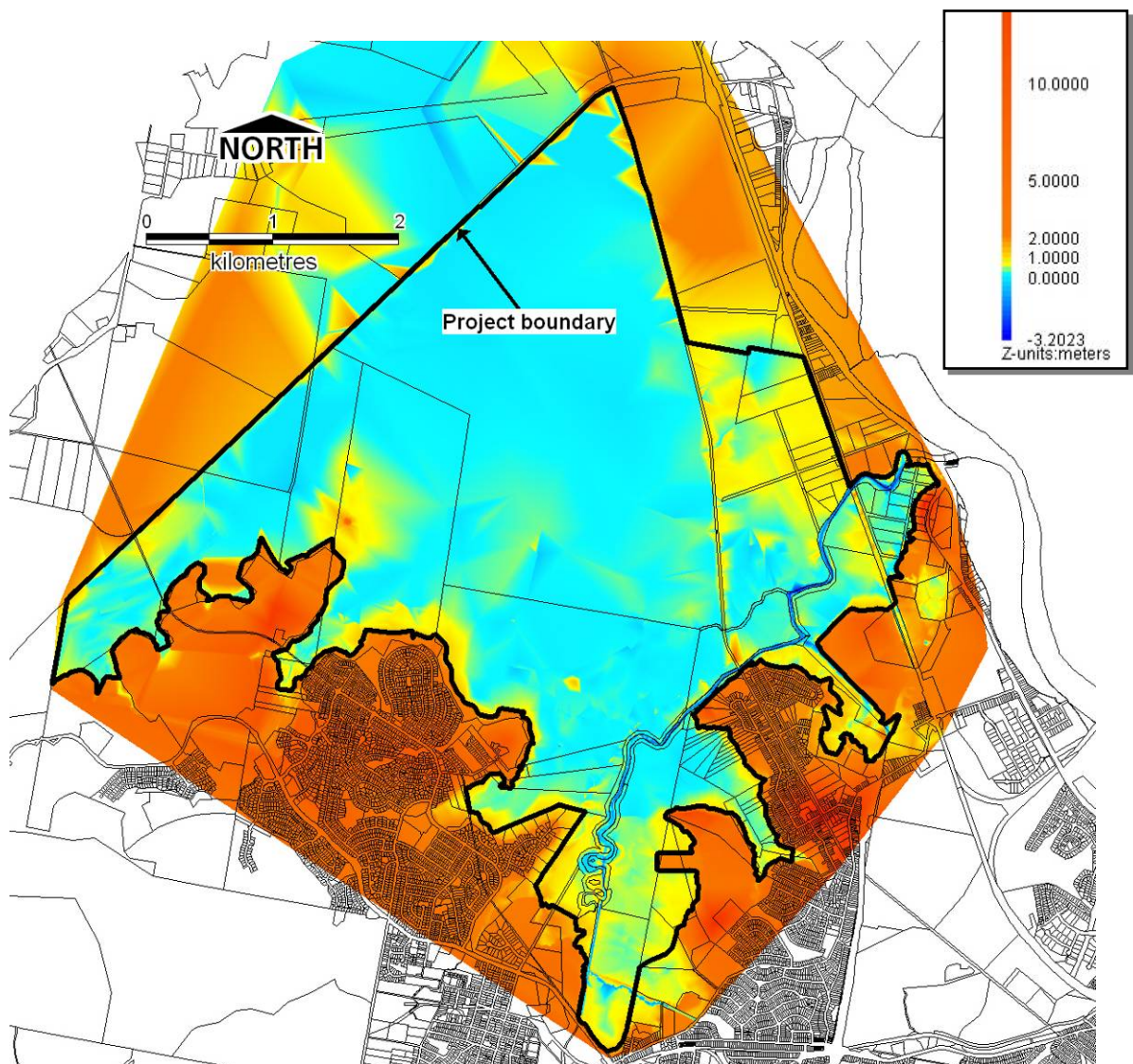


Figure 4.1 Hexham Swamp DTM

The TUFLOW 2D finite difference model was set-up using a grid spacing of 12.5 metres, and was internally linked to a one-dimensional ESTRY model of the main channels within the system.

The model was used to simulate existing conditions, as well as proposed staged floodgate conditions (1 gate open, 2 gates open, 4 gates open and all 8 gates open). The model determined flood levels and inundation extents under both tidal and locally generated flood conditions (for 1 in 1 year ARI and 1 in 20 year ARI events).

4.1.2.2 Tidal Levels

Maximum inundation extents are derived from the peak tidal levels achieved within the swamp. Table 4.2 presents a comparison of predicted peak tidal levels at a number of locations within Hexham Swamp (locations presented in Figure 4.4) for a number of gate open configurations (viz: 1, 2, 4 and 8 gates open). As seen in this table, the spring tide within Hexham Swamp will reach approximately 0.55m AHD, just upstream of the gates, but reduces with distance upstream to a level of approximately 0.41m in the upper tidal reaches of Ironbark Creek. Meanwhile, the king tide (when permitted into the swamp) would reach a maximum level of approximately 0.76m AHD just upstream of the gates, reducing to approximately 0.51m AHD in the upper reaches of the swamp. These levels compare to the current typical peak spring tide level in Ironbark Creek of approximately 0.05m AHD, reducing to -0.03m AHD at the upstream end of the swamp, and current typical king tide level of approximately 0.2m AHD at the gates to 0.1m AHD at the upstream end of the swamp (refer Table 4.2).

Table 4.2 Predicted Peak Tidal Levels in Hexham Swamp (m, AHD)

	u/s of floodgates	Canoe Ck junction	Shelley Ck junction	Dark Ck junction
Existing conditions (spring tide, refer Section 3.3.3.3)	0.05	0.05	0.04	-0.03
Existing conditions (king tide, refer Section 3.3.3.3)	0.20	0.16	0.15	0.10
1 Gate Open (spring tide)	0.26	0.25	0.24	0.25
1 Gate Open (king tide)	0.36	0.34	0.32	0.32
2 Gates Open (spring tide)	0.41	0.38	0.33	0.33
2 Gates Open (king tide)	0.50	0.44	0.40	0.40
4 Gates Open (spring tide)	0.50	0.43	0.38	0.38
4 Gates Open (king tide)	0.64	0.54	0.46	0.47
8 Gates Open (spring tide)	0.55	0.47	0.40	0.41
8 Gates Open (king tide)	0.76	0.62	0.51	0.51

Refer to Figure 4.4 for location of sites

In addition to peak tidal levels, opening the floodgates will change the low tide level, and thus the tidal range in the swamp, as well as the overall mean water level. Predicted high and low tide levels for a range of gate open conditions are shown in Figure 4.2 and Figure 4.3, for spring and king tides, respectively.

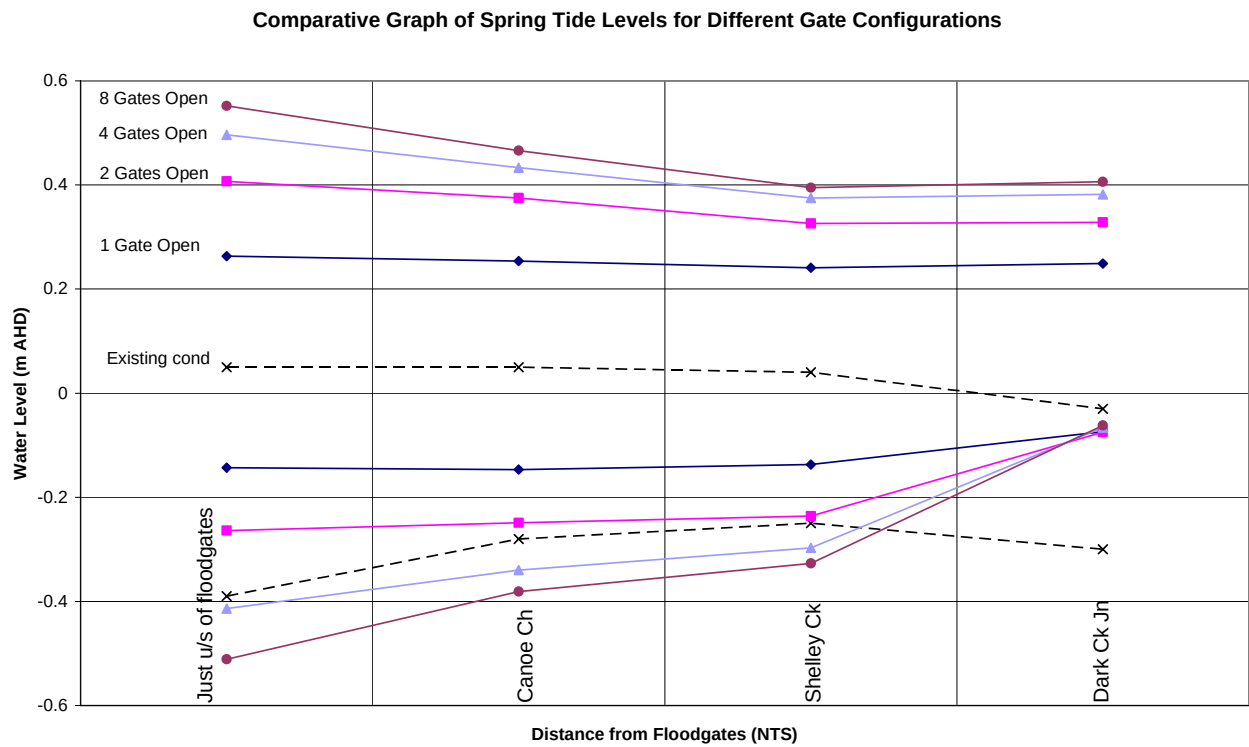


Figure 4.2 Predicted Spring Tide Levels in Hexham Swamp

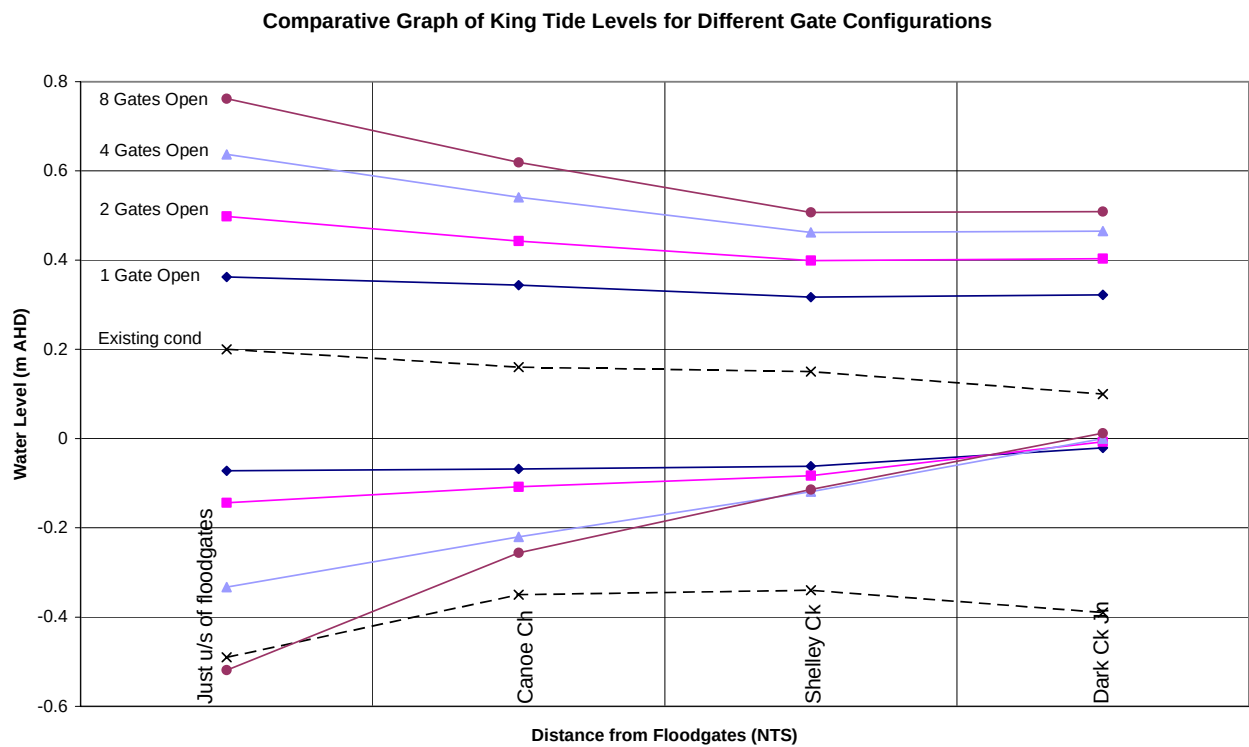


Figure 4.3 Predicted King Tide Levels in Hexham Swamp

As outlined in Section 3.3.3.3 and the above figures, the existing tidal range in Hexham Swamp is highly attenuated through the floodgates. With all eight floodgates open, the modelling predicts that the tidal range within Ironbark Creek (mid-way through the swamp) will increase to between 0.47 and 0.85 metres for spring tides, and between 0.50 and 0.88 metres for king tides (refer Figure 4.2 and Figure 4.3).

4.1.2.3 Inundation Extents

The extents of tidal inundation within Hexham Swamp were predicted using the numerical modelling, based on the peak predicted tidal levels, as presented in Table 4.2.

Figure 4.4 shows predicted inundation levels and extents under king tide conditions in Hexham Swamp when all eight gates are opened. This plot shows that over 750 hectares of land would be inundated by saltwater during king tides. This plot also shows that tidal inundation onto private lands will be prevented by the Marsden Street bund and the Broadcast Australia Limited (BAL) bund.

It is possible that many king tides will actually be excluded from Hexham Swamp in the future. The main reason for this is associated with control of the local mosquito population, as discussed in Section 6.6 (i.e. excluding king tides will prevent inundation of infrequently flushed pondages that subsequently provide ideal breeding habitat for mosquitoes). However, during non mosquito breeding times (i.e. during winter), king tides may be permitted into the swamp to maximise saltwater inundation and stimulate and promote re-establishment of saltmarsh communities.

Figure 4.5 shows predicted inundation levels and extents under typical (mean) spring tide conditions with all eight gates open. Approximately 340 hectares of land would be inundated by spring tides, which would occur several times per fortnight, on average. Again, the Marsden Street bund and the BAL bund would prevent saline intrusion of the spring tide onto private lands.

The area of spring tide inundation predicted by the TUFLOW model (i.e. 340ha) is very similar to the area predicted previously as part of the Hexham Swamp Inundation Study (Lawson and Treloar, 1993) (i.e. 345ha, refer Table 4.1).

Under existing conditions, tides are essentially restricted to the waterway channels, resulting in negligible overbank tidal inundation of the adjacent floodplain. Therefore, opening of the floodgates will result in an additional 340 hectares of overbank inundation during frequent spring tides, and up to 750 hectares of inundation by saltwater during infrequent king tides (which would possibly only occur a few times per year during the winter solstice). The impact of this inundation on existing vegetation communities is discussed in Section 4.4.2.

Numerical modelling has also been used to predict the extents of inundation for the different stages of the project, with different gate open conditions. Inundation extents for 1, 2 and 4 gates open scenarios are presented in Figure 4.6 to Figure 4.8, for both king and spring tide conditions. With one gate open, just 48 ha is predicted to be inundated under king tide conditions. This increases to 298 ha when two gates are open, and 569 ha, when four gates are open. For spring tide conditions, the inundation extents cover approximately 14 ha for 1 gate open, 77 ha for 2 gates open, and 268 ha for four gates open.

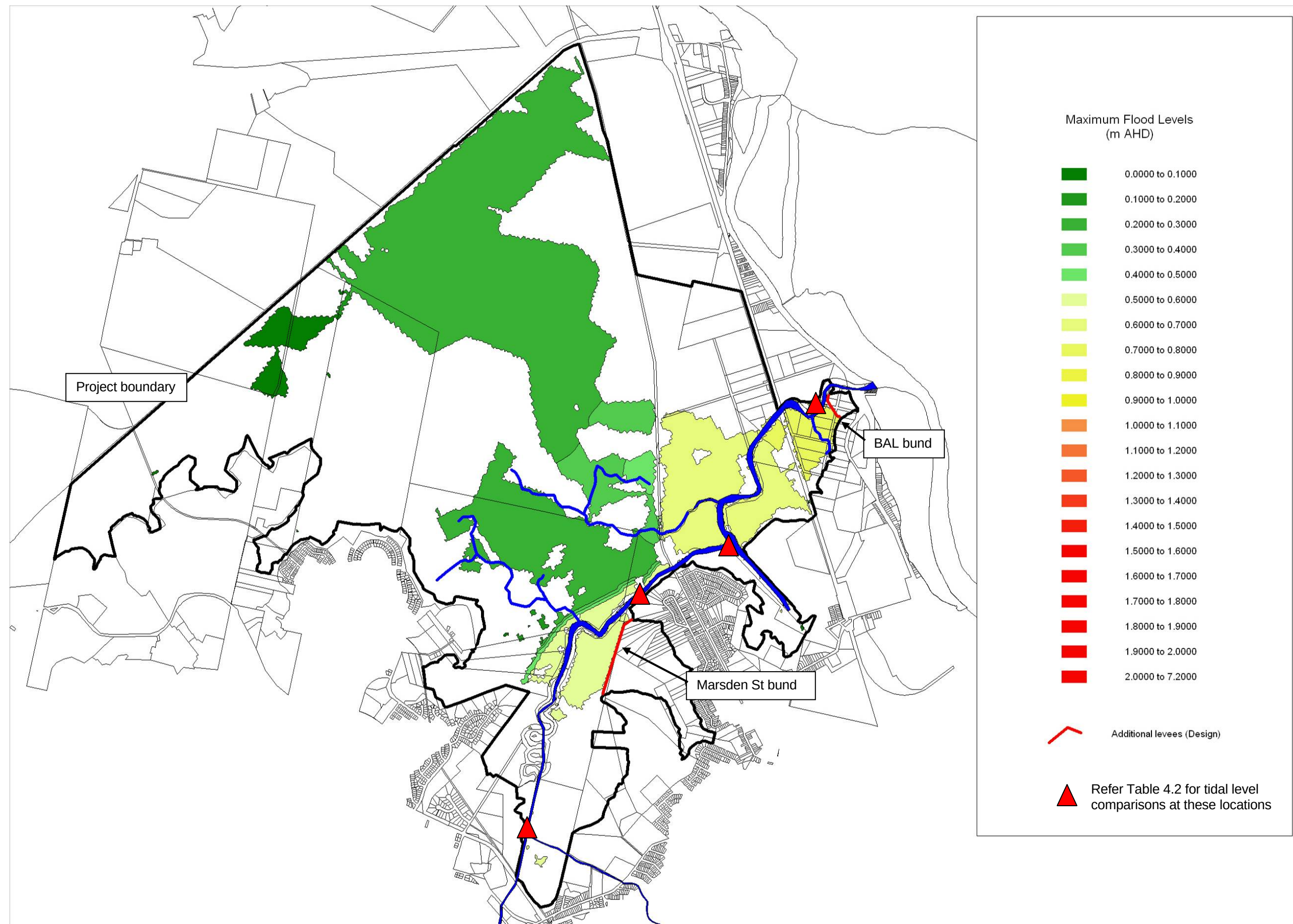


Figure 4.4 Maximum (8 gates open) Inundation Extents under King Tide Conditions

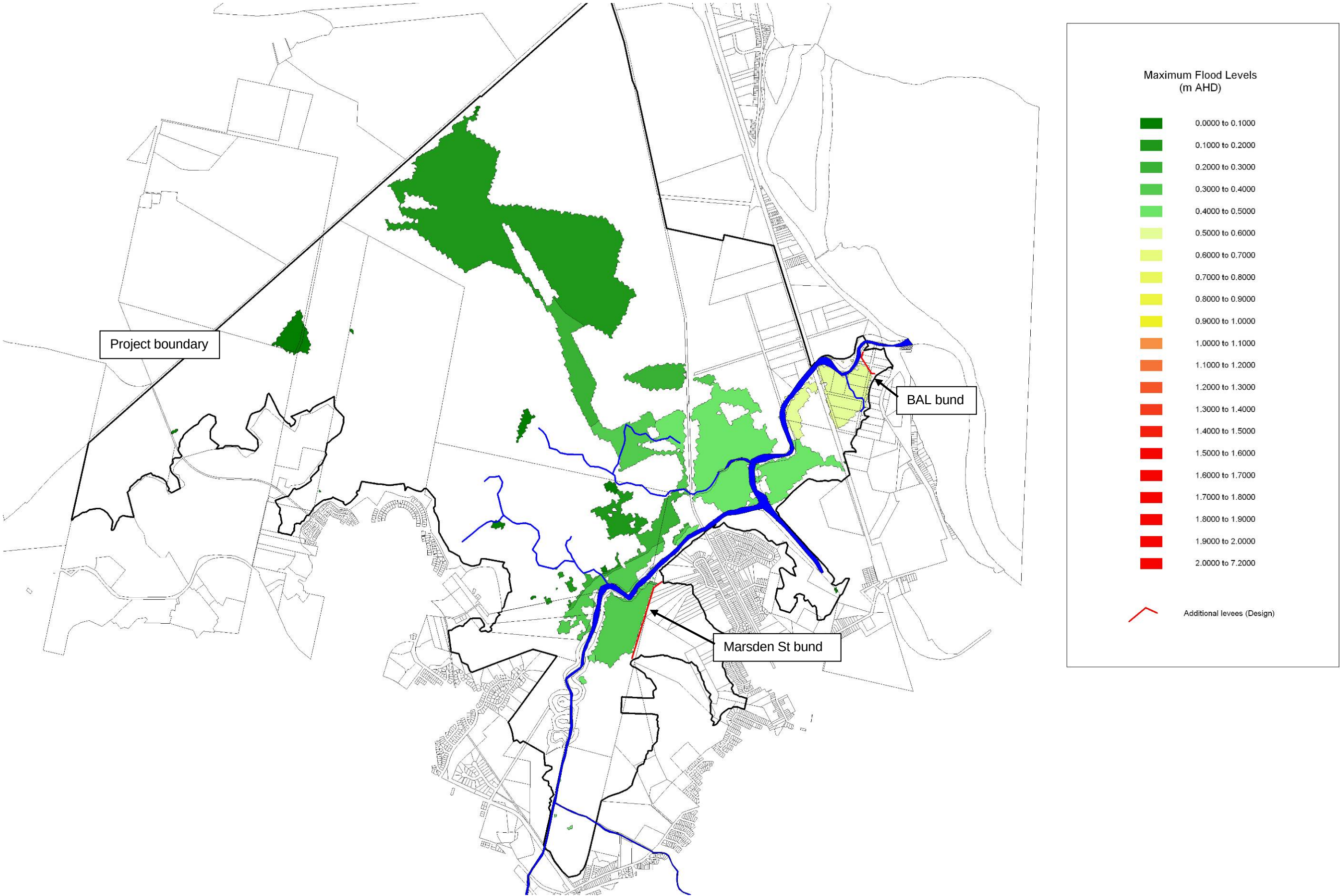


Figure 4.5 Maximum (8 gates open) Inundation Extents under Spring Tide Conditions

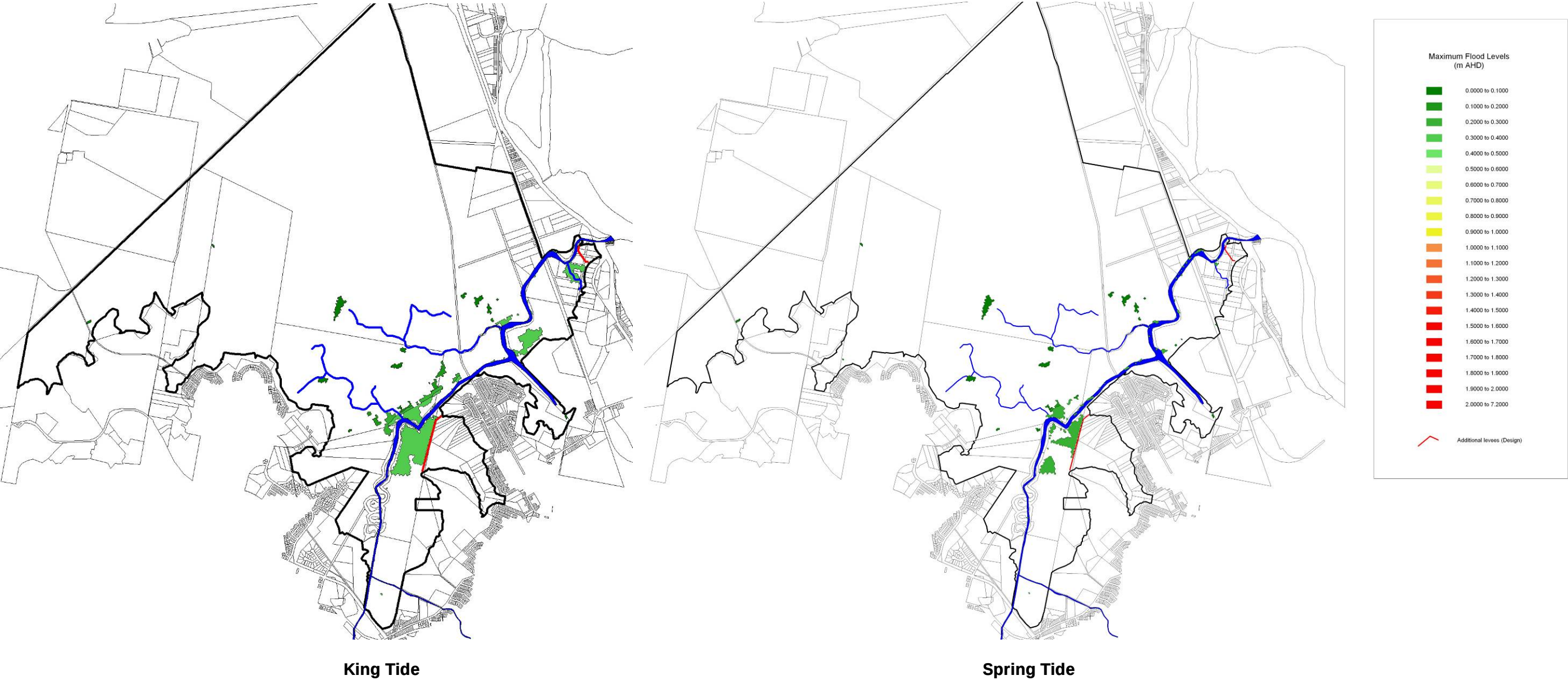


Figure 4.6 Inundation Extents for One Gate Open Conditions

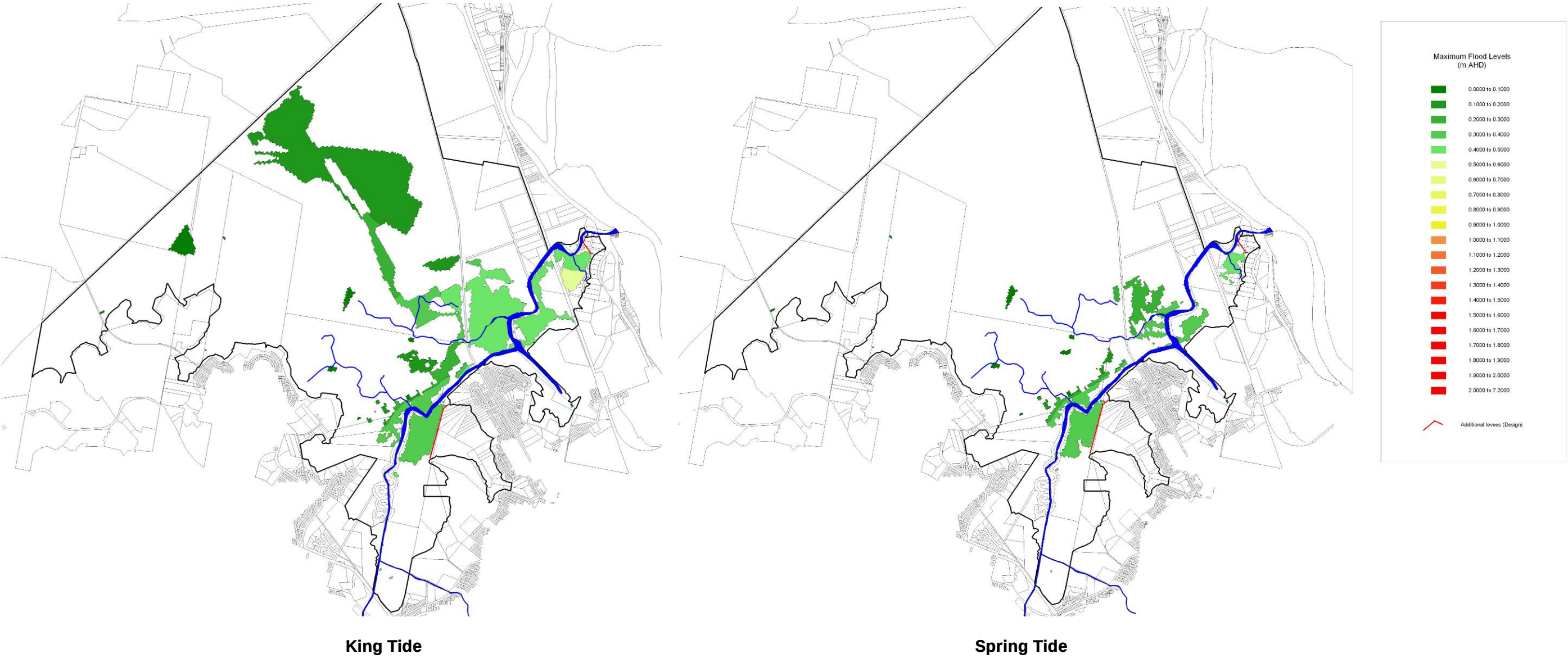


Figure 4.7 Inundation Extents for Two Gates Open Conditions

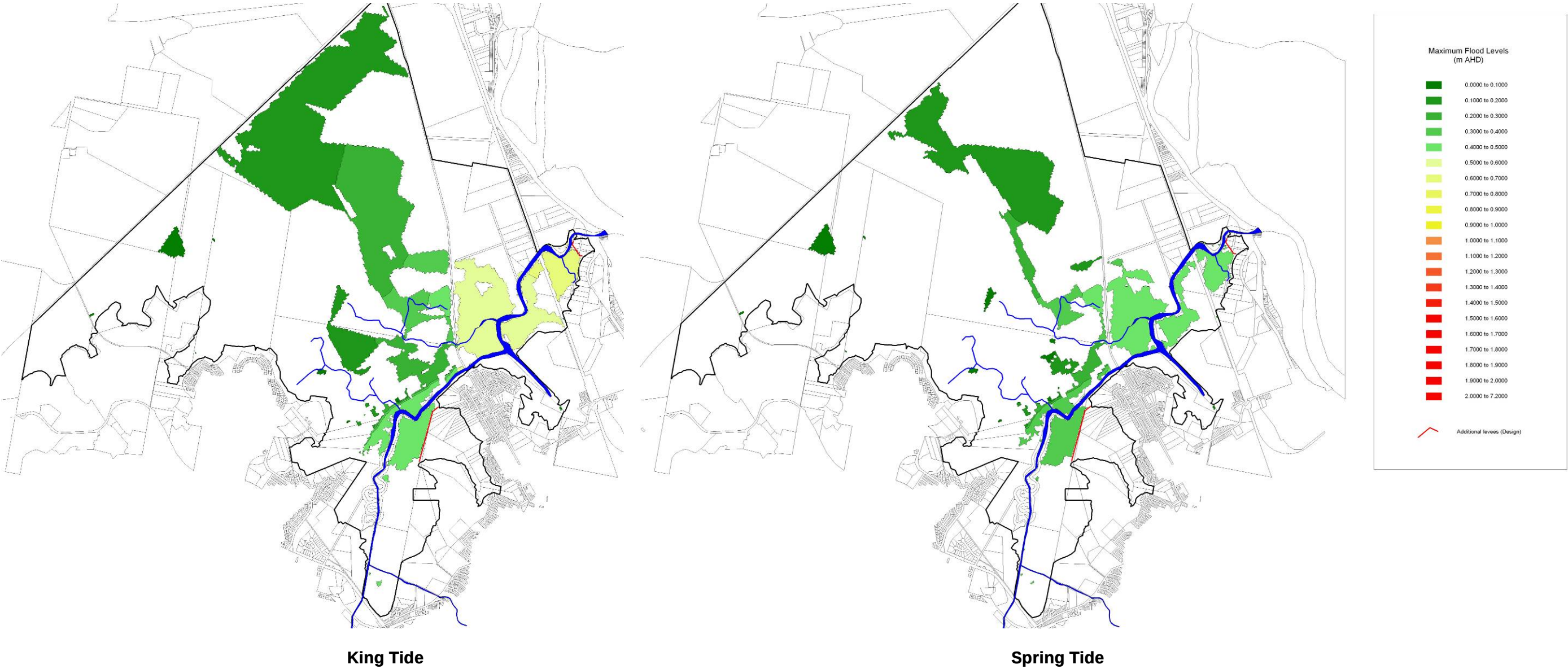


Figure 4.8 Inundation Extents for Four Gates Open Conditions

4.1.2.4 Catchment Flood Inundation

Lawson and Treloar (1993) had previously reported that impacts of opening the floodgates on locally generated flood events were likely to be relatively small. Local flood events were also assessed by the TUFLOW model developed by WBM. The results of this assessment are presented in Table 4.3. For the local flood assessment, two flood events were investigated: the 1 in 1yr ARI event and the 1 in 20yr ARI event (also known as the 5% AEP event). For both events, a storm duration of 2 days was determined to be the most critical, while the peak of the flood was times to coincide with the peak of the tide (spring tide) to ensure ‘worse case’ conditions were considered.

A 1 in 1 year ARI flood event was adopted to represent a flood event that is likely to occur relatively frequently (on average). Given the recent extended dry period, however, even this relatively small flood event has occurred infrequently over the past few years. This has unfortunately distorted the general community’s perception of the extent of flooding and degree of flood liability of the swamp.

Table 4.3 Predicted Local Flood Levels in Hexham Swamp (m, AHD)

	u/s of floodgates	Canoe Ck junction	Shelley Ck junction	Dark Ck junction
1yr ARI (spring tide) Existing Conditions	0.59	0.59	0.81	1.03
1yr ARI (spring tide) 8 Gates Open (difference in brackets)	0.63 (40mm)	0.64 (50mm)	0.85 (40mm)	1.04 (10mm)
20yr ARI (spring tide) Existing Conditions	0.74	0.84	1.06	1.43
20yr ARI (spring tide) 8 Gates Open (difference in brackets)	0.75 (10mm)	0.85 (10mm)	1.06 (0mm)	1.43 (0mm)

Refer to Figure 4.4 for location of sites

The results show that there is relatively little impact resulting from the opening of the floodgates for locally generated flood, with increases in water level of less than 50 mm (refer Table 4.3). Also of interest in Table 4.3 is the fact that the impact on flood levels reduces with distance upstream, and also reduces with increasing flood magnitude.

The main influence of the floodgates condition on local flood levels is related to the initial water level in the swamp when a flood occurs. If the floodgates are open, there is a greater chance that the swamp will contain more water than if the gates are closed. With more water in the Swamp, in theory, the flood storage capacity of the swamp would be reduced, particularly when flooding coincides with high (peak) tide conditions, as assumed in the modelling. For small flood events, the volume of catchment runoff is comparable to the volume occupied by tidal inundation, so impacts on

flood levels are more noticeable. For large flood events, however, the total volume of floodwater stored in the swamp is much greater than the volume associated with tidal inundation, so the impacts of opening the floodgates on these less frequent events are much smaller (refer Table 4.3).

As Hexham Swamp is a flood storage area at the downstream end of the local catchment system, the impact of reduced storage is not as great at locations further up the catchment where the hydraulic gradient is steeper. In essence, the impact of opening the floodgates is restricted to the floodplain area downstream of Minmi Road only, as this is the primary area for flood storage, and is the only area where storage is reduced by tidal inundation. Thus flooding upstream of Minmi Road, including the Wallsend commercial district, would not be affected by the proposed opening of the floodgates at the downstream end of Ironbark Creek. This was also the conclusion of previous flood modelling of the upper reaches of Ironbark Creek (Lawson and Treloar, 1999). Similarly, flooding impacts do not extend beyond Sandgate Road in the Canoe Channel or on Dark Creek, while there would be no impact within the more remote Wentworth Creek and Minmi Creek waterways.

Inundation extents for a 1 in 1 year ARI flood event are presented in Figure 4.9 for existing and eight gates open conditions, while Figure 4.10 shows predicted inundation under 1 in 20yr ARI conditions. Given the limited impacts on flood conditions associated with eight gates open, the intermediate stages of one gate open and four gates open were not considered in respect of catchment runoff flooding conditions. .

4.2 Water Quality

The potential impacts to water quality (both beneficial and negative) due to opening of the floodgates include:

- increased exchange of tidal waters between Hexham Swamp/Ironbark Creek and the Hunter River (including ingress of typically more turbid river water into swamp);
- potential impacts to acid sulfate soil runoff;
- potential interaction with former landfills;
- impacts from vegetation dieback as a result of increased salinity, including decreases in dissolved oxygen and increased nutrient loading (short term impact); and
- increased turbidity due to minor bank destabilisation (short term impact).

For each of these issues, the degree of water quality impact will depend on:

- the number of floodgates modified;
- the tidal inundation area; and
- the rate of floodgate modification.

The issues are discussed in the following sections in greater detail.

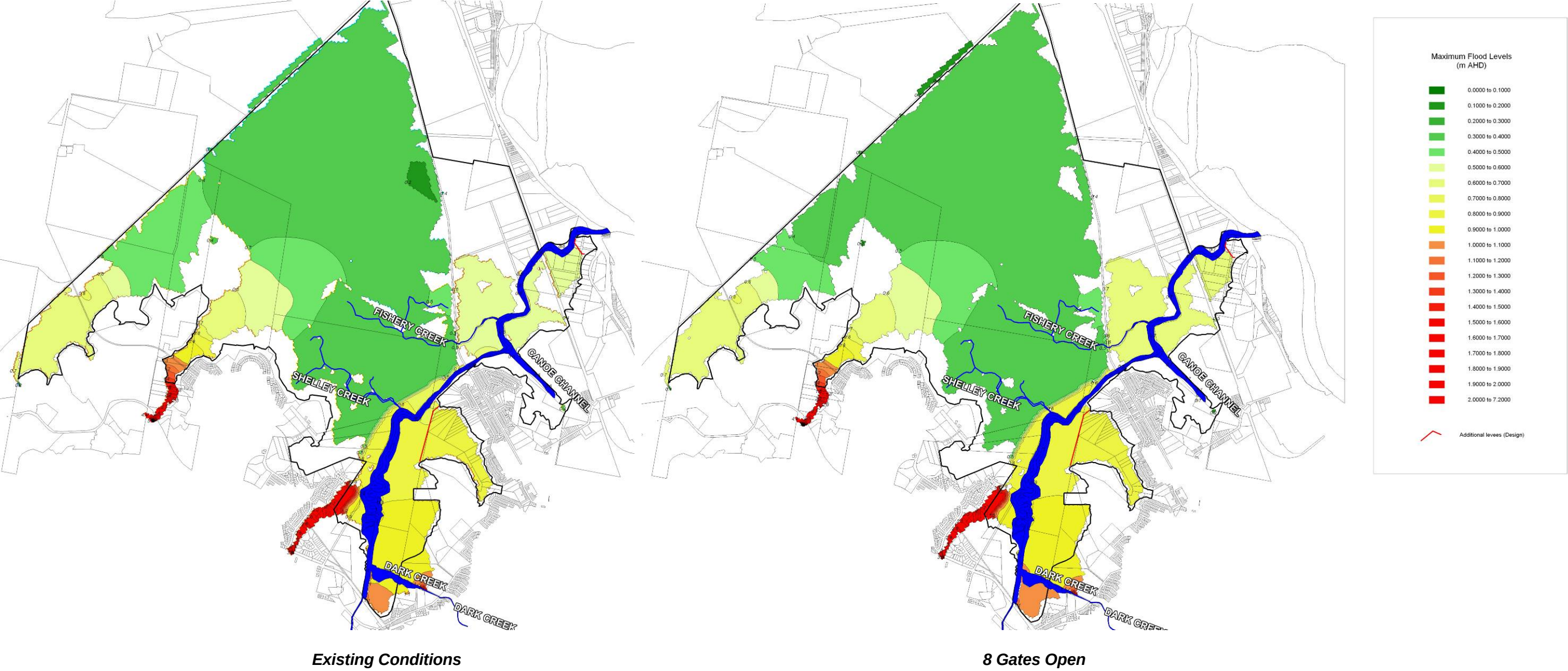


Figure 4.9 Predicted Inundation Extents for 1 in 1yr Local Flood Event

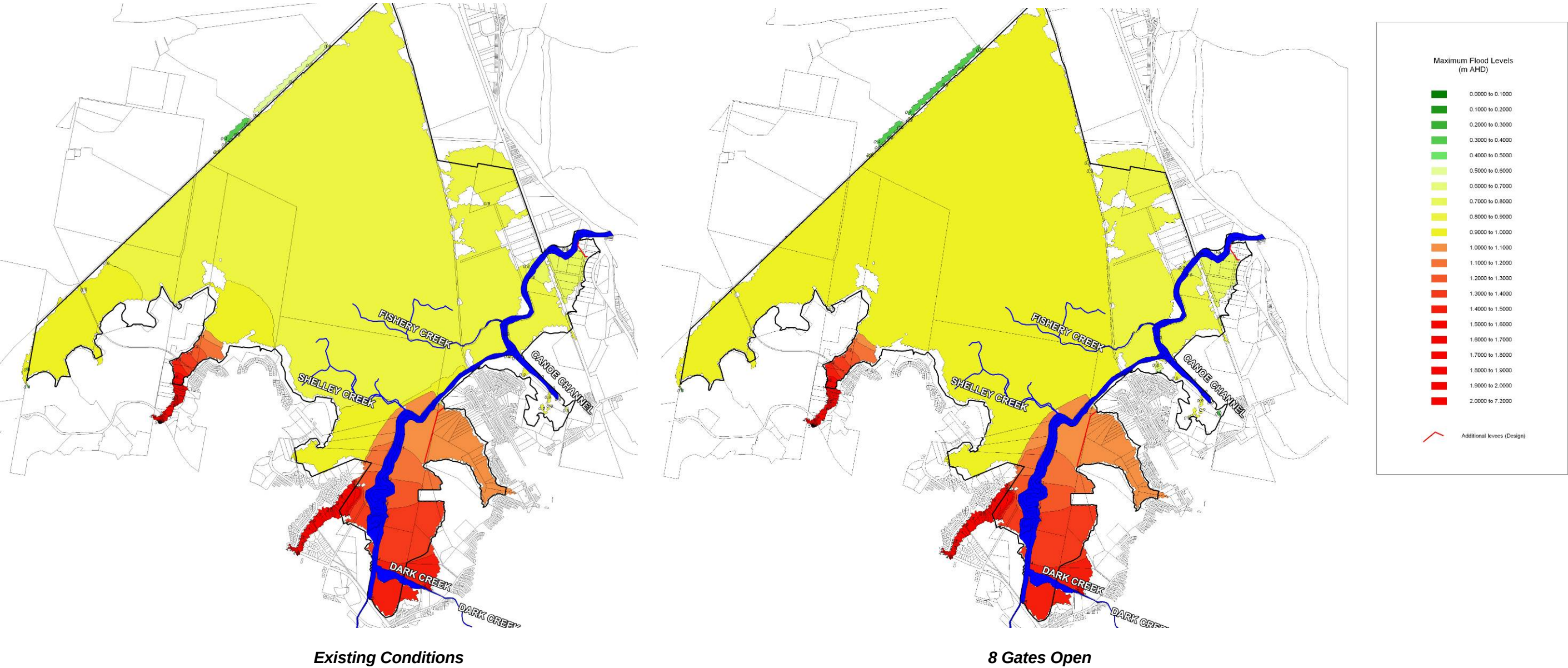


Figure 4.10 Predicted Inundation Extents for 1 in 20yr Local Flood Event

4.2.1 Increase of Tidal Exchange with the Hunter River

The primary benefit to water quality from the opening of the floodgates is that tidal exchange will allow increased flushing of the waters upstream of the floodgates. This will decrease overall residence time of the swamp and reduce the potential for pollutants to accumulate within the waters upstream of the floodgates. As the water quality of the Hunter River is generally better than that in Hexham Swamp and Ironbark Creek (refer Section 3.4), an increase in the exchange of waters between the Hunter River and Ironbark Creek has the potential to improve water quality in the creek (but subsequently locally reduce the water quality of the river, although this would be relatively minor and would occur over the short term only).

Increasing exchange of tidal waters will have several other impacts, the most direct of which will be the increase of salinity upstream of the floodgates. This has no direct implication for water quality in itself, but rather increased salinity can impact on other processes that could influence water quality, such as vegetation dieback and possible changes to sediment geochemistry. The Hunter River also has typically lower water clarity than the swamp or creek. The impacts of this are discussed separately.

Lawson and Treloar (1993) assessed impacts of alternative floodgate configurations on salinity concentrations with the swamp. The assessment used one and two-dimensional hydraulic models, which were calibrated for advection and dispersion against measured salinity data. As the area of spring tide inundation predicted by Lawson and Treloar was similar to that predicted by the more recent WBM modelling, it has been considered that salinity predictions made by Lawson and Treloar (1993) would still be relevant.

Based on the results of the Inundation Study, Lawson and Treloar (1993) predicted that salinity within Hexham Swamp would recover more rapidly following a freshwater flood event and would reach a higher concentration if the gates were opened, compared to the existing (closed) floodgates condition.

At present, saline waters only enter the swamp through the small gap under the gate that is raise two notches (approx. 300mm). With fully open floodgates, saline waters would be able to enter Ironbark Creek much more readily, particularly during post-flood periods when the difference in salinity between the Hunter River and the Swamp could be large.

During rainfall events, freshwater inflows will enter the creek and swamp system from the local catchment, which will slowly drain to the Hunter River (depending on the relative water levels in the river). As catchment runoff has been shown to be of moderate to poor quality (refer Section 3.4), the water quality of the creek and swamp may decrease following rainfall periods until the freshwater is drained and full tidal exchange is restored. Degradation of the water quality in the Swamp would not be any worse following catchment runoff events than under existing conditions.

It should also be noted that areas that will not be tidally inundated / flushed (or are irregularly inundated) will show little change in water quality following the modification of the floodgates. Therefore, large sections of the swamp, particularly areas remote from Ironbark Creek and the major tributaries, will remain freshwater-dominated (just as they were prior to installation of the floodgates), refer Section 4.4.2.

At present, Hexham Swamp is considered a 'large pollutant trap', capturing catchment runoff pollutants before they discharge into the Hunter River. Increasing flushing and decreasing pollutant accumulation in Hexham Swamp/Ironbark Creek (without any reductions in pollutant loadings) will result in an increase in the pollutant loading to the Hunter River. Due to the relative size of the Hexham Swamp catchment when compared with the whole Hunter River catchment, however, this increase in loading is considered to be minor. The introduction of catchment management measures in the catchment of Hexham Swamp will help minimise pollutant loading to the swamp and the Hunter River. The HCRCMA, Newcastle City Council and HWC are actively carrying out catchment management measures within the Ironbark Creek catchment to help address pollutant loadings to the estuarine receiving waters.

4.2.2 Acid Sulfate Soil Runoff

With regard to acidic runoff, saltwater ordinarily has a greater buffering capacity than freshwater. Therefore, increased saltwater could mitigate, to some degree, impacts of acid drainage from exposed acid sulfate soils. Acid produced by these soils is commonly neutralised by the bicarbonates and other buffering agents in seawater, thus attenuating low pH episodes. Whether any low pH episodes are likely following tidal inundation will depend on the amount of acidity produced by exposed acid sulfate soils, the degree of tidal flushing and the buffering capacity of the Hunter River water. Generally, the larger the area inundated by tidal water, the less the potential for oxidation.

In general, providing that no additional areas of acid sulfate soils will become exposed, it is likely that opening the floodgates will increase the potential buffering capacity of the Swamp against acid soil runoff. This would be particularly significant for the areas at the upstream limit of tidal tributaries (i.e. Fishery Creek and Shelley Creek), which presently experience episodic low pH events (refer Section 3.4.3.1).

While the tidal range is predicted to increase in Hexham Swamp as a result of opening the gates (refer Section 4.1.2.2), the half tide level will also increase, meaning that the low tide level after opening of the gates will be approximately the same as the current low tide level (i.e. -0.15 to -0.25m AHD). Therefore it is unlikely that additional areas of ASS will become exposed within Hexham Swamp.

Section 3.5.1.1 outlines the presence of acid sulfate soils within Hexham Swamp. Disturbance of soils within the swamp will provide an opportunity for potential acid soils to become oxidised, and hence release the acid potential. It will be important that any works associated with the Project do not disturb the soil profile of the swamp. This will mean that proposed bunding, as described in Section 2.5, will need to be constructed using imported fill rather than excavations of adjacent soils.

4.2.3 Increase in Turbidity from Hunter River Water Exchange

The water within the Hunter River can be higher in suspended solids than the water within Hexham Swamp and Ironbark Creek. Compared to existing conditions, the increased tidal exchange could reduce water clarity in tidally influenced areas of the swamp. There are too few available data to accurately predict the extent to which turbidity within the swamp may increase compared to existing conditions, however, it is likely to only be a significant issue following major and minor flood events in the river. This point is illustrated by the fact that turbidity in the Hunter River was generally lower than turbidity levels in Hexham Swamp for the period August 03 to June 04 (refer Section 3.4.2.1), due to a lack of catchment runoff and freshwater flow in the river.

One potential benefit of decreased water clarity cited in several references is that decreased water clarity may limit algal growth (due to light limitation). As the water depth in the swamp and Ironbark Creek is predominantly less than 3 metres, the increase in suspended solids would need to be substantial to limit the growth of algae in the water column. If low light conditions do limit algal productivity in the swamp, then higher levels of bio-available nutrients would be effluxed through to the river and possibly the ocean, before uptake by phytoplankton.

4.2.4 Potential Impacts from Interaction with Former Landfills

The Astra Street landfill is located near Hexham Swamp, immediately adjacent to the Canoe Channel. The landfill was decommissioned in 1995 after approximately 20 years of service. As discussed in Section 3.6.1, the site has recently been listed as a Site of Significant Risk of Harm under Section 60 of the Contaminated Land Management Act 1997, with elevated concentrations of heavy metals, PCBs and PAHs within leachate and surface waters, including the Canoe Channel and Ironbark Creek.

The finished surface level of the landfill site is well above the ground level of the swamp, with levels of up to about RL 20m AHD. Model predictions of inundation (refer Section 4.1.2) indicate that spring tides and king tides would inundate the land between Ironbark Creek and the Astra Street landfill, with tides reaching a maximum level of about 0.5m AHD. The crest level of the leachate pond bund, located on the northern boundary of the landfill, is approximately RL 1.6m AHD, and as such, tidal inundation would not impact directly on the leachate pond.

Newcastle City Council is planning to carry out a detailed investigation of the Astra Street landfill site, in response to the recent Section 60 listing (pers comm.. Paul McMurray, NCC, 2004). This investigation will include an assessment of the impacts of opening the floodgates on the landfill, including impacts on leachate collection and treatment, as well as impacts on groundwater gradients and hydrogeological contaminant pathways.

The impact of increased tidal inundation on groundwater within the landfill is discussed further in Section 4.3.2.

As discussed in Section 3.6.2, the former Lorna Street landfill is located relatively high in the catchment, and would be well above the inundation extents. Therefore, there would be no impacts of this Project on the former Lorna Street landfill site.

4.2.5 Freshwater Vegetation Die-off

Increasing saline water exchange within Hexham Swamp may result in the die-off of non-halophytic (salt sensitive) vegetation (refer Section 4.4). As the non-halophytic vegetation matter decomposes, oxygen may be consumed from the water column and nutrients bound in the plant tissue will be re-released to the water. The oxygen demand from decaying material could lower dissolved oxygen concentrations to levels lower than that required for aquatic fauna to survive (i.e. causing fish kills). This circumstance occurred in 1997 (refer DLWC, 1997) when the floodgates were artificially opened (due to vandalism), resulting in extensive saltwater inundation of freshwater vegetation. The floodgates were re-closed shortly after the event, which prevented the swamp from being flushed. Consequently, the detrital organic matter exerted a large BOD load on the small resident volume of the Hexham Swamp waters, lowering DO levels and causing fish mortality.

Increased nutrient levels in the water column (from decaying vegetation) can also stimulate algal growth, which can be problematic if permitted to get to bloom proportions. Algal respiration can also cause oxygen depletion, particularly during night times.

Increased tidal flushing will lessen any impact to water quality from the decaying vegetation, as released nutrients and low oxygen waters will be flushed out of the swamp under tidal action. Additionally, most water quality data indicates that tidal waters will be higher in dissolved oxygen, thus bringing oxygen rich waters to the swamp and helping to meet the oxygen demand from decaying vegetation.

Water quality impacts resulting from the death of non-halophytic vegetation may be relatively minor when the gates are opened in a stage manner, as the die-off process for *Phragmites* may take a long time to complete (pers comm.. M Greenwood, PhD candidate, Newcastle University, 2004). In the longer term, non-halophytic vegetation will be replaced by estuarine wetland vegetation, but only when salinity levels are sufficiently high to allow out-competition of the existing *Phragmites* by more salt-tolerant species.

The die-off of freshwater vegetation will increase the organic load on the sediments of the swamp, particularly within the channels. Depending on the degree of organic loading, decomposition of the organics may result in localised oxygen depletion at the bed surface. If this happens, then anaerobic bacteria may dominate within the sediments, and potentially modify the existing geochemical processes of the swamp sediments. Under anaerobic conditions, denitrification efficiency can be reduced, meaning that more of the nitrogen recycled from the organic matter would be directed back into the water column in bio-available forms. Anaerobic conditions may also result in higher sediment flux rates for phosphorus and carbon (the other base plant nutrients).

If the die-off of vegetation is gradual, as expected based on current research by Greenwood (unpublished), and supplemented by tidal flushing of the swamp, then the organic loading to the bed may be accommodated by oxygen levels within the water column (particularly with inflowing oxygenated water from the Hunter River during each tide), and nutrient releases from the sediments would be minimal.

Decomposition of organic material will release nutrients into the water column. However, given the increased exchange in waters between the swamp and the river, the elevated nutrients would be advected out of the swamp within relatively short timeframes.

4.2.6 Increase in Turbidity from Vegetation Die-off

Increases in turbidity may result from vegetation dieback. As non-halophytic vegetation dies as a consequence of increased salinities, some creek banks may temporarily be unvegetated and therefore prone to erosion. However, many of the banks along Ironbark Creek are stabilised by mangrove pneumatophores, which substantially reduces the potential erosion risk. In areas without mangrove pneumatophores, there may be a greater potential for increased turbidity associated with tidal flows and flood runoff from the swamp, particularly in defined drainage channels.

Overall, it is predicted that there may be some erosion in isolated sections of Ironbark Creek and its tributaries resulting in localised increases in water turbidity in the short-term (measured in months to years). Large scale erosion and turbidity increases are unlikely to occur. In the long-term (measured

in years), estuarine vegetation will re-establish throughout the swamp, thus minimising the risk of erosion in the future.

4.2.7 Summary of Water Quality Impacts

Effects of the proposed gates opening with respect to surface water quality will manifest primarily as a result of:

- Increased tidal exchange between waters in the swamp and the Hunter River; and
- Decomposition of non-halophytic vegetation.

The temporary opening of the floodgates in the past (due to vandalism), resulted in significant short-term effects on water quality, which lead to a fish kill in the swamp. One of the main reasons that water quality degraded in this case was the fact that the gates were re-closed shortly after the event, thereby preventing any effective tidal exchange. As a result, the decomposition of the non-halophytic plants affected by the saltwater inundation was borne by the resident swamp waters only, which were quickly deprived of oxygen. Also, the gates would have prevented escape from the anoxic conditions by fish and other mobile aquatic fauna.

It is considered that the events surrounding the reported poor water quality and fish kill following the last major opening of the gates would not reoccur, given the proposed staging of the works and the fact that the gates will remain open following the initial saltwater ingress, thus allowing tidal flushing and evacuation of the oxygen demand from the swamp.

Overall, in the short-term (i.e. less than about 3 – 5 years), the water quality of the swamp following opening of the gates may be better or worse than under the existing conditions. In the long term, however, once estuarine vegetation has established within the swamp, the water quality would be better than under the existing condition, due to the increased tidal exchange.

In the Hunter River, there may be short-term reductions in water quality, while the swamp is flushed and vegetation changes. Given the large tidal prism and volume of the Hunter River estuary, it is considered that any deterioration in water quality as a result of the opening of Ironbark Creek floodgates would be localised to the area in the immediate vicinity of Ironbark Creek. In the long-term, water quality in the Hunter River would be unaffected by the opening of the floodgates, even at localised scales.

The proposed staging of the floodgate openings will help mitigate any detrimental impacts on water quality. In this regard, only a limited extent of non-halophytic vegetation would be exposed to saltwater inundation at each stage. This would limit any immediate die-off of vegetation, and thus better enable the swamp (through tidal flushing) to meet the demands on dissolved oxygen within the water column.

Also, the proposed timing of the openings has been established giving consideration to minimising impacts on water quality. Apart from the first floodgate, opening of the floodgates resulting in sudden inundation of vegetated areas will occur during winter, when the reed density and hence organic load in Hexham Swamp is relatively low.

4.3 Soils and Groundwater

The impacts of the proposed works on soils and groundwater are summarised in Table 4.4 and discussed in the following sections.

Table 4.4 Impacts on Soils, Groundwater, Erosion and Sedimentation

Impact on	Existing Condition	8 Gates Open
Acid Sulfate Soil	Relative high risk of acid runoff	Generally lower risk of acid runoff, provided that soil is not disturbed during ancillary works
Groundwater	Largest potential for soil oxidation due to low groundwater table	Reduced potential for soil oxidation Recharge of saline aquifer Reduction of hydraulic gradient near Astra Street dump
Erosion	Localised channel bank erosion continuing	Enhanced channel bank erosion due to higher tidal currents
Sedimentation	Continued siltation of lower catchment channels	Enhanced flushing of suspended sediments from the swamp, and possible remobilisation of previously accumulated fines within tidal channels

4.3.1 Acid Sulfate Soils

RCA (1998) indicates that tidal inundation will reduce the potential for acid sulfate soils to generate acid by raising the groundwater table and providing a more static groundwater level. This will limit the depth of potential pyrite oxidation and restrict fluctuations in groundwater levels associated with climate. The other beneficial effect of tidal inundation is the buffering component of saline soils associated with carbon dioxide and bicarbonate ions which tends to maintain a pH within the slightly alkaline range (7.5 – 8.5). The re-introduction of a tidal regime will help to stabilise the current oscillating pH and salinity levels that occur in Hexham Swamp.

The risk of an initial acid discharge into the Hunter River following the onset of tidal flushing is considered to be low. Some minor localised acid discharge may occur associated with spatial variation in acid generating potential and buffering capacity of the surface soils, however, this would be buffered by the saline waters and diluted by non-acidic discharge.

The ‘do nothing’ scenario carries a greater risk associated with potential discharge of acid water into Ironbark Creek due to the continued depression of the groundwater table. Areas proposed to be inundated when the gates are opened are to the north-west of Ironbark, Fishery and Shelley Creeks where acid sulfate soils do not appear to be present.

Acid sulfate soils with high sulfur levels have been identified at Shortland behind the proposed Marsden Street bund. Construction of the bund will prevent inundation of this area with saline waters, and will mostly maintain the existing drained nature of the low lying land. Benefits associated with reducing acid sulfate runoff potential at other locations in the swamp will be reduced in the area behind the bund due to the lack of future tidal inundation. However, groundwater levels behind the bund are still expected to rise, which would still reduce the potential for oxidation of soils.

4.3.2 Groundwater

RCA (1998) indicates that tidal inundation will result in gradual infiltration of saline water into the sandy aquifer that underlies large areas of the site. As the aquifer exhibits saline properties, the opening of the floodgates is not likely to have any major impact on the groundwater apart from raising and maintaining a more static groundwater level.

The rise in groundwater level will have a beneficial effect in reducing the depth of soil subject to oxidising conditions and hence limiting the potential of acid sulfate soils to generate acid (refer Section 4.3.1). The rise in groundwater level may, however, have a detrimental effect on existing infrastructure within the Swamp (such as access tracks, easements, and the Wallsend airstrip) as soil strength will tend to decrease with saturation resulting in deterioration of subgrade conditions. Further discussion of these potential impacts is discussed in Sections 4.3.2.1 to 4.3.2.4.

Another beneficial effect of the elevated groundwater level will be to reduce the hydraulic gradient for any leachate contained within the Astra Street land fill at Shortland. Landfills typically have a “mound” of poor quality groundwater within them, due to seepage of rainfall and contamination from leachate within the landfill. Should any leachate be dissipating into the environment, a reduction of the hydraulic gradient between the landfill and the swamp will reduce flow rates from the landfill.

4.3.2.1 Access Tracks

The main access tracks through Hexham Swamp are associated with the Transgrid power lines and the Hunter Water pipeline. The Transgrid access track is elevated compared to adjacent swamp ground levels, and effectively forms a levee during flooding in Ironbark Creek.

The Hunter Water pipeline access track is also elevated in most sections, however, there are some parts of the track that are low, and susceptible to flooding. There are also some sections of access track that are relatively low within The Wetland Centre, and along the main northern railway, on the Newcastle side of Ironbark Creek bridge.

Increasing groundwater levels in the swamp, although likely to take many years (or even decades) to reach new groundwater levels, have the potential to reduce the structural integrity of the access tracks within Hexham Swamp.

It is likely that some low areas of access track will require maintenance from time to time. Mitigation measures to address potential weaknesses in the access tracks are discussed further in Section 6.8, while the actual track maintenance works are described fully in Sections 2.5.5, 2.5.6 and 2.5.7.

4.3.2.2 Radio Towers

An assessment of groundwater conditions at the Broadcast Australia Limited radio towers, Sandgate, was carried out by Robert Carr and Associates (2002). The existing level of the land around the towers is approximately RL 0.6m AHD. A bore installed by RCA approximately 4 metres from the edge of the creek indicated that the groundwater table was located approximately 0.57m below the surface, at a level of between RL 0.02 and 0.05m AHD.

Water quality analysis of the water in the groundwater bore and the creek showed that there is currently little influence of the creek on groundwater conditions. Groundwater levels at the site appear to be largely controlled by both rainfall and the hydraulic gradient created by groundwater flowing from the hill immediately behind the site. This conclusion was also supported by the low permeability of the aquifer in the location of the bore, which would act to prevent rapid ingress of the tidal water through the groundwater.

Following opening of the floodgates, it is expected that the mean tidal level in Ironbark Creek would increase by about 0.3 metres (refer Section 3.3.3.3). RCA (2002) state that groundwater levels within the aquifer will eventually rise to at least the new mean tide level in the creek. Recharge of the groundwater will result in a complex interaction between competing recharge sources, these being the creek, rainfall and groundwater flow from the hills behind. Given the low permeability of the soils, however, recharge to the new groundwater level (of approximately RL 0.1m AHD or slightly higher) across the whole site would take a considerable length of time (in the order of 40 – 50 years).

4.3.2.3 Wallsend Airstrip

The surface level of the Wallsend Airstrip is currently between about 0.8 and 1.5m AHD, while adjacent swamp levels are as low as 0.5m AHD. As presented in Section 3.3.3.3, the mean tide level in Ironbark Creek is likely to increase by about 0.3m. Therefore, groundwater levels would increase by approximately an equal amount, although the timescale in which this happens may be many years or even decades (RCA 1998, 2002).

An elevated groundwater level below the Wallsend Airstrip may compromise the structural integrity of the runway, resulting in local subsidence and potholes. As outlined in Section 2.5.4, the runway will be elevated by approximately 0.2 – 0.3 metres using coarse gravel fill (i.e. chitter). The elevation and resurfacing of the runway will be sufficient to mitigate any detrimental effects of increasing groundwater levels in the swamp.

4.3.2.4 Private Bores

There are a number of privately owned bores around Hexham Swamp, which draw freshwater from subterranean aquifers for stock watering and irrigation. RCA Australia (2004) carried out an investigation of one such bore, which is located only 10 metres from Ironbark Creek, at the end of Marsden Street, Shortland. A comparison of water quality (using cations and anions) between the groundwater bore and Ironbark Creek carried out by RCA showed that there is presently little hydraulic connectivity between the two waterbodies. From the available information, RCA stated that the bedrock aquifer would be recharged by a combination of surface water and rainfall / groundwater flow from the area of the bedrock outcrop.

Based on the results of the RCA Australia (2004) study, changes to the salinity of Ironbark Creek, associated with opening of the floodgates, are unlikely to affect the conductivity of the underlying bedrock aquifer. Therefore, the Project would not affect the current irrigation or stock watering uses of the private bores around the swamp that are connected to the underlying bedrock aquifer.

4.3.3 Creek Bank Erosion

The banks along Ironbark Creek, and to a lesser extent Fishery and Shelley Creeks, are currently undergoing localised erosion. Opening the floodgates will result in increased tidal velocities along the main channel reaches as a function of the increased tidal prism. In the short term this may result in an increase in the rate of bank erosion due to:

- Increased groundwater seepage from creek banks associated with an increase in groundwater levels;
- Greater wetting and drying of creek banks due to the increased tidal range (i.e. greater localised saturation and drawdown at the banks);
- Minor scour effects associated with tidal flows;
- Concentration of tidal over-bank flows at low points along the creeks;
- Gradual die-off of salt intolerant vegetation such as grasses, and associated exposure of underlying soils before estuarine vegetation can become established.

In the long term the re-establishment of native vegetation such as mangroves will have a beneficial effect on creek bank stability. Once established, the rate of erosion is likely to be less than that presently occurring. In terms of creek rehabilitation, re-vegetation with estuarine species should be undertaken where necessary along the creek banks to improve bank stability (refer Section 6.3.2).

4.3.4 General Sedimentation

ICTCMC (1996) noted that the swamp acts as an efficient sediment trap with the annual volume of sediment input greatly exceeds the output to the Hunter River. Gradual sedimentation of the drainage paths and creeks is currently being promoted by the sediment surplus and the ponded conditions induced by existing flood-gate operation.

Opening of the floodgates will promote tidal flushing of suspended sediments and reduce the risk of further sedimentation along the waterways. In terms of the total sediment input into Hexham Swamp, however, tidal inundation is unlikely to significantly reduce the amount of sediment that accumulates within the swamp (given the rate of sediment washoff from the surrounding developed and developing catchment).

Dredging of the creeks and drainage channels to enhance tidal flushing has not been included in the scope of this Rehabilitation Project, including dredging within Muckeye Creek. Site inspections have shown that sedimentation of the swamp has been gradual, and has essentially progressed from upstream to downstream reaches. Therefore, dredging of creeks and channels would not significantly increase the tidal prism of the swamp or the extents of saline inundation. Dredging of small sections of the swamp would necessitate the pragmatic consideration and assessment of environmental impacts, as well as substantial financial investment, for limited environmental returns.

It is considered that, in time, some of the sediment that has accumulated within the creeks and channels would be remobilised by the increased tidal flows, and would be transported out of the swamp environment. This process would slowly migrate from the downstream to the upstream reaches, and would be facilitated by the gradual die-off of aquatic vegetation (eg *Phragmites* and *Typha*) within the channels.

In some sections of the swamp, which have experienced significant sedimentation (eg Muckeye Creek), it may be possible that increased tidal flows will promote mangrove colonisation of the creek beds before the sediment can be scoured out. In these circumstances, it is unlikely that the conditions prior to installation of the floodgates can be restored by this Project.

4.3.5 Bund Wall Construction

A number of low level bunds are proposed around Hexham Swamp to limit the extent of saltwater inundation on privately owned properties. The subsurface profile of Hexham Swamp mostly comprises soft to firm estuarine clays to depths in excess of 1.6m with shallow groundwater levels and acid sulfate soil conditions. These characteristics constrain bund construction as follows:

- Excavation of site soils for use in bund construction would result in oxidation of potential acid sulfate soils. Significant remediation of the excavated and in-situ material would be required, which is considered impractical for this Project;
- Bunds will undergo settlement in the future due to consolidation of the underlying soft to firm clays with the rate and amount of settlement dependant on the height of the wall, as well as the depth and geotechnical properties of the underlying clays;
- Poor access and ground conditions for construction plant.

Given the above limitations, it is considered that construction of the bunds would require importation of clean fill, and would need to be overfilled to allow for settlement and consolidation of underlying soil profile in the future. The bunds would also require periodic crest elevation survey to monitor settlement and ensure that design crest levels are maintained to prevent overtopping and saline intrusion of protected lands behind.

4.4 Vegetation

4.4.1 'Do Nothing' Option

It is anticipated that if current management conditions persist, the expansion of Common Reed would continue at the expense of the remaining 'freshwater swamp' and 'pasture' areas as mapped by Morrison (2000).

In addition, as sedimentation continues due to deposition of silt from the catchment and insufficient flushing of the wetland, deeper pools and scour holes will continue to be filled in. Common Reed would continue to spread into these areas. As a consequence, shallow, open areas of water, together with the deeper pools may progressively disappear from the wetland as Common Reed communities continue to spread into shallow, less frequently inundated areas.

A successional shift in vegetation composition and community structure is expected to occur as the wetland dries out due to sedimentation, reducing groundwater levels and as a result of the reduction

in soil salinity due to the lack of tidal flushing. These successional processes are currently evident, as Swamp She-oak has been observed within parts of the Common Reed communities. The occurrence of juvenile Swamp She-oaks in many parts of the common reed pastures suggests that these areas may be experiencing not only a reduction in soil salinity as a result of freshwater flushing of the wetlands and minimal tidal influence, but that the water levels (both surface pools and water table) may be decreasing, allowing colonisation of Swamp She-oak.

Swamp she-oak tends to grow in brackish situations along streams and is often found fringing mangrove communities. It generally occurs on flat, swampy sites and on river banks and streams affected by tidal influence. The soils are usually acidic, but saline and the watertable is usually within 1m of the surface. While it usually grows on drier ground fringing mangrove and *Melaleuca* swamps, it may be found growing intermixed with *Melaleuca* species.

In the absence of grazing and tidal flushing, Swamp She-oak is likely to further colonise substantial parts of the degraded salt marsh community. Aerial photography indicates that the large stand of Swamp She-oak adjacent to the main northern railway, on the southern bank of Ironbark Creek consisted of an open woodland (<10% FPC) of approximately 4 ha in 1954. Currently, this stand consists of open forest to closed forest (30-100% FPC), and extends over an area of approximately 16ha. It is possible that further reduction in soil salinity due to continued freshwater flushing could see large areas of current Swamp She-oak communities succeeded by *Melaleuca* communities, particularly in the upper reaches.

Consequent to the relatively recent removal of cattle from much of Hexham Swamp, the rate of expansion of Common Reed has accelerated and there has also been an increase in the establishment of Swamp She-oak saplings (pers. obs. G. Winning, HWR Ecological, 2004).

4.4.2 Managed Opening of Floodgates

Opening eight gates would result in a tidally inundated vegetated area of approximately 758ha at king tide level (refer Table 4.5). All of the mapped vegetation community types would be affected. Apart from the obvious inundation of relic areas or previously tidal mangroves and saltmarsh, the greatest impacts will be on Common Reed and Swamp She-oak communities, the two community types that have been the most invasive since the construction of the floodgates.

Comparison of the modelled inundation with the pre-floodgate condition, as interpreted from 1966 aerial photography, shows that the modelled 758ha is approximately 80% of the 933ha area inferred to have been subject to tidal inundation from the 1966 aerial photography (refer Table 4.6).

This difference is most likely, at least in part, due to the unavoidable inherent imprecision in the predictive inundation model. It seems counter-intuitive to accept that the resumed area of inundation would be less than the pre-floodgate condition. There is even evidence that the area of inundation is likely to be greater than the pre-floodgate condition. Dredging of Newcastle Harbour and associated filling of tidal channels and wetlands on Kooragang Island is assumed to have contributed to a measured maximum increase of approximately 20 centimetres in the spring tide range at approximately 28 kilometres upstream from the river mouth between 1955 and 2000 (Manly Hydraulics Laboratory, 2004). This increase in tidal range, although only partially attributable to harbour dredging, would have been expected to result in an increased area of inundation in Hexham Swamp if the floodgates had not been constructed. Inferentially, complete opening of the floodgates

would result in a greater area of inundation than the inundation experienced prior to their construction in the early 1970s.

Table 4.5 Modelled Impacts on Vegetation

Cover	Existing Area* (ha)	Area to be Inundated by King Tide (ha)	KT inund'n as % of Existing Area (ha)	Area to be Inundated by Spring Tide (ha)	ST inund'n as % of Existing Area (ha)
Mangrove	22	12.3	56%	5.9	27%
Saltmarsh	6	5.0	85%	1.2	20%
Freshwater swamp	575	102.2	18%	26.1	5%
Common Reed	918	526.0	57%	227.9	25%
Broad-leaved Cumbungi	110	0.4	0%	0.0	0%
Swamp She-oak	47	26.8	57%	16.0	34%
Paperbark	31	2.0	6%	0.0	0%
Pasture/grassland	369	80.1	22%	57.5	16%
other ('urban/industrial')	339	2.7	1%	1.8	1%
Total	2417	758		336	

* Source: Morrison (2000)

Table 4.6 Comparison of Pre-floodgate with Modelled Inundation (Areas Inundated at King Tide)

Cover	1966 Area* (ha)	Modelled Area** (ha)
Mangrove	173	-
Saltmarsh	761	-
Total	933	758

* Source: Morrison (2000)

** The model lacks sufficient precision to predict the extent of different communities

Note, open water extents have been excluded from this comparison

Due largely to a lack of micro-topographical data within Hexham Swamp, the model is unable to accurately predict the extents of various states of the tide, such as mean sea level and mean high tide, which would assist in predicting the extent of various intertidal communities. While it is tempting to assume that the resumed inundation would result in a similar distribution of intertidal communities to the pre-floodgate distribution, there is evidence that this would not be the case. Over the last 40 years, mangroves have expanded considerably within the Hunter River estuary (excluding Hexham Swamp)

at the expense of saltmarsh (Williams *et al.*, 1998), a trend that has also been observed along the south east coast of Australia (Saintilan and Williams, 1999). Assuming that this trend may also apply to Hexham Swamp once tidal influence is restored, it can be expected that the area of mangrove communities within the Swamp may be larger than that in 1966, while the area of saltmarsh may be less.

Because of the variables that cannot be precisely addressed by the predictive model, the proposal provides for a managed approach to opening of the floodgates, to provide data that can be used to help optimise the ultimate floodgate opening regime. The preferred condition is to maximize the distribution of saltmarsh and to minimise the distribution of mangroves beyond their 1966 extents.

Saline inundation of *Phragmites* stands is unlikely to result in sudden die-off of this species. Laboratory research being undertaken by Mary Greenwood at the University of Newcastle suggests that *Phragmites* will tolerate saline conditions and resist succession to more salt-tolerant while ever salinity is less than about 20 ppt and there is occasional inflows of freshwater (e.g. from catchment runoff flood events). Greenwood (unpublished data) indicates that *Phragmites* will continue to dominate vegetation assemblages in Hexham Swamp even in areas that experience low or periodic salt intrusion (albeit at lowered vigor). With higher salinity, the biomass / density of *Phragmites* stands is likely to decrease to a level where other halophytic species (such as *Juncus* and other saltmarshes) are able to compete. These results are supported by informal field trials carried out by Geoff Winning (pers comm.. G. Winning, HWR, 2004).

The impact of the proposal on *Zannichellia palustris* is described in the Eight Part Test, provided in **Appendix H: Volume 2**. Measures to minimise the impact of an eight gate opening (including a research program into the habitat requirements of *Zannichellia palustris*) are described in Section 6.5.2.

4.5 Significant Ecological Communities

4.5.1 Coastal Saltmarsh

Fragmented and highly degraded examples of the Endangered Ecological Community (EEC) exist within Hexham Swamp. Compared to pre-floodgate conditions, some 99% of coastal saltmarsh has been lost from Hexham Swamp. The primary reason for this decline is the dramatic reduction in tidal inundation of the swamp following construction of the floodgates at the mouth of Ironbark Creek.

Table 4.5 shows that over 750ha of Hexham Swamp will be inundated by the king tide once all eight floodgates are opened. Whilst it cannot be determined precisely how much of this land will return to saltmarsh habitat, it can be expected that there will be significant increases in the extent of the EEC within the swamp. If the full extent of predicted tidal inundation is restored to saltmarsh, then the coverage of saltmarsh within the lower Hunter estuary would be increased by almost 100%.

4.5.2 Swamp Oak Floodplain Forest

Opening the Ironbark Creek floodgates and re-introducing tidal waters to Hexham Swamp is likely to affect existing areas of Swamp Oak Floodplain Forest EEC. Table 4.5 shows that some 27ha of the currently mapped 47ha of swamp she-oak in Hexham Swamp may be inundated by king tides once

all eight floodgates are opened. Hydraulic modelling predictions indicate that of this 27ha, 16ha is likely to be inundated by typical spring tides.

The proposed opening of Ironbark Creek floodgates and associated re-inundation of Hexham Swamp with saline tidal waters is an integral component of the Ironbark Creek Total Catchment Management Strategy (ICTCMC, 1996), aimed at increasing saltmarsh and mangrove coverage within the Lower Hunter estuary. At present, the area of coastal saltmarsh in the Lower Hunter estuary totals 820ha (1994: see Table 3.22). Restoration of estuarine vegetation, and saltmarsh in particular, is considered to be critical to the long-term viability of international status of the Lower Hunter estuary wetlands. MHL (2003) reports that the Lower Hunter estuary has lost some 84% of coastal saltmarsh communities since European settlement. This trend is common throughout NSW, and is the reason for the community being listed as an Endangered Ecological Community (EEC).

Clause 15 of the determination recognises that there will be variations to the extents of EECs due to future management of hydrological regimes. In this regard, when managing ecological systems as a whole, there may be justifiable occasions when one endangered ecological community could be benefited by specific actions at the expense of another endangered community.

Within Hexham Swamp, the expected reduction in extent of the Swamp Oak Floodplain Forest EEC will be offset by a commensurate increase in the extent of the Coastal Saltmarsh EEC. Given the dramatic reduction in saltmarsh experienced in the Lower Hunter estuary over the past 200 years, and given the large potential for increasing the extent of saltmarsh by opening the floodgates (i.e. the extent of saltmarsh in the Lower Hunter estuary could be almost doubled), it is considered that the priority for restoration of coastal saltmarsh is more important from a whole-of-catchment, and indeed regional (and national), perspective than the priority for preservation of existing swamp-oak communities within Hexham Swamp.

4.5.3 Coastal Floodplain Wetlands

Coastal floodplain wetlands communities include those freshwater wetlands that are dominated by the common reed, *Phragmites australis*.

The extent of *Phragmites* in Hexham Swamp has expanded significantly since the construction of the floodgates in the early 1970s, increasing from just 24ha in 1966 to 918ha in 2000 (refer Table 3.20). From Table 4.5 it can be seen that approximately 526ha of *Phragmites* reedland within Hexham Swamp will potentially be affected by saltwater intrusion following opening of the Ironbark Creek floodgates. This means that at least 392ha of *Phragmites* would be preserved in Hexham Swamp following implementation of the project (which is still substantially more than that prior to the construction of the floodgates).

As described in the assessment for the Swamp Oak Floodplain Forest EEC (refer Section 4.5.2), coastal saltmarshes in the Lower Hunter estuary have declined dramatically over the past 200 years, and the Hexham Swamp Rehabilitation Project offers an opportunity for major rehabilitation of this lost community type. Rehabilitation of saltmarsh communities within Hexham Swamp will come at the expense of the extent of the *Phragmites* endangered community. However, given the importance of the saltmarsh restoration at regional level, and given that a significant area of *Phragmites* will be retained following the project, it is considered that the priority for saltmarsh restoration is higher than the priority for preservation of the full extent of the *Phragmites* community.

4.6 Fauna

The impacts to fauna associated with the proposed opening of the Ironbark Creek floodgates are summarised in Table 4.7. These impacts are also discussed further below.

4.6.1 Fish and Macroinvertebrates

4.6.1.1 Impacts Associated With Changes In Nutrient And Dissolved Oxygen Concentrations

Do Nothing Option

Under the present conditions, the floodgates limit tidal exchange and flushing of Ironbark Creek. Consequently, water quality is generally poor, with frequently high nutrient concentrations and algal blooms (Shepherd 1994). These impacts on aquatic communities, with Shepherd (1994) reporting an almost complete loss of fish and macro-invertebrate species in sections of Ironbark Creek following algal blooms and declines in dissolved oxygen concentrations.

Under the do nothing option, water quality degradation would continue, and could worsen over time. This would result in the further decline of ecosystem health.

Table 4.7 Impacts on Fauna

Impact on	Do nothing	Opening of all eight floodgates
Estuarine fauna	Possible decline in diversity & abundance due to decline in water quality and on-going habitat degradation. Continuing loss of potential fisheries habitat.	• Long-term improvement in diversity and potential abundance in flushed areas. • Habitat diversity moderately increased. • Area of reinstated estuarine waters increased compared to present. • Moderate potential for increase in long-term fisheries yields. • Short-term impacts due to vegetation die-back and associated water quality degradation.
Freshwater fauna	Gradual decline in diversity & abundance due to decline in water quality and on-going habitat degradation.	• Community structure, diversity & abundance reduced. • Habitat diversity/area reduced. • Change in composition in some areas to more salt tolerant species. • Minor short-term impacts due to vegetation die-back and associated water quality degradation.

Impact on	Do nothing	Opening of all eight floodgates
Avifauna	Potential for further decline in diversity & abundance of waders due to the on-going conversion of formerly estuarine to freshwater habitats Maintenance of relatively depauperate wader habitat and riparian community for a range of common and threatened species.	• Long term benefit to wader diversity & abundance resulting from rejuvenation of extensive areas of currently degraded salt marsh • Long term improvement in quality and extent of habitat for a range of common and threatened species including black bittern, painted snipe and black-necked stork. • Minor decrease in potential habitat diversity (no ponding at upper tidal limit)
Herpetofauna	Possible improvement to abundance due to on-going conservation of formerly estuarine to freshwater habitats.	• Likely significant change to diversity and abundance of common frog fauna in tidally influenced areas. • Reduction in abundance in frog fauna may affect two species of snake. General reduction in abundance of common reptiles. • Whilst areas suitable for breeding / foraging for Green and Golden Bell Frog would be diminished, the long-term impact on viability of the population within Hexham swamp is uncertain.
Mammals	Possible improvement to abundance due to on-going conversion of formerly estuarine to freshwater habitats.	• No adverse affects on the foraging, roosting or breeding habitats of common or threatened microbat species. • Likely improvements in quality of prey and habitat for water rat. • Potential for moderate reduction of potential swamp rat habitat.

Opening of the floodgates

The opening of floodgates will increase tidal exchange and flushing throughout most of the Ironbark Creek channel and parts of the surrounding wetland. This will improve the long-term water quality of the creek (Section 4.2.7), which will have beneficial effects to aquatic communities. In the long-term, the scale and frequency of algal blooms and associated dissolved oxygen reductions will be reduced compared with those that presently exist, thereby providing:

- improved water quality conditions;
- improved ecosystem health; and
- improvements in fisheries resources (habitats and potential future yields).

As discussed in Section 4.2.1, it is likely that there will be short-term impacts to water quality under this option. Also, some freshwater wetland areas will be inundated by saline waters, resulting in the eventual death of most of this vegetation. The decaying vegetation will cause short-term reductions in dissolved oxygen and the release of nutrients to the water column and the substrate. It is anticipated

that short-term water quality degradation will result in impacts to aquatic fauna communities within the creek and surrounding wetland.

Water quality impacts would be most evident in irregularly flushed areas (eg. small drainage channels and some wetland areas), but less so in the well flushed Ironbark Creek channel. In the poorly flushed areas, sensitive fish and aquatic invertebrate species may be asphyxiated if dissolved oxygen concentrations fall below critical (species-dependent) thresholds. The breakdown of vegetation would also result in the mobilisation of ammonia and nitrite, which at high concentrations may have toxic effects to aquatic fauna. These aquatic fauna communities are in a degraded state due to existing water quality degradation (see Section 3.7), and are unlikely to contain large numbers of pollutant sensitive taxa.

Given appropriate environmental safe-guards, such as a staged opening of floodgates over a number of years, impacts to aquatic faunal communities associated with poor water quality could be considerably reduced.

4.6.1.2 Impacts Associated With Changes In Hydrological And Salinity Regimes

Do nothing option

Under the do nothing option, there is currently no tidal inundation of land areas outside the main channels. Hydrological and salinity regimes will not alter from present conditions, but would be substantially different from those present prior to the installation of floodgates.

Opening of floodgates

The estimated land area inundated by tidal waters (at king tide level) is approximately 750 ha (see Table 4.5), while the estimated inundation area for the mean spring tide is approximately 330 ha. This is predicted to result in the re-establishment of significant intertidal wetlands across the 330 ha of land likely to be directly inundated by the mean spring tide.

The full opening of the Ironbark Creek floodgates will result in an immediate change in the salinity and hydrological regimes of the Ironbark Creek system, causing both positive and negative impacts to its flora and fauna communities. With the opening of the gates, there will be an increase in tidal flushing and the area of tidally inundated lands during certain tides when compared to the do nothing option. In the long term, this would result in:

- the reinstatement of large shallow estuarine areas that are important nursery habitats for a range of commercial prawns and fish. To a large degree, the value of these areas to estuarine fauna will depend on the frequency and time that they are tidally inundated. In general, areas that are only rarely tidally inundated (eg. 2-4 times a month during spring high tides) would be used far less regularly than areas that are frequently inundated (ie during every tide);
- some remobilisation of recently accumulated sediment, although this would be limited, as the sediment may form suitable habitat for colonisation of mangrove propagules (eg Muck Eye Creek);

- an increase in the area of saltmarsh and mangrove habitats (see Section 4.4), providing a wider diversity and quantity of habitats and food resources to fish and crustaceans;
- a reduction in the area covered by the Common Reed (*Phragmites australis*) and related potential increase in open-water bodies; and
- as a result of above processes and products, a greater diversity of estuarine habitats within Hexham Swamp than presently exists, and a potentially greater fisheries yield.

There may be some negative impacts to freshwater communities, which to a large extent will be dependent on the tolerances of individual species. The freshwater macroinvertebrates and fish that presently inhabit the channel areas of Ironbark Creek are presently subjected to fluctuations in water salinity concentrations, depending on the amount of rainfall, tidal phase and other catchment influences. All 'freshwater' fish species recorded in Ironbark Creek are known to inhabit brackish estuarine waters (i.e. are diadromous), and have some salinity tolerance (Hart *et al.* 1991).

The ubiquitous distribution of 'freshwater' macroinvertebrate taxa throughout Ironbark Creek also indicates that many of the species are tolerant of brackish salinities. Almost all freshwater macroinvertebrate taxa previously recorded in Ironbark Creek have been recorded adjacent to, or within 1 km of, the floodgates. Salinities in this area typically vary from 0‰ to 25‰ (McGregor 1979) indicating a relatively high degree of euryhalinity (i.e. able to tolerate fresh and brackish salinities) in these taxa.

Although most of the freshwater fish and macroinvertebrate species recorded are able to inhabit brackish waters, many species would probably experience osmotic stress at prolonged elevated salinities. Furthermore, more extensive sampling of freshwater macroinvertebrate communities across a range of habitats would be expected to yield additional species, many of which may be intolerant of elevated salinities. It would be expected that the penetration of highly saline waters into the study area would result in some freshwater fish and mobile invertebrates either migrating upstream above the salt-water interface, and/or the loss of some salt sensitive species.

Overall, increased tidal exchange would be expected to result in a stronger salinity gradient along Ironbark Creek than presently exists. Due to differences in the salinity tolerances of individual species, it is likely that the community structure of fish and aquatic macroinvertebrates will be altered.

4.6.1.3 Aquatic Species Likely To Occur In The Area Following Floodgate Opening

Opening the floodgates would enable fish and macroinvertebrates unimpeded access into Ironbark Creek. Currently under existing conditions this does not occur. Combined with the long-term improvement in water quality, regular tidal exchange, and an increase in the area and diversity of high quality estuarine habitats, Ironbark Creek has the potential to become an important habitat for estuarine flora and fauna.

Some freshwater fish and macroinvertebrates will be lost from tidally inundated areas after saline water intrusion and short-term declines in water quality. Given suitable nutrient and dissolved oxygen

concentrations, euryhaline invertebrates and fish would recolonise tidally affected areas after a relatively short period of time (i.e. at least within one year).

4.6.1.4 Fisheries Value Of Ironbark Creek Following Floodgate Opening

Do nothing option

The waterway presently supports a functional nursery habitat for a range of economically important species. However, as a result of a combination of impacting processes associated with flood-gates, fisheries values have been diminished. Fisheries values would remain the same or diminish as a result of on-going water quality degradation, habitat degradation and lack of access.

Opening the floodgates

The opening of floodgates would be expected to greatly enhance the fisheries value of Ironbark Creek and the Lower Hunter River region in general.

Once the system stabilises after opening the floodgates, many of the aquatic species presently occupying estuarine sections of the Hunter River would be expected to utilise Ironbark Creek. Juvenile and sub-adult/adult stages of important commercial fish species such as yellowfin bream, tarwhine, silver biddies, dusky flathead, sea mullet, flattail mullet, luderick, longfinned eels and sand whiting would be expected to utilise estuarine sections of Ironbark Creek as nursery and feeding areas. Re-establishment of estuarine flora habitat would also favour commercial crustacean species such as the school prawn (*Metapenaeus macleayi*) and mud crab (*Scylla serrata*). Overall, this would be expected to greatly increase the potential fisheries yield of Ironbark Creek.

On a regional scale, the re-establishment of fisheries habitat and potential increase in fisheries yield would be likely to have significant flow-on effects for the Hunter region fisheries. The Hunter River estuary (excluding Hexham Swamp/Ironbark Creek) contained approximately 2,416 hectares of mangroves and saltmarsh in 1994 (see Section 3.7.3.2). As discussed previously, opening the floodgates will result in the estimated reinstatement of approximately 330 ha of tidally inundated lands (at the mean spring level), increasing the regional estuarine wetland area to 2746 ha (i.e. 14% increase). Most species of direct fisheries importance rely upon estuaries during at least part of their life-cycle, either for breeding, feeding or shelter. Degradation of estuarine biotopes can directly affect these fisheries habitat resource values, and the numerous physio-chemical and biological processes that maintain ecosystems on which estuarine fisheries are dependent. The restoration of Ironbark Creek would represent a major step in ensuring the long-term viability of a regionally important fisheries resource.

Restoration of Hexham Swamp is also expected to have positive benefits for fisheries throughout the east coast of Australia. Prior to the construction of the floodgates, prawns that were tagged at Hexham were actually recovered from within Moreton Bay, Queensland, thus highlighting the mobility of aquatic species that utilise the estuary during nursery and juvenile stages (pers comm.. Ian Craig, Newcastle Fishermans Co-op, 2005).

4.6.2 Wetland and Terrestrial Fauna

There is a paucity of information on the impact on terrestrial fauna populations with regards to the construction or decommissioning of tidal floodgates. In addition, there was no systematic collection of terrestrial fauna population data within Hexham Swamp prior to, or following, the construction of the floodgates.

In the short term, maintaining the current flood control regime is not considered to alter or impact upon the suite of fauna species currently associated with Hexham Swamp.

However, it is expected that, compared to pre-floodgate conditions, the wetland habitats have been simplified and de-valued, due to spread of common reed. As a consequence, a decline in the diversity of fauna species (both common and threatened) known or considered likely to occur is expected to have occurred across the wetland. Assessment of these historical impacts is considered to be outside the scope of this EIS, which is primarily required to assess the impacts of the opening all the eight floodgates.

This study contends that, for terrestrial fauna, the potential impacts likely to result from increased tidal flushing relate primarily to changes to the type, nature and extent of vegetation cover. Increased saline water exchange will result in the decline of salt sensitive vegetation and communities and associated benefits for those that are salt tolerant (eg. *Sporobolus* sp. and saltmarsh). The extent to which such changes may occur will be dependent on the degree of tidal flushing. The impacts of returning the current freshwater wetland areas, created by installation of tidal floodgates and reduction of tidal influence, to intertidal wetlands areas via removal of those floodgates and the restoration of tidal flushing, would be significant. There is likely to be a related change in community composition of terrestrial fauna species associated with the wetland. The degree of change will be related to changes to the type and extent of vegetation cover and the associated habitat quality and value that those vegetation communities support for terrestrial vertebrate fauna.

4.6.2.1 Birds

Do Nothing

Maintenance of the current flood control regime, is not considered to impact upon avifauna communities in the short term.

However, in the long term, it is anticipated that under the existing conditions, both swamp she-oak and common reed areas will continue to expand at the expense of habitats such as the degraded saltmarsh (see also Section 4.4). In terms of diversity, the common reed areas (*Phragmites* and *Typha* spp. dominated) are expected to support a relatively lower diversity of birds compared to the diversity which could be supported by the equivalent area of healthy saltmarsh, a community, which prior to the installation of the floodgates, was considerably more extensive in Hexham Swamp (see Section 3.7.3.1). Under the current conditions, the longer term effects of habitat succession and subsequent degradation and simplification are anticipated to result in declines in the existing species richness and abundance of a limited variety of birds associated with such habitats.

Opening the floodgates

The opening of eight floodgates is likely to result in the inundation of up to 750 hectares of vegetated habitats. Excluding the *Typha* communities and the semi-permanent and permanent ponds within the southern portion of Hexham Swamp, all other vegetation communities are likely to be impacted by the saltwater inundation. The common reed community will be substantially impacted with approximately 25% subject to inundation under mean spring tide conditions, and 57% under king tide conditions (refer Table 4.5).

This option is anticipated to rejuvenate saltmarsh, primarily at the expense of the common reed community, although this succession may take some time to complete, given the partial salt tolerance of *Phragmites* (see Section 4.4). This outcome has the potential to reverse the decline of vegetation communities favoured by many species listed under JAMBA and CAMBA, and predominant before the installation of the floodgates. The anticipated positive effects, on saltmarsh together with the expected benefits for the mangrove communities, will provide improved habitat values for a range of species groups, particularly migratory waders (JAMBA & CAMBA), listed species, snipe, herons, egrets, ibises, spoonbills and stork.

Of the threatened species known or likely to occur within the common reed communities of Hexham Swamp, only the Black Bittern or the Australian Bittern (both listed as vulnerable under the *TSC Act 1995*) are likely to be potentially affected by the opening of the floodgates. Detailed discussion on the likely impacts to these species is provided in an Eight Part Test (see **Appendix H: Volume 2**).

The large vegetated area and potential for extensive dieback, indicates that the extent of subsequent impacts on feeding resources and the birds may also be extensive. However, with the recommended staged opening of the gates, such impacts would be minimised. During this staged approach, an impact monitoring program would be undertaken which would allow evaluation of changes to avifauna habitat values and provide the basis to inform the development and implementation of any impact mitigation measures which may be required.

The opening of the eight floodgates and the subsequent improvements in habitat diversity for migratory waders ensures that the proposal is consistent with Australian Migratory Bird Treaty obligations (JAMBA and CAMBA). In particular, the proposal can be justified under the JAMBA Treaty, Article VI (a) which states that the Australian government should “seek means to prevent damage to such birds and their environment”, and under CAMBA Treaty, Article IV (b) which states that the Australian government should “take appropriate measures to preserve and enhance the environment of migratory birds”. Under the current limited tidal regime and degraded nature of terrestrial and aquatic ecosystems, particularly with the spread of fauna exclusionary species such as *Phragmites* across the swamp (ie. *Phragmites* are not able to be used by migratory waders), these international obligations are not being met.

4.6.2.2 Herpetofauna

Do nothing option

Hexham Swamp currently provides habitat for thirteen frog species, with the majority likely to have only occurred along the periphery of Hexham Swamp prior to installation of floodgates.

The dominant habitat in the swamp is the *Phragmites australis* reedland which is associated with an absence of frogs or at best, a depauperate frog fauna characterised by a very low diversity and abundance. Markwell (1983) noted that only one species, the Green and Golden Bell Frog, was recorded from vegetation communities dominated by *Phragmites australis*, where it was found to occur only on the margins of this vegetation type. It is important to note that Green and Golden Bell Frog was common throughout the lower Hunter valley in the early 1980s (Waterhouse, 1981), but has not been recorded within Hexham Swamp since that time.

In the short term, reptile species recorded in Hexham Swamp are not likely to be affected by maintaining the *status quo*. Populations of most species occur in habitats of the adjoining areas. Furthermore, areas providing similar habitats would remain and, as a result, the richness and / or abundance within Hexham Swamp will not be significantly altered.

However, the longer term effects of maintaining the floodgates is expected to see a decline in both habitat diversity and quality, as common reed communities invade remaining areas of the wetland. This gross scale process of habitat simplification is considered to result in a reduction in the diversity of reptile species supported by the wetland. The species considered likely to dominate typically are those common to the area and tolerant of high levels of disturbance and poor quality and diversity of habitats. The abundance of those species may not change in relation to species diversity.

As noted above, frog species diversity and / or abundance within Hexham Swamp is unlikely to change as a result of maintaining the *status quo*. Given this, any flow-on effect on both local frog-eating species, the Red-bellied Black Snake (*Pseudechis porphyriacus*) and Black-bellied Swamp Snake (*Hemiaspis signata*) is considered unlikely.

Opening the floodgates

The opening of all eight gates would lead to large areas of the swamp being inundated (at least periodically) by saline waters, which would markedly reduce frog populations. Some species (eg. Brown-striped Frog *Limnodynastes peronii*) have habitat tolerances such that populations may persist on the brackish swamp margins, particularly where freshwater input occurs (eg. western sectors). The capacity of such areas to support all species presently recorded in the swamp in the long term is unknown. Remnant populations near freshwater inputs would be spatially separated and subject to pollutants conveyed in stormwater draining from urban and rural areas reducing their viability.

All frog species recorded in Hexham Swamp, and considered likely to be affected are common in the Hunter region (Markwell 1984) with one exception, the Green and Golden Bell Frog. Substantial populations of most species of frogs occur in nearby freshwater wetland and lagoon areas including Beresfield to the north. The Green and Golden Bell Frog is listed as *endangered* under the NSW TSC Act reflecting the recent decline in its New South Wales' distribution. As such, a formal "eight part test" assessment has been completed for this species, which is presented in **Appendix H: Volume 2**.

The opening of all eight floodgates would bring about a significantly reduced amount of habitat available to amphibians, as sections of the now freshwater wetland, albeit highly modified, would return to an intertidal dominated wetland. However, recent surveys by the University of Newcastle failed to record the Green and Golden Bell Frog in Hexham Swamp, indicating that the habitat value of the Swamp has declined substantially in the last 15 years. Ongoing opportunistic and targeted surveys of frogs as part of the baseline ecological monitoring study has also failed to detect Green

and Golden Bell Frog in Hexham Swamp as at December 2004. The decline is probably related primarily to the gradual decline in water quality of the wetland as a whole, the simplification of habitats supported and infestation of the predator fish *Gambusia holbrooki* in Hexham Swamp which is a known predator of native fish and frogs.

Whilst areas suitable for breeding/foraging for Green and Golden Bell Frog would be diminished, the long term impact on viability of the population within Hexham swamp is uncertain.

With regard to reptiles, it is expected that there may be a general reduction in both the species richness and abundance of common reptiles known or likely to occur within the swamp in its present condition, as habitat conditions become intertidal. Only those reptiles tolerant of estuarine type conditions and habitats are considered likely to persist.

As identified previously, the opening of eight floodgates is likely to result in changes to an extensive vegetated area and subsequent flow-on affects (extensive dieback, water quality impacts). The extent of subsequent impacts on the reptiles (principally snakes), through either impacts on their habitat or prey (eg. frogs) may be extensive. Given the potential for significant impacts, a staged opening of the floodgates over a number of years is recommended (see Section 2.4). This would allow for a gradual and progressive set of changes to occur which could be subjected to an impact-monitoring program. This program should be implemented to allow evaluation of changes to herpetofauna habitat values and provide the basis to undertake impact mitigation measures where they may be required.

4.6.2.3 Mammals

Whilst both Koala and Squirrel Glider are known from the vicinity of Hexham Swamp, the paucity of suitable habitat trees, sparse tree cover, lack of records and indirect evidence of presence within Hexham Swamp indicate that the site is unsuitable for the species. Furthermore, this suggests that the NPWS Atlas records are likely to relate to observations of the species in more suitable and extensive habitats (e.g. forested foothills to the west) which are included within the ten square kilometre grid square in which Hexham Swamp is located. Consequently, impacts to these species are not considered relevant.

Under maintenance of existing conditions, the continual degradation of terrestrial habitats and encroachment of the common reed on other habitats is considered to be highly likely. This would result in a reduction in the overall value of the habitats supported by the swamp and potentially a decline in both the species richness and abundance of species occurring/supported therein.

Of the microbat species, only the Greater Broad-nosed Bat is likely to use Hexham Swamp given the extent and quality of the swamp habitats it supports and the habitat requirements of the species. Again, given the low suitability of Hexham Swamp habitats to support these species, the records of the NPWS Atlas are far more likely to relate to more suitable habitats that occur to the west of Hexham Swamp.

The Swamp Rat (*Rattus lutreolus*) is the only mammal species that is likely to be adversely affected by the opening of the floodgates and the subsequent return of the wetland to estuarine dominated habitats. This species is, however, regarded as widespread and moderately common within suitable habitats within other parts of Hexham Swamp and a range of habitats throughout the region. The habitats that support the Water Rat that are likely to be affected are expected to be improved in terms

of their suitability and overall condition for this species. That is, the rejuvenation of saltmarsh and riparian mangrove communities, improvement in the nature, diversity, extent and structure of wetland habitats present, improvement in water quality, and of the diversity and abundance of aquatic fauna which comprise an important component of the Water Rat's diet.

Monitoring of terrestrial fauna, as discussed in Section 6.5.3, will incorporate opportunistic monitoring of mammals within the swamp.

4.7 Fire Management

Opening the floodgates in Ironbark Creek would lead to an increase of moisture in Hexham Swamp, and conversion of vegetation from tall reeds to low-lying saltmarsh groundcover and mangroves. This situation would decrease the potential for fire events to occur within the study area. There may, however, be a period of increased fire potential following the initial opening of the gates. This would occur due to the death of some areas of reeds due to increased salinity, and the corresponding increase in dry litter material during dry periods in spring and summer. This situation would be short-lived, with the final outcome being a decreased area of the highly combustible reed community, causing a further reduction in the likelihood of fire occurrence.

It is considered, therefore, that opening the gates would not have a significant impact on the fire regime of Hexham Swamp. The only likely impact would be a reduction in the potential for fires to occur, and a consequent reduction in the need for fire management practices.

Considerations associated with the *Rural Fires and Environmental Assessment Legislation Amendment Bill 2002* are not triggered by the proposal, as the proposed development does not introduce life, dwellings or other assets to bushfire risk.

4.8 Stock Management

Cattle have historically been grazed on Hexham Swamp, when the majority of the swamp was under private ownership. As much of the former grazing land has now been acquired by the HCRCMA, cattle have been removed from the swamplands. Removal of stock has provided a number of environmental benefits, including soil stabilisation and nutrient input control, however, Phragmites have now grown thick on those lands where grazing has been ceased, and has recovered quicker than anticipated (pers. comm.. G Winning, HWR, 2005).

Following opening of the floodgates, maximum tidal penetration will be achieved if there is minimum impediment to the flows by vegetation. Therefore, it would be advantageous to limit the extents of Phragmites within the swamp prior to the staged floodgate opening. The most effective means of limiting the vegetation is to allow controlled stock grazing on lands likely to be inundated. Reduction of existing vegetation on these lands will also minimise the load of vegetation that may die-off following reinundation by saltwater. A reduction in this vegetation load would limit the potential for organic oxygen reduction in the waterways and nutrient inputs associated with the natural breakdown of the vegetation.

4.9 Weeds and Pests

4.9.1 Weeds

Increased tidal inundation within Hexham Swamp would reduce freshwater environments. As such, any opening of the floodgates is likely to reduce the occurrence of exotic plant species, most of which are killed or restricted by tidal inundation.

Under current circumstances, alligator weed is actively spreading throughout the swamp. Water hyacinth is a potential threat to Hexham Swamp, with infestations mainly in the upper fringe of the swamplands. The HCRCMA and NCC are working together to assist and encourage upstream landholders to manage these weeds.

Although alligator weed will tolerate flowing brackish water up to 30 % of sea strength (Lamp and Collet 1996), its growth appears to be restricted in tidal reaches (EAM Consultants 1991). Winning (1997) indicated that opening of the floodgates would present the best opportunity for long term control of alligator weed in Hexham Swamp. He argued that tidal inundation should effectively control all of the alligator weed infestations within the Hexham Swamp Nature Reserve.

While Center and Balciunas (1975) noted that water hyacinth has a greater tolerance for salinity than alligator weed, growth of water hyacinth also appears to be restricted by elevated salinities. The only infestations occurring within the area are in the upper margins of the swamp.

Opening the floodgates would increase the tidal inundation within Hexham Swamp, and therefore is likely to restrict the future spread of alligator weed, water hyacinth and other weeds into the lower reaches of the Swamp. Conversely, if Hexham Swamp is exposed to increased tidal inundation and the related increases in salinity levels that follow, the area may become more susceptible to invasion by the introduced wetland species *Juncus acutus*.

4.9.2 Exotic Pests and Livestock

Increased tidal inundation within Hexham Swamp would reduce freshwater environments. As such, it is likely to reduce the occurrence of exotic pests, such as pigs, rabbits, hares, foxes, feral dogs and cats, as well as livestock species found in Hexham Swamp, all of which generally prefer freshwater environments. Changes anticipated in the nature of the vegetation would also restrict the suitability of the area for exotic pests. For example, a change from dense reed land to open saltmarsh would diminish the area of shelter available within the swamp.

Suitable habitat for exotic pest species is likely to be reduced following the opening of the floodgates. Increasing salinity and salt-tolerant vegetation within the swamp would also make the area less suitable for livestock, which would likely be removed from the swamp as a direct consequence.

4.9.3 Mosquitoes

4.9.3.1 Mosquito species

Over 20 species of mosquito have been collected from the Hunter region, with pest mosquitoes associated with estuarine, brackish water and freshwater habitats.

4.9.3.2 Mosquito habitats

It is difficult to accurately predict the change to mosquito habitats in Hexham Swamp following the re-establishment of tidal flows through the opening of the floodgates at Ironbark Creek. Based on modelling of maximum flood levels for king tides and spring tides, a relatively large area of Hexham Swamp along Ironbark Creek, Fishery Creek and Shelley Creek will be inundated. Much of this area contains relatively flat habitats that currently do not retain substantial amounts of water following rainfall, and consequently, are unlikely to retain tidal water and thus are unlikely to be ideal potential mosquito habitat.

Much of Hexham Swamp remains difficult to sample for mosquitoes due to the extensive stands of *Phragmites* and other freshwater vegetation. It is difficult to determine the suitability of these habitats for mosquito breeding following tidal inundation without a better understanding of how the vegetation will respond and how water is retained in these areas. It is unclear how mosquito populations will respond to the habitats when in transition from a predominantly freshwater to estuarine wetland.

The areas of greatest concern are north of Fishery Creek to the east of the water pipeline where remnant channels are likely to retain water following tidal inundation. These areas currently retain water following major rainfall events and, while they only represent significant breeding habitats for the freshwater mosquito *Cx. annulirostris*, it is unclear how the saltmarsh mosquito, *Oc. Vigilax*, will respond following the introduction of greater tidal influence.

Table 4.8 summarises the expected response of the mosquito habitats, and mosquito abundance, to the opening of the floodgates, compared to the do nothing condition. Although a potential increase in abundance of several species may occur within Hexham Swamp following the opening of the floodgates (refer Table 4.8), it is considered that the total number of mosquitoes produced in the Lower Hunter estuary would not increase significantly, due to the dominance of Kooragang Island and Tomago Wetlands as principal local mosquito breeding habitats.

Table 4.8 Impact of two tidal inundation options on mosquito habitats and mosquito abundance in Hexham Swamp

Option	Saltmarsh Mosquito (<i>Ochlerotatus vigilax</i>)	Hexham Grey Mosquito (<i>Ochlerotatus alternans</i>)	Common Banded Mosquito (<i>Culex annulirostris</i>)	Banded Saltwater Mosquito (<i>Culex sitiens</i>)
Do nothing – Mosquito habitat	No effect	No effect	No effect	No effect
Do nothing – Mosquito abundance	No effect – generally low abundance dependent on rainfall	No effect – generally low abundance dependent on rainfall	No effect – potentially high abundance dependent on rainfall	No effect – generally low abundance dependent on rainfall

Option	Saltmarsh Mosquito (<i>Ochlerotatus vigilax</i>)	Hexham Grey Mosquito (<i>Ochlerotatus alternans</i>)	Common Banded Mosquito (<i>Culex annulirostris</i>)	Banded Saltwater Mosquito (<i>Culex sitiens</i>)
Open floodgates – Mosquito habitat	Increase in potential habitat within areas of tidal inundation as salinity increases and total area of saltmarsh vegetation increases	Increase in potential habitat within areas of tidal inundation as salinity increases and total area of saltmarsh vegetation increases	Decrease in suitable habitat due to increased salinity. Habitats beyond tidal inundation remain with no effect	Increase in potential habitat within areas of tidal inundation as salinity increases but dependent on duration of inundation
Open floodgates – Mosquito abundance	Potential increase dependent on inundation frequency, duration of inundation and rainfall	Potential increase in areas of tidal inundation dependent on inundation frequency, duration of inundation and rainfall	Decrease in tidally influenced habitats, no change in other areas but dependent on rainfall.	Potential increase in areas of tidal inundation but dependent on duration of inundation.

4.9.3.3 Nuisance biting & public health risks

The tolerance of the community to mosquito impacts greatly determines the degree of nuisance caused by the local mosquito populations. Currently, the Lower Hunter estuary is often impacted by severe nuisance biting impacts by *Oc. vigilax* during the summer months. As this species disperses widely from breeding habitats, the adult mosquitoes produced from habitats on Kooragang Island and from habitats surrounding Fullerton Cove and Tomago can have a wide reaching impact on the greater Hunter region including Newcastle. These pest impacts are likely to be greatest during the months of December, January and February, particularly following inundation of the estuarine wetlands by tides and/or rainfall with a peak in impacts approximately 10-14 days following the inundation event and typically lasting for two weeks. Without an extensive program of source reduction (through habitat modification and/or control agent application), there is little that can be done to significantly minimise nuisance-biting impacts during these periods of peak mosquito activity in the Lower Hunter region.

The Hexham Swamp is currently considered as only a minor contributor to the overall pest impacts in the Lower Hunter estuary. Due to the exclusion of tides, the site is only inundated following major rainfall events. While there is a relatively minor production of *Oc. vigilax* from some of the remnant saltmarsh areas, during “wet” seasons, the site is more likely to produce large populations of freshwater species such as *Cx. annulirostris* and *Cx. quinquefasciatus*.

It is difficult to quantify the relationship between the quantity of mosquitoes produced from an individual wetland, within a network of productive mosquito habitats, and the nuisance impact of mosquito biting on the local community. As indicated previously, given that there is extensive mosquito breeding habitats elsewhere in the Lower Hunter region, the relative contribution by newly created habitats in Hexham Swamp following the opening of the floodgates may not be substantial.

In coastal areas of NSW, the risks of arbovirus disease are an important consideration in mosquito management and the two major diseases, traditionally known as Epidemic Polyarthritis, are Ross River (RR) and Barmah Forest (BF). These diseases are caused by viruses that are transmitted to humans through the bite of mosquitoes. The viruses have been isolated from many mosquito species and in coastal areas, *Oc. vigilax* is considered the major vector (disease carrying) species. Serological

studies and laboratory investigations have indicated that native mammals, most likely kangaroos and wallabies, are natural hosts for RR virus but little is known about the hosts of Barmah Forest virus.

Following human infection, a wide variety of symptoms may occur from rashes with fevers, to arthritis that can last from months to years with RR virus infection. There are no specific treatments and actions that reduce mosquito bites are the best form of prevention against these debilitating diseases. While the annual rates of human infection with RR and BF virus vary, from July 1996 through until February 2004, a total of 948 human notifications of RR and BF infections were reported by the Hunter Area Health Service (<http://www.arbovirus.health.nsw.gov.au>), indicating that existing mosquito populations represent potential public health risks. While *Oc. vigilax* is considered the major vector species, the relative contribution of this species, compared to other mosquito species, in this region is not fully understood.

Both *Oc. vigilax* and *Cx. annulirostris* are produced from Hexham Swamp, with populations greatest during “wet” years. However, the mosquitoes produced from the habitats in Hexham Swamp are unlikely to make a substantial contribution to the overall public health risks in the lower Hunter region considering the large quantity of mosquitoes currently produced from the other major breeding sites on Kooragang Island and Fullerton Cove.

There are no public health risks associated with dengue virus or malaria in the Hunter region as the disease causing pathogens, and mosquitoes that carry them, are not abundant in the local area or are likely to be as a result of opening the floodgates.

4.9.3.4 Mitigation strategies

Predicting the impact of opening the floodgates on the mosquito habitats and production of pest mosquitoes is difficult. However, with the ability to control the timing, frequency and quantity of tide movement through the gates, and subsequent inundation of the wetland, the HCRCMA is well placed to manage unexpected or unusually large mosquito abundances. The exclusion of tides altogether, or the regulation of tidal inundation according to season and tide magnitude will enable direct control of the provision of potential mosquito habitats and subsequent adult mosquito production.

Given the difficulty in accurately predicting potential increases in mosquitoes due to uncertainty in the extent and duration of tidal inundation, opening the floodgates during the non-mosquito season, from May to October, will enable an initial assessment of the area affected by tidal inundation and facilitate a more accurate assessment of potential mosquito increases.

Physical strategies: Tidal flow management

Potential increases in breeding by *Oc. vigilax* will be influenced by the frequency and extent of tidal inundation and the duration that pools and depressions remain inundated. If water remains in pools for more than 5 days it is sufficient for mosquitoes to complete development from larva to adult. Mosquitoes require standing water to complete their development. Mosquitoes do not breed in vegetation or damp soil. If the pools remain inundated for more than 4 weeks, despite an initial production of mosquitoes, subsequent tidal inundation events will result in the production of fewer mosquitoes due to the increased likelihood of the establishment of predator (i.e. fish) populations and the inability of mosquitoes to lay eggs in preferred oviposition sites (i.e. the base of vegetation).

There are already areas where potential pools may form (e.g. old mangrove lined channels) and depressions (e.g. areas of excessive disturbance from cattle) and these areas have the greatest potential to provide suitable breeding conditions for *Oc. vigilax*. The suitability of these habitats may be reduced through the construction of channels or runnels, or the removal of earthen barriers to natural draining, to increase the flow of tidal (as well as rainfall) inundation from productive pools and/or depressions and decrease the area, and persistence, of ponding water.

The frequency of tidal inundation can greatly influence mosquito production. Generally, areas of estuarine wetlands that receive tidal inundation on at least a weekly basis are less likely to produce mosquitoes as larval mortality is increased due to flushing and increased contact with predators. However, areas that are only inundated by the highest tides (e.g. king tides) are much more likely to produce mosquitoes. The production of mosquitoes in Hexham Swamp may be regulated by the manipulation of tidal inundation via the floodgates at Ironbark Creek, in particular the restriction of king tides and limiting the volume of tidal water entering the wetland during the highest tides of each month (i.e. large spring tides). Restricting tidal flows will limit the extent, as well as the duration, of inundation, and subsequently minimise mosquito production.

The regulation of mosquito populations following rainfall is more difficult and the composition of species and relative abundance following exposure to salt water is difficult to predict. An increase in the soil salinity of the wetland will result in greater salinity of pools formed after rainfall events, consequently creating more favourable conditions for *Oc. vigilax* and *Oc. alternans*. These conditions will also reduce the suitability of the wetlands to the production of freshwater pest species such as *Cx. annulirostris*.

Control agents: Larval mosquito populations

Although there are products available that may be useful against adult mosquitoes (e.g. Maldison, Chlorpyrifos and Permethrin) during times of exceptionally large populations or epidemic virus activity, these products are not effective for the control of mosquitoes over a large area, can be expensive and may have greater non-target impacts. The most effective way to control larval mosquito populations is to use control agents that specifically target the immature stages of mosquitoes. This can be achieved through the application of mosquito control agents that are toxic to larvae, prevent larvae developing to adults, or are efficient predators or reducing the source of mosquito breeding by eliminating habitats or making them unsuitable for mosquito production.

Temephos: Temephos (trade name ABATE) is an organophosphate compound that has been used in mosquito control since the early 1950's. Although it is highly effective, it is not totally selective and may have toxic effects on non-target organisms such as birds, fish and some invertebrates. Additionally, there have been concerns regarding the development of resistance in target species and, combined with the potential non-target and environmental impacts, local control authorities have reduced the use Temephos in favour of alternative control agents.

Bacillus thuringiensis israelensis: The bacterium *Bacillus thuringiensis israelensis* (*B.t.i*) (various trade names e.g. TEKNAR, CYBATE, AQUABAC, VECTOBAC) produces a protein crystal which contains a number of microscopic pro-toxins that, when ingested, are capable of destroying the gut wall and killing mosquito larvae within 12 hours of ingestion.

The greatest benefit of *B.t.i.* is that it is highly specific to mosquito larvae and very few non-target effects have been recorded when the product is applied at recommended rates. In Australia, it has been used successfully to reduce pest mosquito populations in both saline and freshwater habitats. The product does, however, have some disadvantages in that the efficacy is reduced in habitats with a high organic content or when applied when larval populations are young (ie. 1st instar) or nearing pupation (late 4th instar larvae stop feeding and so may not ingest the *B.t.i.*). There is a very small window of opportunity for effective treatment of larval populations, as the product has no residual activity. It must be applied after larval populations have hatched and during the summer months, there may only be a 3 day period in which application can be effectively undertaken. Treatments will also be required following each new inundation event due to the absence of residual activity.

The most effective application method for a large area of wetland would be via aerial application (eg. fixed wing aircraft or helicopter fitted with appropriate dispersal equipment and GPS). Liquid *B.t.i.* can be applied undiluted or diluted in water and the recommended application rate for estuarine wetlands is 600ml – 1.2L/ha.

s-methoprene: The insect growth regulator, *s-methoprene* (trade name ALTOSID) is a synthetic mimic of juvenile hormone produced by insect endocrine systems and in Australian saltmarshes, *s-methoprene* has been shown to be an effective control agent of pest mosquitoes without adversely effecting the non target organisms. When absorbed by the larvae, development is interrupted and larvae fail to successfully develop to adults, usually dying in the pupal stage. This is a great benefit of *s-methoprene* as it maximises the presence of mosquito larvae in the aquatic ecosystem long enough to provide food for predators.

The product is available in three formulations, liquid, pellets and briquets. The application rate for the liquid formulation is 220ml/ha for shallow water, low density mosquito habitats and increases to 290-360ml/ha for organic rich, high density mosquito habitats. The advantage of the pellet and briquet formulations is that they offer extended periods of control, reducing the need to treat wetlands on numerous occasions during the 'mosquito season'. The recommended application rate of the pellets is 3g/ha in estuarine wetlands with an increased rate required in habitats with a high organic content. At the recommended application rate, one briquets can effectively treat an area of 20m² if pools are less than 30cm deep and 10m² if pools are greater than 30cm. Manual application of pellets and briquets, however, can be time-consuming and can potentially generate additional breeding habitat through foot holes and trampling. To combat this, aerial application of *s-methoprene* pellets has been used successfully over wetland areas (most notably in south-east Queensland).

The most common chemical approach to mosquito management in Australia, and overseas, is *B.t.i.*, and is considered to be the most appropriate method for managing mosquitoes at Hexham Swamp if considered necessary. Application to Hexham Swamp would require aerial spraying, and would need to be closely coordinated with field sampling to ensure that larvae are at a developmental stage that will respond to the agent. *B.t.i.* would mostly used to control populations of *Oc. Vigilax*. As the growth of this particular species is triggered by specific flooding / inundation events, there is generally uniform development of the larvae, meaning that single applications of *B.t.i.* would be effective at reducing emergent populations (subject to appropriate timing of the application).

Biological control

A number of organisms have been investigated to determine their suitability as effective predators of mosquito larvae. These include invertebrates (eg, Diptera and Coleopteran larvae, Copepods, Crustaceans, Notonectids, Odonates) and vertebrate predators (eg. fish). The most common of these have been fish, although their application to estuarine wetlands, which periodically dry out, is considered limited. Macroinvertebrates hold greater potential in freshwater wetlands, and like fish, are of limited effectiveness in estuarine wetlands.

The 'mosquitofish' *Gambusia holbrooki* was introduced to Australia from North America at the beginning of the 1900s and has since spread to most of the waterways in Australia. There is some debate as to the effectiveness of *G. holbrooki* as a mosquito control agent, and in Australia the species has been implicated in significant adverse impacts on aquatic native fauna, particularly fish and amphibians.

A number of native fish have been identified that may be appropriate for mosquito control in Australia, in particular *Pseudomugil signifer* (Pacific Blue-eye). However, the frequent drying and high salinity of saltmarsh habitats, the highly polluted nature of constructed wetlands and proliferation of *G. holbrooki* limits the likely success of native fish for mosquito control.

There are other native fish that consume mosquito larvae but rather than introducing them to habitats, it may be more effective to facilitate the movement of naturally occurring fish in the estuary to access pools on the saltmarsh when inundated. The nature of the saltmarsh vegetation provides refuge for larvae and the drying of habitats prohibits the establishment of fish populations on site. As well as allowing unrestricted access of fish to Ironbark Creek via the floodgates, channels or runnels connecting pools may potentially increase predation on mosquitoes.

While fish may be considered an important component of integrated mosquito control, it is unlikely that fish alone will minimise the production of mosquitoes from estuarine wetlands, especially upper marsh habitats.

Integrated and Co-ordinated Mosquito Management across the Lower Hunter Area

Given the relatively minor role of Hexham Swamp in producing mosquitoes across the Lower Hunter estuary, management of Hexham Swamp alone is unlikely to have any impacts on the existing biting mosquito problems of the Lower Hunter area. To effectuate mosquito management in the area, an integrated and co-ordinated approach applied to the whole region will be necessary.

A cross-agency Committee, lead by the Premier's Department, has been established for addressing long-term mosquito management in the Hunter region (pers comm.. N. Staheyeff, HCRCMA, 2005). This Committee will be responsible for the development and implementation of plans and strategies aimed at the sustainable management of mosquitoes and their impacts on the burgeoning urban development around areas such as Hexham Swamp. Future management of mosquitoes in Hexham Swamp will be carried out in accordance with the proposed Committee plans, and may incorporate physical treatment and works, such as application of larvicides, growth regulators, and runneling.

4.9.3.5 Mosquito monitoring

The monitoring of adult and immature (larvae) mosquito populations, as well as actual and potential mosquito habitat, is crucial for effective management of mosquito populations associated with Hexham Swamp. The assessment of mosquito population change cannot be accurately achieved without sampling the local mosquito fauna. These assessments cannot focus on the Hexham Swamp wetland alone and consideration must be given to the production of wetlands elsewhere in the lower Hunter estuary (e.g. Kooragang Island and Fullerton Cove).

Adult mosquito populations are sampled using a dry-ice baited trap, most commonly an Encephalitis Vector Surveillance (EVS) trap. The carbon dioxide released by the dry-ice attracts and traps host seeking (female) mosquitoes. A network of traps should be operated around the Hexham Swamp and nearby wetlands to sample mosquitoes dispersing from and into a wetland area. The adult trap collections provide the only reliable method to identify the mosquito species responsible for nuisance biting impacts. It is not unusual, even close to estuarine wetlands, that the species causing nuisance biting impacts may have originated from brackish water, freshwater habitats or domestic habitats and in this instance, the biting impacts should be disassociated from Hexham Swamp.

Larval mosquito populations are most commonly sampled using a 300ml “dipper”. The collection, and correct identification, of mosquito larvae is the only reliable method of identifying the breeding habitats and determine the spatial and temporal distribution of productive mosquito breeding sites. The number and location of sampling sites in Hexham Swamp will be dependent on the eventual area influenced by the tidal inundation regime once all eight gates are open. Sampling of larval populations at sites within and outside the areas of inundation (where access allows) should be undertaken during the months from December through until April.

The timing and frequency of larval population sampling is an important consideration as mosquitoes have short life cycles and the environmental/climatic factors influencing population increases varies with species. As mosquito larvae in the estuarine wetlands can hatch from eggs and complete development to adults within 7-10 days, monitoring programs must ensure sampling is undertaken with a week of wetland inundation. Sampling outside this period may not provide adequate information from which to make an accurate assessment of the impact on mosquito populations resulting from increased tidal inundation of Hexham Swamp.

It is crucial that the sampling and identification of specimens collected be undertaken by an organization experienced in the methodologies of mosquito sampling back with an appropriate understanding of mosquito ecology, biology and taxonomy.

4.9.4 Introduced Fish Species

Three introduced fish species occur in the study area: Mosquito fish (*Gambusia holbrooki*) European Carp (*Cyprinus carpio*) and Oriental Gobies.

Two species (*Gambusia* and *Carp*) are primarily freshwater species, but can tolerate moderately elevated salinities (see Section 3.7.4.2), although saline waters are not their preferred habitat. The opening of all eight floodgates would increase tidal flushing and ambient salinities throughout much of the wetland. Increased tidal flushing would result in a large reduction in optimal habitat for both species, particularly in the lower creek reaches. As a consequence, it could be expected that the

abundance of *Gambusia* and Carp within Hexham Swamp would decrease following opening of the gates.

The oriental goby typically inhabits marine and brackish waters, so the increase in tidal flushing may actually provide more habitat for this species to inhabit, possibly resulting in an increase in numbers within the swamp.

4.10 Noise Impacts

The main impact that the proposal will have on the existing acoustic environment relates to the construction of the low-level earthen bunds and filling of private lands. The primary area of impact will be along Marsden Street, where the construction of the Marsden Street bund may affect existing residences.

An acoustic assessment has been carried out by Global Acoustics (2004) (refer **Appendix I: Volume 2**) to predict the likely impacts of bund construction on the existing acoustic amenity of Shortland. Existing background noise levels were discussed previously in Section 3.10 (refer Table 3.27).

The impacts of construction plant and equipment were superimposed on background noise levels to determine the likely impacts on noise as a result of the proposed construction activities. These predicted levels were then compared to the construction noise criterion as defined by the NSW EPA's Environmental Noise Control Manual. Given that the construction period for the bund is likely to exceed 4 weeks, but be less than 26 weeks, the criterion was defined as 10 dB greater than the existing background (L_{A90}) noise level. Based on acoustic monitoring carried out for this Project (refer Section 3.10), the daytime background noise level for Shortland is approximately 36 – 38 dB. Therefore, the construction noise criterion is 47 dB (i.e. 37 + 10).

The predicted noise levels (and criterion exceedances) at Shortland are presented in Table 4.9 for a range of distances away from the proposed works. The minimum distance between the Marsden Street bund and existing residences in Marsden Street is approximately 300 metres. Therefore, for approximately 18 houses in Marsden Street, the construction criterion would be exceeded by more than 5 dB, although the timeframe for exceedance would be relatively short. For the majority of houses along Marsden Street, the typical distance to the bund is approximately 700 – 800 metres. At this distance, the predicted construction noise level is only marginally above the construction criterion.

Given that construction of the bund will be carried out in a linear manner, starting at the southern end (which is furthest from the existing residences), it is likely that noise impacts on local residents would be kept to a minimum. Nonetheless, exceedances of the noise criterion are still predicted. Global Acoustics (2004) indicate that such exceedances are not uncommon for works of this nature, and that community information and liaison (preferable through direct contact) can be adopted as a means of construction noise management.

Global Acoustics (2004) also indicate that traffic noise impacts from movements of trucks and other vehicles on local roads would be considered to be low, given the small number of total truck loads required to construct the bund (i.e. approximately 175 loads over a 2 – 3 month period).

Table 4.9 Predicted Impacts of Proposed Construction Activities

Distance (m)	Predicted Noise Level (dB)*	Criterion (dB)	Predicted Exceedance of Criterion (dB)
300	55.5	47	8.5
400	52.5	47	5.5
500	50.5	47	3.5
600	49.5	47	2.5
700	47.5	47	0.5
800	46.5	47	0 (no exceedance)

* Taken as the average of two scenarios adopting different numbers of construction plant operating concurrently (refer **Appendix I: Volume 2** for details).

4.11 Air Quality Impacts

Air quality would potentially be affected by pollutants associated with the diesel motors used in plant and equipment for the construction of the low-level bunds and other minor filling works. These pollutants would primarily include:

- Volatile organic compounds (VOCs);
- Carbon Monoxide (CO);
- Various nitrogen oxides (NO_x);
- Sulfur dioxide (SO₂); and
- Particulate matter <10 µm in aerodynamic diameter (PM₁₀).

Ash and metallic additives would contribute to the particulate content of the exhaust.

Construction of the bunds and other filling works will be completed within a period of less than 6 months, with all of the works being undertaken prior to opening of the floodgates.

Construction of the bunds may take three to four months to complete. During this timeframe, the equipment (including trucks, dozers, compactors, excavators and other ancillary plant), would utilise between 1000 and 5000 litres of diesel fuel per week. The predicted pollutant emissions associated with this quantity of fuel usage are shown in Table 4.10. These predictions were made using the Emission Estimation Technique Manual for Combustion Engines published by the Environment Australia for the National Pollutant Inventory.

Table 4.10 Estimated Weekly Air Pollutant Emissions

Pollutant	Emission (kg/week)
VOCs	1.3 – 6.6
CO	14 - 70
NO _x	52 - 263
PM ₁₀	1.6 – 8.2
SO ₂	2.5 – 12.5

Usage of 1,000 - 5,000 L of fuel per week was estimated to be equivalent to 143 - 715 tonnes of CO₂ released per year (although construction would only last for a few months). By comparison, Australia's net greenhouse gas emission in 1999 was 458,200,000 tonnes (ERM, 2001).

It is anticipated that air quality impacts from the proposed construction activities will not have a significant impact on the environment. As such, no specific mitigation measures associated with air quality are required apart from water spraying of construction roads and earthworks areas if dust is considered problematic at nearby residences.

4.12 Traffic Impacts

The primary impacts of the proposal associated with traffic would relate to the construction of the earthen bunds, the raising and resurfacing of the Wallsend airstrip and the filling of private low-lying floodplain lands. In total, approximately 15,000 tonnes of imported material will be required to complete the proposal, with the material required at several different locations around the swamp. This quantity of material could be supplied in as little as 400 truck loads (assuming that up to 40 tonnes of material can be supplied by truck and dog), which would be provided over an approximate 4 month period (i.e. approximately 5 per day).

Given that the destinations for the imported material, and hence the actual traffic routes taken, are spread around the margins of Hexham Swamp, combined with the period over which the works are to be carried out, it is considered that the impact of the proposal on local traffic would be minor, and does not warrant further consideration in this environmental assessment.

4.13 Visual Landscape

4.13.1 Assumptions

Visual landscape units for areas around Hexham Swamp were described in Section 3.12. The value of each landscape unit can be assessed using a number of assumptions widely accepted in landscape studies. These assumptions are based on public surveys and have been adapted from the State Pollution Control Commission (1981). They include the following (among others):

- People prefer natural to artificial landscapes. Naturally vegetated areas are regarded as the most attractive and industrial areas the least;

- Trees are highly valued in the landscape. Forested areas are preferred to non forested areas;
- Water is a valued landscape unit. Moving water is preferred to still water; clean water is preferred to muddy water; and large water bodies are preferred to narrow streams;
- Natural riverbanks are preferred to artificial or modified banks;
- Contrast between landscape units creates visual interest, with natural contrasts being considered successful and enjoyable, while artificial contrasts can be regarded as an 'eyesore';
- Movement and activity, both natural and artificial are valued in a view, with natural movement being in general considered more valuable;
- The most favoured views are those over a long distance including water bodies and extensive areas of trees.

4.13.2 Impacts

Table 4.11 summarises the projected impacts of the proposed works, on the basis of the above assumptions.

Table 4.11 Impact of Visual Landscape

Landscape Unit	Existing Conditions	Proposed Conditions (floodgates open)
Waterways	Further reduction as Phragmites continues to invade freshwater swamps	Increase in water bodies and extent of periodic inundation
Developed areas	No impact	New bunds, but these would be low and vegetated, and difficult to see from a distance
Trees	Gradual establishment of Casuarinas amongst Phragmites as ground level builds and groundwater table falls	Possible gradual reduction in Casuarinas, significant increase in area covered by mangroves
Reed Lands	Small increase with further expansion into freshwater swamps	Large areas replaced by low-profile saltmarsh

It is considered that the proposed conditions, with all eight floodgates open, would have net positive impacts on the visual amenity of the site. These positive impacts would mainly occur through the increase in size of water bodies present on the site due to tidal inundation. The gradual increase and decrease in the size of these water bodies (due to tidal cycles) would also add movement to the landscape increasing visual interest.

Another important impact of the proposed conditions would be the increased area covered by trees (specifically mangroves). Although it is possible that some Casuarinas may be lost due to their intolerance to saline water, expansion of mangroves would significantly increase the total area

covered by this landscape unit. As trees are a highly valued landscape aspect, any increase in the forested areas of the site would improve the overall visual amenity of the area. Fringing stands of mangroves along the defined watercourses in the swamp would be more valued than isolated she-oaks that are starting to establish amongst the reeds, and will continue to establish if the swamp hydrology remains unaltered (i.e. maintaining the *status quo* of one gate partly open by 0.3 metres, or two notches).

4.14 Planning, Heritage, and Archaeology

The impacts of the proposal with respect to the various planning and heritage provisions relevant to the proposal are listed in Table 4.12.

No urban land will be affected by the proposal. Future expansion of the Newcastle City to the west and in the immediate vicinity of Hexham Swamp (such as the future Blue Gum Vista estate) will not be affected by the proposal.

On the basis of the archaeological field assessment and the discussions presented in Section 3.15, it can be concluded that there are no archaeological constraints on the proposed opening of the floodgates, apart from the artefact found in the location of the proposed Marsden Street bund.

Table 4.12 Impact on Planning and Heritage Provisions

Instrument or Policy	Impact
SEPP 14	Will be partially inundated, see Section 4.14.1
Hexham Swamp Nature Reserve	Will be partially inundated, see Section 4.14.2
Regional Environmental Plan	No items listed under a Regional Environmental Plan will be affected by the proposal
Local Environmental Plan	No items listed under a Local Environmental Plan will be affected by the proposal
National Trust of NSW	The proposal will affect the landscape character of the area, thus impacting on the Hunter River Estuary Landscape Conservation Area. The impact of the proposal is addressed in Section 4.13.
NSW Heritage Office	As noted previously, there are no items within the study area, or likely to be affected by any of the options, that will require an application to the NSW Heritage Office
National Parks and Wildlife Act 1974	At least one known artefact site would be disturbed or destroyed during the construction of the bunds, see Section 4.14.3.

4.14.1 SEPP 14 Wetlands

Wetland areas within Hexham Swamp that are gazetted under SEPP 14 are shown in Figure 2.20. Wetlands listed under SEPP 14 are recognised as being significant in a regional or state context. The extent of direct tidal influence (from the king tide) on the SEPP 14 area is shown in Figure 4.11.

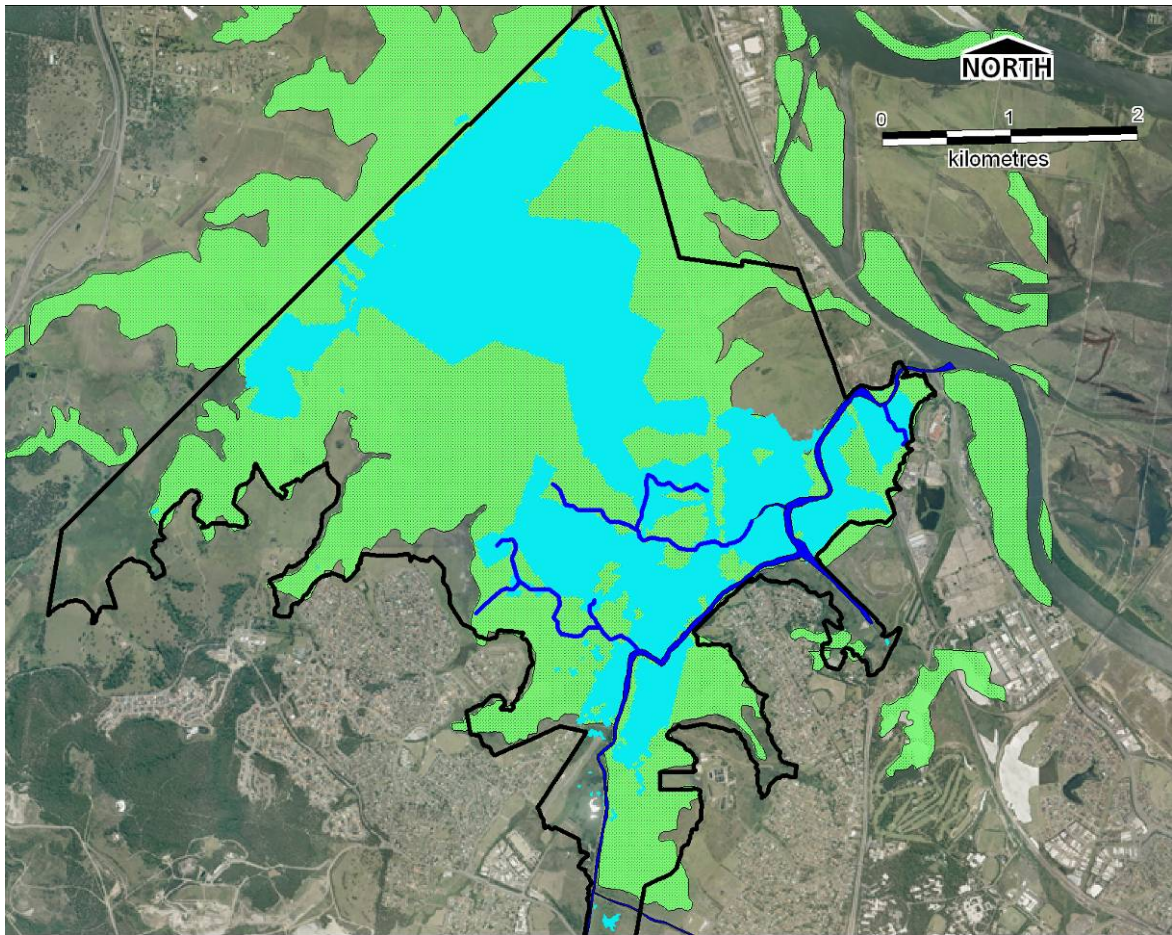


Figure 4.11 SEPP14 Wetlands and King Tide Extent in Hexham Swamp

Impacts on the existing SEPP 14 wetlands from the proposal are expected to be primarily a result of inundation with saline waters of the essentially freshwater vegetation communities (particularly *P.australis* and reed species), formed since the construction of the floodgates. Almost the entire predicted extents of saltwater inundation are contained within the SEPP 14 boundary. This means that approximately 750 hectares of SEPP 14 (No. 840) are likely to be affected by the proposal, representing approximately 35% of the total area of Wetland No. 840.

The installation of floodgates has severely modified the flow regimes and the diversity of habitats previously found in Hexham Swamp. In summary, the floodgates have formed a barrier to normal tidal flow, which has resulted in:

- the infilling and closure of some tributaries and deep water holes through siltation. The most significant closure is Muckeye Creek, located approximately 1 km upstream of the floodgate, which prior to floodgate installation was approximately 12-15 m wide and 1.5-2 m deep. The creek is presently covered by reeds (*Phragmites australis*) and almost completely infilled;
- the absence of tidal inundation of shallow saltmarsh habitats; and

- extensive losses of shallow estuarine habitats (mangroves and saltmarshes).

There are now two broad habitat types (containing a range of micro-habitat types) within the Ironbark Creek catchment:

- Channel habitat, comprised of Ironbark Creek and its major tributaries; and
- Wetland habitat, comprised of the shallow, seasonally inundated freshwater wetland areas of Hexham Swamp.

The impacts from the proposal on the vegetation communities within these habitats have been assessed and discussed previously in Section 4.4. With respect to the SEPP 14 area specifically, the majority of the impact will occur to existing *Phragmites* communities. Approximately 526 hectares of *Phragmites* within the SEPP 14 area would be potentially inundated by saltwater and likely to be replaced by a more salt-tolerant community (eg mangroves and saltmarsh). It is interesting to note that since the gazettal of the SEPP 14 wetland in 1985, the extent of the *Phragmites* community within the wetland has expanded by 219 hectares (or 31%) largely at the expense of mangroves (reduced by 58%), saltmarsh (reduced by 97%) and freshwater swamp (reduced by 17%) (see Section 3.7.3.1).

The mangrove and degraded saltmarsh communities that were present under a tidally inundated hydrological regime, are currently senescent or degraded. Re-inundation by tidal water would rejuvenate these communities. In summary, although the effects on existing vegetation communities are expected to be significant, the re-establishment of a habitat similar to that prior to the construction of the floodgates is expected. This habitat, once established, would provide a more stable ecosystem within Hexham Swamp.

4.14.2 Hexham Swamp Nature Reserve

No physical works are proposed within the Hexham Swamp Nature Reserve, however, as noted in the previous Sections, the opening of the floodgates will result in:

- regular inundation by tidal water;
- improved water quality in the long run;
- a gradual replacement of inundated areas of common reed with plant species more adapted to saline conditions, thus diversifying the habitats available within Hexham Swamp and the Nature Reserve;
- a replacement of affected freshwater fauna with species more adapted to saline environments, thus increasing the fauna species diversity within Hexham Swamp and the Nature Reserve.

As noted in Section 2.7.5.3, a specific objective of the Hexham Swamp Nature Reserve is “to maintain and promote the population numbers and species diversity of waterfowl and migratory waders” (NPWS, 1996a, p11). Waterfowl are essentially birds of freshwater although some, such as Black Swan, thrive in hypertidal ponds which can be rich in filamentous green algae. While some migratory waders, such as Marsh Sandpiper, are known to utilise freshwater habitats, many species

use estuarine habitats, typically feeding on mud flats and roosting in saltmarsh and other habitats with clear long distance views (to sight potential predators) such as sand banks.

The present condition of Hexham Swamp Nature Reserve provides seasonal habitat for waterfowl and other freshwater birds, such as herons, when inundated. The key to this habitat is the present areas of Water Couch (*Paspalum vaginatum*) that form a mosaic with the extensive stands of Common Reed. This mosaic habitat is also important to Australasian Bittern which, although commonly considered to be a bird of reeds, is mostly associated with small open patches among reeds or reed edge habitats.

The areas of Water Couch have been maintained by grazing. The relatively recent cessation of grazing has result in an increased rate of expansion of Common Reed as described in Section 4.4.1.

Left to existing processes, the majority of Hexham Swamp Nature Reserve would eventually be dominated by Common Reed and Swamp She-oak (Section 4.4.1). These communities support little habitat for waterfowl species or migratory waders, and would result in a reduced biodiversity in the Nature Reserve.

Under the proposed managed opening of the floodgates, the southern approximately half of the Nature Reserve would be subject to tidal inundation whereas much of the northern sections would not. While Common Reed and Swamp She-oak may persist in the north, these communities would be replaced in the south by more salt-tolerant communities, such as saltmarsh and mangroves (see Section 4.4). It is an objective of this proposal to maximize the area of saltmarsh, which would provide potential roost habitat for migratory waders. Some hypertidal ponds may also develop, and these may provide habitat for Black Swan but, otherwise, there would be little habitat for other waterfowl in the areas affected by saltwater inundation.

The proposal would also have the potential to encourage educational and research programs both within the Nature Reserve and on adjacent lands, thus forming a nexus with the second specific objective pertaining to Hexham Swamp: “to encourage educational and research programs into the values and management of estuarine and freshwater wetlands..” (see Section 2.7.5.3). An example of such a program would be the research proposed on the plant species *Zannichellia palustris* as part of the current proposal (see Section 6.4.2).

4.14.3 Aboriginal Archaeology

As outlined in Umwelt (2003), the Hexham Swamp Rehabilitation Project will not affect the stability or conservation status of Aboriginal sites in the area. No Aboriginal sites have previously been recorded in the low-lying sections of the swamp that will be affected by the re-inundation of saltwater. The proposal will restore the variety of wetland landscapes and the associated flora and fauna resources that would have been experienced and enjoyed by Aboriginal people in the past. Such landscapes and resources will be of cultural value to today’s Aboriginal community. Additionally, the restoration of a tidal environment is likely to improve the conservation status of Aboriginal sites still in existence on the swamp margins by restoring more of the original context of the site.

Umwelt (2003) explains that the Awabakal Local Aboriginal Lands Council (LALC) and traditional owners of the Hexham Swamp area are supportive of the proposal and are keen to become involved

in the rehabilitation process, wherever possible (eg weed removal, replanting, documentation). In this respect, future discussions should be held with the LALC regarding opportunities for further involvement.

One Aboriginal stone artefact scatter was located during the archaeological survey of the proposed Marsden Street bund location. The artefacts are not in-situ, being located at the base of a spur on a low ridge. The area has been disturbed by earthworks, cultivation and stock trampling. The Awabakal LALC has requested that the artefacts not be removed and the site be buried by clean imported fill during the construction of the bund. An application for a 'Consent to Destroy' an Aboriginal artefact for the site in accordance with Section 90 of the *National Parks and Wildlife Act 1974* should be submitted to DEC (NPWS) prior to construction of the bund.

4.15 Socio-Economic Impacts

Doing nothing in Hexham Swamp would not cause any impacts on the socio-economic context of the local environment. Opening the floodgates, however, is likely to have wide-reaching socio-economic impacts, following from changes to hydrology and vegetation communities. These impacts are discussed in the following Sections.

4.15.1 Quantification of Economic Impacts

4.15.1.1 Project Construction And Operation

Works associated with the project include construction of low level earthy bunds, earth fill, and installation of new floodgates on small drainage lines. These works total approximately \$700,000.

Operational costs would be relatively small and only marginally more than the existing operational costs for lowering the floodgates, particularly as the gates would be closed relatively infrequently (during significant floods in the Hunter River only).

4.15.1.2 Commercial Fishing

Discussions were held with three commercial fishermen who had worked in Hexham Swamp prior to construction of the floodgates in Ironbark Creek. Their knowledge of Hexham Swamp corroborated various scientific studies, which indicate that the swamp was a very important habitat and nursery for School Prawns, King Prawns, Mud Crabs, Blue Swimmer Crabs, Bream, Sea Mullet and Flathead, and other commercial species. The importance of Hexham Swamp to the overall fisheries of east-coast Australia was highlighted by the capture of a prawn in Moreton Bay (south-east Queensland), which was tagged at Hexham by Nick Ruella of DPI (Fisheries) prior to the floodgates being constructed (pers comm.. Ian Craig, Newcastle Fishermans Co-op, 2005).

After construction of the floodgates in the early 1970s, the migration / movement of prawns, fish and other aquatic species through Ironbark Creek to the Hunter River largely ceased. Since the construction of floodgates, commercial fishers noted that prawns are only caught in the South Channel after floods, whereas previously there were regular flows of prawns into the South Channel, particularly "on the moon". In addition, since about 1972, smaller quantities of King Prawn have been harvested in lower sections of the Hunter River. Major drainage and flood mitigation works,

together with large scale filling of tidal channels on and between islands, and construction of weirs in the Hunter River catchment were seen as primary causes of the decline in the King Prawn catch.

Historical prawn catch records for the period 1955 to 1992 are shown in Figure 4.12 (as taken from Pease *et al.*, 1995). This figure highlights the reduction in prawn catches from the Hunter River in the years following the construction of the Ironbark Creek floodgates. Whilst a decline in prawn catch was observed in the years following construction of the gates, this data does not provide unequivocal evidence that the gates caused the decline, as there may have been other factors also contributing to the difference, such as dominance of flooding in the river.

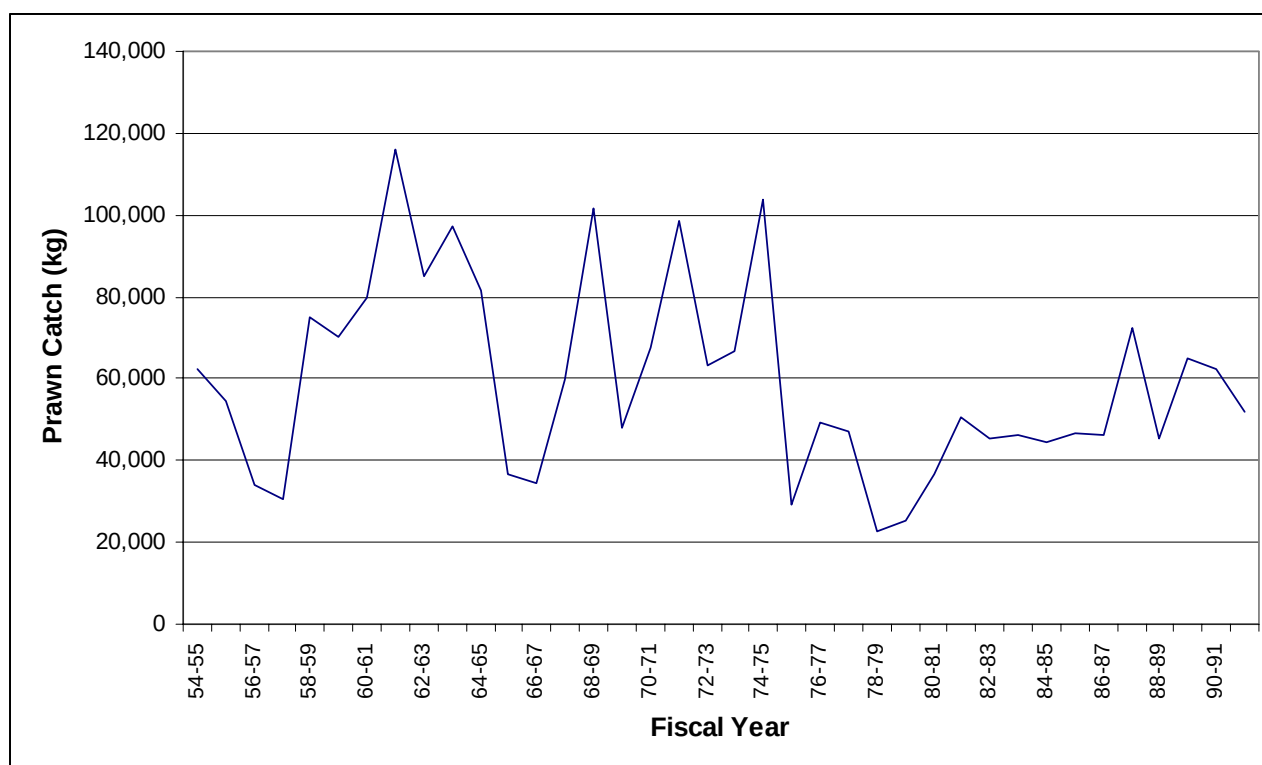


Figure 4.12 Prawn Catch Records for the Hunter River 1955 – 1992 (based on Pease *et al.*, 1995)

The commercial fishermen consulted as part of this study emphasised the importance of tidal flushing in Hexham Swamp. Tidal movements are needed to flush out silt in the creeks and free the creek systems of weed growth, which is clogging the waterways. Rising and falling tides also allow juvenile fish species to swim between shallow, warmer waters on the tidal fringe and deeper waters in the main creeks.

Evaluation of the impacts of rejuvenating Hexham Swamp for commercial fishing would require detailed estimation of the potential fish catch before and after raising the floodgates. Although there has been considerable scientific research of fish life above and below the floodgates in Ironbark Creek, such estimates have not been provided by the literature. However, research suggests that the main commercial species would re-colonise the swamp if the floodgates were raised.

The following discussion provides indicative estimates of economic benefits / disbenefits based on the likely increase in mangrove and saltmarsh areas in Hexham Swamp following opening of the floodgates, and recollections of commercial fishermen of fishing activity prior to the floodgates being installed.

Method 1: Existing literature values

In a study of mangrove productivity in Moreton Bay, Queensland, Morton (1990) estimated the value of commercial fish species utilising mangrove areas to be \$8,380/ha/yr (1990 dollars). Based on standard CPI increases over the past 14 years, this value would be approximately equivalent to \$12,150 in 2004. In a similar study in the United States, Constanza *et al.* (1997) estimated that both mangroves and saltmarshes provided a net economic value of US\$9,900/ha/yr, while seagrass areas have a value of up to \$19,000/ha/yr.

Williams *et al* (1998) estimate the total mangrove and saltmarsh resource in the Hunter estuary as approximately 2416 ha. If the floodgates were opened, the estuarine habitat area in the Hunter River catchment would ultimately increase by approximately 750 ha (approximately 30% of the total Hunter estuary habitat area (refer Section 4.4)). The net economic value of re-establishing some 750 ha of mangroves and saltmarshes would be in the order of \$9 million per year.

Method 2: Productivity changes method - based on estimated increase in productive mangrove and saltmarsh areas in Hexham Swamp

Method 1 is a clear over-estimate of the economic value of the rehabilitation project, as the actual value of the commercial fish take from the entire river is much less than that quoted by Morton (1990) and Costanza *et al.* (1997).

Commercial fish catch statistics for the Hunter River indicate that between 1971 and 1992, the quantities harvested in the Hunter River averaged 81 tonnes of fin fish and 69 tonnes of crustaceans, giving an average total catch of 151 tonnes per annum (Pease *et al* 1995). Based on wholesale fish prices of approximately \$4,000 per tonne for fin fish and \$10,000 per tonne for crustaceans, the value of the fish catch in the Hunter River has been averaging approximately \$1 million per annum.

Assuming that there is a direct relationship between productive habitat area and fish production, then a 30% increase in the total area of mangroves and saltmarshes in the Hunter estuary should correlate to an increase in the value of the fish catch by approximately \$300,000 per annum. This estimate should be considered as indicative only given the complex relationship between fish and their habitat (i.e. biological interactions are not taken into account, density-dependent relationships between fish and habitat are assumed etc.) and the duration over which the vegetation (and habitat) change will occur.

Method 3: based on fishing activity prior to construction of the floodgates

Important observations by the commercial fishermen regarding conditions prior to constructing the floodgates included the following:

- Between the mouth of Ironbark Creek and Shortland there were approximately 17 fishermen's shacks (some commercial fishermen and others recreational fishermen);

- At least 15 to 20 boats periodically worked deeper sections of Ironbark Creek; and
- Approximately two to five small scale fishing enterprises were largely dependent on fishing inside Hexham Swamp. Their activities included trawling and mesh netting lower sections of Ironbark Creek, and block netting tributary creeks.

Discussions with opinion leaders in the industry indicate that present incomes of small fishing enterprises in the Hunter River are approximately \$30,000 per annum after excluding expenses. Assuming that expenses are approximately 50% of gross sales, the total value of fisheries harvested from within the swamp was possibly in the order of \$60,000 per fishing enterprise. This would indicate that the value of the Hexham Swamp to the commercial fishing industry was up to \$900,000 per annum (i.e. \$60,000 x 15 boats) prior to installation of the floodgates.

Summary of Methods Considered

Three very different values of commercial fishing value have been determined using the three different methods described above. The calculated range for commercial fishing benefits is between \$300,000 and \$9 million per year, although the greatest confidence would be given to Method 2, yielding the lowest economic benefits.

For the purposes of economic assessment of the proposed rehabilitation of Hexham Swamp, a conservative approach has been followed, with an annual commercial fishing benefit of \$300,000 being adopted.

4.15.1.3 Recreational Fishing

There are strong indications that recreational fishing was of considerable importance in the Hexham Swamp in earlier years. In some studies, including the Department of Land & Water Conservation (1996) "Economic appraisal on the Kooragang Wetlands Rehabilitation Project", it has been assumed that the increased value of recreational fishing would be comparable to increased commercial fishing values. However, details of the incidence of recreational fishing and the quantities of fish caught by recreational fishermen in areas impacted by Hexham Swamp were not available to the current study.

Two methods of consideration of recreational fishing benefits were considered.

Method 1: Productivity changes method

NSW Fisheries (2002) conducted a survey of recreational fishers across NSW and found that approximately 1 in 5 people carried out recreational fishing including a total of 130,000 people in the Hunter area. The average annual investment for each recreational fisher was \$550.

As there are many waterways located within the Hunter district (including Lake Macquarie and Port Stephens), it was assumed that just 5% of the area's fishers (or 6,500) actually fish in the Hunter River estuary. With an expected fisheries productivity increase in the estuary of 30% (as discussed in Section 4.15.1.2), an equivalent 30% increase in recreational fishers utilising the estuary would equate to an extra 1,950 fishers, at a total investment of just over \$1 million per year (based on \$550 per fisher per year; NSW Fisheries, 2002).

Method 2: Proportion of Commercial Fishing Value

NSW Fisheries (2002) state that approximately 13 million finfish are taken annually by recreational fishers, which is approximately 30% of the commercial fish catch. However, where the bulk of commercial fishing is carried out offshore, the majority of recreational fishing is carried out within estuarine waters.

As stated in the Kooragang Wetlands Economic Appraisal (DLWC, 1996), research on the Clarence and Richmond Rivers by West (1992) indicates that the value of the recreational catch is at least as great as the value of the commercial fish catch.

For the conservative assumption of \$300,000 per year increased revenue for commercial fishing, it can be assumed that rehabilitation of Hexham Swamp would also add \$300,000 of value to the recreational fishing industry.

Summary of Recreational Fishing Methods Considered

Method 1 yields a total of \$1,000,000 per year, while Method 2 yields \$300,000. Again, adopting a conservative approach, a value of \$300,000 (based on Method 2) for recreational fishing value has been included in the economic assessment.

4.15.1.4 Tourism

Hexham Swamp is partially integrated with activities conducted by The Wetlands Centre at Shortland, which is located adjacent to the swamp. Important activities include canoeing on Ironbark Creek, interpreted walking tours and education visits, and bird watching. There would also be some scope for limited “catch and release” recreational fishing if saline fish species were to re-colonise Hexham Swamp. Discussions with the Centre indicate that present visitation levels are approximately 25,000 per annum, comprising about 80% from the region and 20% from Sydney and other areas external to the region.

The long term strategy for The Wetland Centre is to become the ‘gateway to the Lower Hunter Estuary wetlands’. The Centre hopes that a new marketing strategy would achieve a considerable increase in visitor numbers, with as many as 20,000 people attracted by the proposed Hexham Swamp Rehabilitation Project. Based on an average expenditure of \$10 per visit, the project would contribute an extra \$200,000 per annum to The Wetland Centre. However, as canoeing has become an important commercial activity for the Centre, the benefits of the Project to the Centre would be reduced if increased tidal flows in Ironbark Creek discouraged canoeing.

Given that the benefits of the Project to tourism would be based on a number of additional factors, such as marketing approaches and targets, and available facilities for tourists, economic inputs and outputs have been assessed with and without the impact of tourism.

4.15.1.5 Cattle Grazing

Method 1: Recent Sales and Former Stocking Rates

The land area formerly used for grazing enterprises within Hexham Swamp (prior to major land acquisition by the HCRCMA) was approximately 744 ha. This area carried approximately 500 adult

cattle equivalents (primarily cows or steers for finishing). Based on information obtained from the DPI (Agriculture) (December 2004), gross margin for finished steers is approximately \$250 - \$300 per head, giving a total of approximately \$140,000 per annum.

Method 2: Stewardship Payment for not Grazing

DPI (Fisheries) has also negotiated agreements with some cattle graziers on the NSW north coast for stewardship payments, associated with wetland rehabilitation (pers comm.. Sarah Fairfull, DPI Fisheries, 2005). In essence, landholders are paid to limit cattle grazing in freshwater / brackish wetlands to allow rehabilitation of these environments. Payments have been negotiated at between \$61 and \$130/ha/yr. Assuming that these payments define the 'grazing value' of wetland areas, based on a total of 744 ha at Hexham Swamp and an average rate of say \$100/ha/yr, the grazing value of Hexham Swamp would be approximately \$75,000.

Summary of the Methods Considered

Method 1 provides a high economic value of Swamp, although it is doubtful that 500 head of cattle could be supported on the Swamp except in good years. To maintain a conservative approach in the economic assessment, the value of cattle grazing within Hexham Swamp has been adopted as \$140,000. Note the higher number has been chosen as this is the maximum value that will be *lost* due to the rehabilitation project.

4.15.1.6 Estimation Of Direct And Flow - On Impacts

Impacts have been broadly quantified for the following measures of regional activity:

- Output: gross turnover in the regional economy;
- Value-added: incomes (wages, salaries and supplements paid to labour), gross operating surpluses of enterprises (return on capital and land), and indirect taxes net of subsidies.
- Employment: full year equivalents per annum.

To measure these impacts, input-output multipliers are applied to estimate direct and flow-on changes in these variables. The direct impacts relate to the initial change in output as estimated in the forgoing Sub-sections. Flow-on impacts measure the changes which occur as a result of inter-industry transactions and induced changes in household expenditure caused by changes in household incomes.

Input-output multipliers for the Hunter Region have not been published and were not available for this study. However, it is possible to provide broad indicative assessments of impacts based on known input-output multipliers for other regions in Australia. The impact analysis has been based on the following assumptions:

Direct impacts

- Output: based on estimates of costs and revenues from previous Sections.
- Value-added.
 - ◇ Cattle grazing. Approximately 56% of output, based on gross margin analysis.
 - ◇ Other sectors. Approximately 50% of output.

- Employment.
 - ◇ Construction. Approximately 3.5 person years for construction of the earth bunds and other works.
 - ◇ Grazing. Very small change because of integration into other grazing operations.
 - ◇ Commercial Fishing. No change as the number of fishing licences will not be increased.
 - ◇ Recreational Fishing. Approximately 5 persons per \$1 million of output.
 - ◇ Tourism. Approximately 10 persons per \$1 million of output.

Flow-on impacts

- Output: Approximately 100% of direct change in output.
- Value-added: 50% of flow-on change in output.
- Employment: Approximately 10 persons per \$1 million of change in output.

Estimates for each of the economic elements are provided in Table 4.13. Estimates in parentheses show total impacts less the impacts of expanding tourism opportunities.

From Table 4.13, it can be seen that the impact of the Proposal in Year 1 would be relatively high owing to the considerably greater outlays for the construction of low-level bunds and other minor filling (estimated cost of \$0.7 million). In Year 1, this would lead to total output expanding by about \$1.4 million, value-added by \$0.7 million, and employment by 10.5 full year equivalents. Impacts for later years show a net positive return, which is increased further if tourism is included in analysis. Even without tourism, the benefits associated with improved commercial and recreational fishing would still be significantly greater than the loss of grazing income.

Table 4.13 Input-output impacts

	Output \$'000			Value-added \$'000			Employment FT equivalents		
	Direct	Flow-on	Total	Direct	Flow-on	Total	Direct	Flow-on	Total
Year 1 only									
Construction	700	700	1,400	350	350	700	3.5	7	10.5
Year 2 only									
Grazing	-140	-140	-280	-78	-78	-156	Neg	-1	-1
Year 3+									
Grazing	-140	-140	-280	-78	-78	-156	Neg	-1	-1
Comm fishing	300	300	600	150	150	300	Neg	1.5	1.5
Rec. fishing	300	300	600	150	150	300	1.5	1.5	3
Tourism	200	200	400	100	100	200	2	2	4
<i>Sub-total</i>	660	660	1320	322	322	644	3.5	4	7.5
(No tourism)	(460)	(460)	(920)	(222)	(222)	(444)	(1.5)	(2)	(3)

4.15.2 Inundation of Private Properties

Numerical modelling estimates that up to approximately 750 hectares would be inundated (assuming a king tide occurrence in the swamp). Most of the king tide inundation would occur within the Hexham Swamp Nature Reserve (524 hectares), the Hunter Water land adjacent to the Shortland WWTW (27 hectares), Council-owned land to the north of the former Astra Street landfill (45 hectares) or Crown land associated with the waterways reserves (20 hectares). Approximately 140 hectares of inundation would occur on private property (all of which is zoned 7(b) under the new Newcastle LEP 2003). All of this private property affected by king tide inundation has been purchased, or is in the process of being purchased, by the Hunter-Central Rivers Catchment Management Authority.

In addition to the land that will be directly affected by tidal inundation, the Hunter-Central Rivers Catchment Management Authority has purchased, or is in the process of purchasing, easements over fringing private lands. In most circumstances, these easements extend to the 3.5m AHD contour, which is Council's flood planning level based on flood inundation from the Hunter River (refer Section 3.3.3.1). Easements to a level of 1.5m AHD have also been negotiated at a small number of properties around the swamp.

4.15.2.1 Land behind the Marsden Street Bund

The construction of a low-level bund between the end of Marsden Street and the Shortland WWTW will prevent saltwater inundation of private rural-residential properties that front onto Marsden Street and Alister Street. The construction of a bund was chosen as the preferred solution by the affected landholders as it will allow them to maintain their existing usage without being affected by a change in vegetation (which would result should saltwater be allowed to inundate the land).

In the long-term, an increase in groundwater levels associated with the proposal is likely to increase the susceptibility of the lowest-lying lands to saturation. Also, the construction of the bund would also retard the drainage of freshwater off this land following a catchment runoff flood event. Given that these low-lying lands are already mostly inundated by freshwater during the winter months, it is considered that the predicted change in groundwater levels would not have a significant detrimental impact on the overall existing usage of the land.

To cover the possible impacts of the proposal on the land behind the bund, the Hunter-Central Rivers Catchment Management Authority has purchased, or is the process of purchasing, easements over the affected lands. This easement essentially gives the CMA the right to inundate the land. Negotiated outcomes with landholders regarding easements over this land have factored expected hydrological and groundwater changes, and the associated impacts on vegetation and land usage.

Easements have also been purchased over other privately owned properties around the perimeter of the swamp. In general, easements have been purchased to a level of RL 3.5m AHD (which is equivalent to the 1 in 100yr ARI flood level in the Hunter River), or a level of 1.5m AHD (which has been adopted as the Project Boundary).

4.15.2.2 *The Wetlands Centre*

The Wetlands Centre contains a series of freshwater ponds that are disconnected from the existing Ironbark Creek system, and a brackish / saline channel that is connected to the creek (i.e. the Canoe Channel). The predicted changes to hydraulics within the swamp are not expected to impact on the existing freshwater pond habitats, as these areas are not directly connected to the estuary. The increase in elevation of the tide levels will not overtop the banks of these ponds, however, some maintenance may be required on surrounding access tracks to ensure they remain serviceable. This maintenance may include minor filling and raising of low sections of the tracks that traverse The Wetlands Centre (see Section 2.5.6). Some of these tracks are also utilised by Transgrid for servicing of the high voltage power lines that are located on the land adjacent to the Canoe Channel.

It is expected that the proposed changes to Hexham Swamp would be beneficial to The Wetlands Centre, as it would increase local diversity of habitats, and is expected to increase diversity of birdlife and other fauna utilising these modified habitats.

4.16 Recreational Activities

At present, there is not a large amount of recreational activities carried out in Hexham Swamp. Recreation is essentially limited to activities within The Wetlands Centre, which include walking, nature observation and canoeing. Canoes are hired from The Wetlands Centre, which can be used throughout the Hexham Swamp waterways.

The Project would potentially enhance many of the recreational activities that are associated with nature appreciation, as it will enhance the local biodiversity by improving the condition and increasing the extents of estuarine-based vegetation. However, the proposal will also result in a significantly increased tidal prism within the swamp, which will increase the tidal currents travelling through swamp waterways. This increase in tidal currents may be a potential disbenefit for canoeists as the increase in currents may prove difficult to navigate.

A potential mitigation measure may be to discourage such activities from the areas of greatest tidal current during the largest (solstice) tides and/or introduce gate management practices to reduce the total tidal prism, and hence reduce tidal currents during the biggest of the tides. This corresponds to proposed floodgate management for mosquito control (during the summer solstice period at least).

4.17 Services and Infrastructure

4.17.1 Main Northern Rail Line

The Main Northern Rail Line is highly unlikely to be impacted by inundation due to the proposed modification of the floodgate operation. Figure 4.13 shows the railway embankment levels along the 6.5 km section from the Kooragang Branch Line South Fork to the Hexham Bridge. The lowest point along this section is 2.0 m AHD, which is well above the 0.7m AHD peak tidal level in Ironbark Creek.

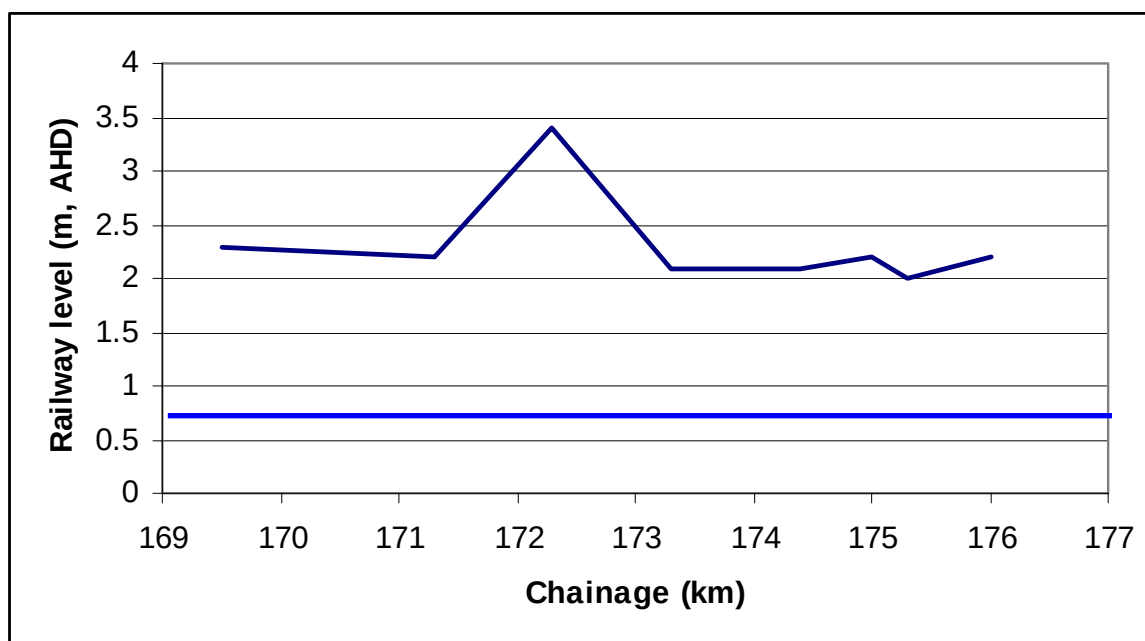


Figure 4.13 Level of Main Northern Railway

Local floods from the Ironbark Creek catchment would present the only flooding threat (if any) to the railway. As discussed in Section 4.1.2, opening of the floodgates would have a small impact on low-level frequent flood events. For large local catchment floods, where water levels in the swamp approach 2m AHD, the impact of the proposal would be insignificant.

Robert Carr and Associates (2001) assessed the geotechnical conditions of the rail embankment adjacent to the Ironbark Creek bridge. RCA determined that the rail embankment consisted of gravelly fill (rail ballast, coal chitter) overlying soft to firm clay. Fill was estimated to be up to 2.5 – 3m in depth along the rail line. Given the low bearing strength of the underlying clay, it is likely that consolidation of the rail line has occurred since its construction more than 150 years ago. Given the age of the structure, it is likely that current rates of consolidation would be small.

Modelling predictions indicate that low-lying areas adjacent to the rail embankment on southern side of Ironbark Creek would be subject to periodic inundation once the floodgates are opened. Depth of inundation adjacent to the embankment would generally be less than about 0.3 metres, and would remain some 1.5 metres below the top of the embankment. The tidal inundation would result in minor wetting of the base of the embankment structure. Given that the structure comprises gravelly fill, the periodic wetting is unlikely to dislodge any material or compromise the structural integrity of the embankment.

However, inundation may affect the access track that runs adjacent to the railway line between Sandgate and Ironbark Creek (south side). While specific ground levels of the track are unknown, it

is considered that any localised low areas in the track could be addressed by minor filling with coarse aggregate (refer Section 2.5.7). Similar filling of low-lying section of the access track adjacent to Hunter Water's Chichester pipeline is also proposed (refer Section 2.5.5).

Opening the floodgates is also likely to raise groundwater levels by approximately 0.2 to 0.3 metres, particularly in areas close to Ironbark Creek. Given that primary consolidation of the embankment would already be complete (due to the age of the structure, see RCA, 2001), changes in groundwater level are unlikely to alter the foundation capacity of the embankment or the future rates of creep consolidation.

Also, tidal inundation of lands adjacent to the rail embankments would have been common prior to construction of the floodgates in the early 1970s. Therefore, it is expected that the embankment would already be fully adjusted to the hydrological conditions that will result once the floodgates are opened.

4.17.2 Power Transmission Lines

High voltage power transmission lines, owned and maintained by Transgrid, traverse through Hexham Swamp, located adjacent to the Canoe Channel and Ironbark Creek. The towers that support the power lines are elevated above the typical ground level of the swamp, while the access service track between the towers is also elevated (refer Section 3.13.2).

Given the existing floodprone nature of the swamp, the pads at the base of the towers and the access track would be periodically inundated by floodwaters, derived both from the local catchment, and from the Hunter River during large flood events (wherein floodwaters overtop the floodgates and the Pacific Highway road embankment).

As the access track and the towers are elevated above the typical swamp level, they will not be significantly impacted by the proposed increase in tidal levels within the swamp. Consequently, no specific mitigation measures are considered necessary, although monitoring of water levels with respect to the crest level of the access track should be undertaken. If it is found that isolated low sections of the track become inundation by tidal waters in the future, then minor filling and raising of the track should be carried out. Similar works are proposed for the access tracks within The Wetlands Centre and beside the Chichester water supply pipeline.

4.17.3 Water Supply and Wastewater Pipelines and Treatment Facilities

As discussed in Section 3.13.1, the main Chichester water supply pipeline transects Hexham Swamp. This pipeline services the city of Newcastle with water from Chichester Dam, on the upper reaches of the Williams River. The pipeline itself is supported on concrete saddles, and is mostly elevated above the ground level of the swamp. The pipeline has been in place since the 1920s, and is currently being considered for replacement by Hunter Water.

With respect to impacts, the primary consideration is related to access along the service track that runs parallel to the pipeline. This track has a number of low sections, which may be subject to periodic tidal inundation when the gates are opened. Section 2.5.5 described works associated with raising the level of the track in order to mitigate any impacts of serviceability of the pipeline. The

main avenue for mitigation involves raising the level of the track, and thus maintaining accessibility along the track, using compacted coarse aggregate. Locations and quantities of material required to 'top up' the Hunter Water access will be finalised during on-site inspections at the time of the works.

The proposed works are unlikely to have a significant impact on the foundation capacity of the concrete saddles that support the pipeline. Given that the pipeline has been in place for approximately 80 years, it is considered that consolidation of the ground under the saddles would have mostly occurred already, particularly during the more saturated ground conditions that prevailed in the swamp prior to construction of the floodgates.

Differential settlement of the saddles has required on-going maintenance of the structure by Hunter Water over the past 80 years. Returning tidal waters to the swamp is not considered to impact on the maintenance requirements (although given the age of the structure, it is likely that increasing levels of maintenance will be required in the future, and hence a greater reliance on the service track adjacent to the pipeline).

4.17.4 Air Transport Services

The Wallsend airstrip, located within Hexham Swamp near its southern boundary, provides air transport services to a small number of privately owned aeroplanes. The airstrip is a relatively poor condition (refer Section 2.5.4) and is only marginally elevated above the surrounding swamp ground levels.

Works proposed at the Wallsend airstrip include raising and resurfacing of the runway (refer Section 2.5.4). The airstrip would be raised by 0.2 to 0.25 metres at the northern end and 0.1 to 0.15m at the southern end (ie a minimum resurfacing cover) using coarse to medium aggregate (possibly chitter, sourced locally from mine sites). These works would mitigate any impacts on air services associated with an increase in groundwater levels as a consequence of opening the floodgates (as discussed in Section 4.3.2.3).

4.17.5 Landfill

The impacts of the proposal on former landfill areas within and surrounding Hexham Swamp have been discussed in Sections 4.2.4 and 4.3.2. In summary, the increase in peak tidal level within Ironbark Creek is insufficient to overtop existing leachate collection ponds around the landfill site, while the increase mean water level will reduce the groundwater gradient between the landfill and the adjacent natural waterways, thus reducing the flux of polluted leachate to the external environment.

An increase in the degree of tidal flushing within Ironbark Creek would also increase the capacity of the system to assimilate and disperse pollutant that find their way into the environment, thus improving water quality within Hexham Swamp. Minor increases in pollutants may, however, occur within the Hunter River adjacent to Hexham Swamp (with the greater evacuation of pollutants from the swamp), as discussed in Section 4.2.

4.17.6 Radio Towers

Three radio tower sites are located within or adjacent to Hexham Swamp: BAL, 2KY and 2HD. Predictive modelling of the swamp hydraulics (refer Section 4.1.2.3) indicates that only the BAL site

would be affected by the proposal. The BAL site is located immediately adjacent to the floodgates, at the downstream end of the swamp. The site is surrounded by low-lying land that would be inundated by saltwater following opening of the gates. As a mitigation measure, a low-level earthen bund will be constructed around the towers (refer Section 2.5.2). Drainage from behind the bund will be achieved via one-way flapgates on the existing drainage paths. Construction of the bund will be sufficient to prevent any adverse impacts of the proposal on the BAL radio towers and their associated buried earthen cables.

The 2KY towers are located beyond the extents of predicted saline intrusion. The main impact that would be experienced by the 2KY site would be a possible small increase in groundwater levels, experienced over the long-term. Given that the radio tower sites have been selected specifically in swampy areas on the basis of shallow groundwater levels, it is considered that any change to the groundwater level would not have a detrimental impact on the broadcast operations (providing that the groundwater remains predominantly freshwater).

As a mitigative measure for the 2HD site, one-way flapgates are recommended on the downstream side of the culverts under the R&H Transport access road, located immediately downstream of the 2HD ponds. These flapgates, which will be attached to the headwall of the culvert, will allow drainage from the 2HD ponds, but will prevent backwater inundation from the swamp (refer Section 2.5.10). The gates would fully seal flow through the culverts from the downstream side, but would swing open when discharging flows from the upstream side.

5 ALTERNATIVES AND PROJECT JUSTIFICATION

This chapter presents and assesses a range of alternatives to the Project, and compares them to the existing (do nothing) condition with regard to economic, environmental and social factors (i.e. the Triple Bottom Line). Following the assessment of alternatives, justification is given for proceeding with the preferred option, along with a cross-check against the general principles of Ecologically Sustainable Development (ESD).

5.1 Project Alternatives

There are few alternatives to the Project as such, as the floodgates are either open (under the proposed scenario), or closed (under the existing scenario). Alternatives are essentially limited to the number of gates open, the proposed operation of the floodgates, and the extent of ancillary works that are carried out as part of the Project.

Alternatives investigated were as follows:

- Option 2: **One gate open.**
- Option 3: **Eight gates open**, but with no bunding of selected private properties (and instead, outright purchase of private lands or easements over land to be inundated).
- Option 4: **Eight gates open – king tides excluded**, and again no bunding of selected private properties (assuming that alternative arrangements will be made regarding inundation of private lands).
- Option 5: **Eight gates open – with bunding of selected properties**, but no exclusion of king tides

Note that the do nothing scenario is referred to as *Option 1*, and the proposed works, which incorporates eight gates open with bunding and likely exclusion of the king tides (especially during summer months when mosquitoes are active), is referred to as *Option 6*.

5.1.1 Economic Assessment

5.1.1.1 Introduction

An economic analysis was conducted to assess the incremental economic costs of the Project with the Project's potential economic benefits. It provides a rationale for comparing the different options considered, including the do nothing option (Option 1).

Not all benefits and incremental costs can be quantified, thus the results have been qualified as appropriate. It has also been beyond the scope of this study to conduct various surveys to measure benefits which are not readily measured by the market, including the values to the community relating to securing a natural environment for present and future generations (existence and bequest values) and options for future direct use (option values).

There is also some uncertainty regarding the benefits of the Project for recreational activities promoted by The Wetlands Centre at Shortland. Therefore, results are shown with and without incremental tourism benefits incorporated in the analysis for comparative purposes.

It has been assumed that the project would be conducted over a 30 year period (the expected design life of proposed capital works). All benefits and incremental costs are discounted over this period at a real discount rate of 7% per annum. Sensitivity analysis was conducted to test for adverse changes in costs and benefits and variations in the real discount rate.

5.1.1.2 Assessment of Incremental Costs

Capital costs

Costs of constructing the bunds and other infrastructure works have been estimated to be approximately \$700,000. It has been assumed that these costs would be mostly incurred in Year 1 of the project.

For Option 2 (1 gate open), only infrastructure works in the immediate vicinity of Ironbark Creek were included in the costs. This included the Marsden Street bund, local fill areas and floodgates on some drainage channels.

For Options 3 and 4 (no bund) all works were included with the exception of the 700 metre long bund at Marsden Street.

For Options 5 and 6 (with bund), all works were included as described in Section 2.5.

Property and Easement Costs

Costs associated with purchase of farmlands within Hexham Swamp and purchase of easements over fringing non-farming lands have been provided by the Hunter-Central Rivers Catchment Management Authority. Purchase of land title within the swamp totals \$2.9 million. Purchase of easements over lands behind the Marsden Street bund has been estimated at \$210,000, while other easements around the Swamp are estimated at approximately \$90,000 (pers comm.. S. Vernon, HCRCMA, 2005). Purchase of land behind the Marsden Street bund has been estimated by the State Valuers Office at \$1.5 million (pers comm.. R Eldridge, Department of Commerce, 2005).

For Options 2, 5 and 6, which include the construction of the Marsden Street bund and purchase of easements behind the bund, the total cost of property and easement purchases is approximately \$3.2 million.

For Options 3 and 4, which do not include the Marsden Street bund, and therefore, require additional property purchase along Marsden Street, the total cost of property and easement purchases is approximately \$4.5 million.

5.1.1.3 Assessment of Economic Benefits

The two major benefits considered in the analysis comprised tourism benefits; and fishing benefits. Other benefits could not be quantified. However, with the possible exception of mosquito control, most non quantified benefits would be positive. Negative benefits associated with loss of grazing

benefits on farmland in Hexham Swamp have been offset by the purchase costs of these lands in Year 1 of the analysis. Quantified benefits are briefly discussed below.

Tourism benefits

Potential incremental increases in tourism revenues have been estimated at approximately \$200,000 per annum. The economic benefit has been assumed to be approximately \$100,000 per annum allowing for an incremental increase in operating costs of about 50% of revenues. These benefits would accrue in Option 2. For Options 3 to 6, control of tidal flows within Ironbark Creek would be critical to realising these benefits. The analysis allows for cases with and without tourism benefits to account for the uncertainty in these benefit values.

Fishing benefits

Estimation of fishing benefits is based on the expected returns for commercial and recreational fishing enterprises that would be benefited by restoring the fish habitat in Hexham Swamp. The expected increases in commercial fish catch from Year 3 have been estimated at \$30,000 per annum for Option 2 and \$300,000 per annum for Options 3 to 6, while the same economic benefits are assumed for improved recreational fishing opportunities in the estuary.

It has been assumed that the incremental operating costs associated with the increased catch would be approximately 50% of gross revenues. The total (commercial and recreational) benefits have been estimated at \$30,000 per annum for Option 2 and \$300,000 per annum for Options 3 to 6.

5.1.1.4 Cost Benefit Analysis

Cost benefit analysis has been based on the following assumptions:

- Project life: 30 years;
- Residual values: set at zero at the end of the project life;
- Real discount rate: 7% per annum, and 10% for sensitivity analysis.

Costs and benefits were as discussed in the previous Sections. All capital costs would be incurred in Year 1. Costs of property and easements purchases would also be incurred in Year 1. Tourism and fishing benefits would be incurred from Year 3. Sensitivity analysis has allowed for a 20% increase in costs and a 20% decrease in benefits.

To determine the economic efficiency of each intervention option (Options 2 to 6), discounted cash flow analysis was applied to projected incremental cost and benefit streams (being net of expected costs and benefits projected for Option 1 - the base case). The results are presented in Table 5.1.

From the cost benefit analysis, it is evident that the costs of purchasing land along Marsden Street are more than the costs of constructing a bund and purchasing easements over the properties. Consequently, the economic returns of Options 5 and 6 are greater than those for Options 3 and 4.

Apart from normal assumptions for Options 5 and 6 (including tourism), economic returns for all options would be negative, owing to the relatively high costs associated with property and easement purchases, which would not be offset by benefits in fishing and tourism within the 30 year analysis period. For Options 5 and 6, however, when adopting normal assumptions, a positive economic

return would be achieved within 30 years, although this is reliant upon achieving the tourism benefits associated with rehabilitation of the swamp (refer Table 5.1).

Table 5.1 Cost Benefit Analysis and Sensitivity Analysis

Assumptions:	With tourism benefits incorporated			Without tourism benefits incorporated		
	NPV \$'000,000	BCR (ratio)	NPVI (ratio)	NPV \$'000,000	BCR (ratio)	NPVI (ratio)
Option 2						
(1) Normal assumptions of analysis	-2.22	0.38	-0.62	-3.28	0.09	-0.91
(2) 10% real discount rate pa	-2.50	0.29	-0.71	-3.27	0.07	-0.93
(3) 20% increase in costs	-2.94	0.32	-0.68	-4.00	0.07	-0.93
(4) 20% decrease in benefits	-2.50	0.31	-0.69	-3.34	0.07	-0.93
(5) Worst case (2),(3),(4) combined	-3.40	0.19	-0.81	-4.02	0.04	-0.96
Options 3 and 4						
(1) Normal assumptions of analysis	-0.06	0.99	-0.01	-1.12	0.74	-0.26
(2) 10% real discount rate pa	-1.11	0.74	-0.26	-1.87	0.55	-0.45
(3) 20% increase in costs	-0.92	0.82	-0.18	-1.98	0.62	-0.38
(4) 20% decrease in benefits	-0.91	0.79	-0.21	-1.75	0.59	-0.41
(5) Worst case (2),(3),(4) combined	-2.56	0.49	-0.51	-3.17	0.37	-0.63
Options 5 and 6						
(1) Normal assumptions of analysis	+0.60	1.16	0.16	-0.46	0.87	-0.13
(2) 10% real discount rate pa	-0.47	0.87	-0.13	-1.24	0.65	-0.35
(3) 20% increase in costs	-0.13	0.97	-0.03	-1.19	0.73	-0.27
(4) 20% decrease in benefits	-0.25	0.93	-0.07	-1.10	0.70	-0.30
(5) Worst case (2),(3),(4) combined	-1.79	0.58	-0.42	-2.41	0.43	-0.57

NPV Net Present Value (Present value of net benefits).

BCR Benefit cost ratio (Present value of benefits divided by present value of costs).

NPVI Net Present Value to Investment ratio (NPV divided by potential costs incurred by a public authority).

When comparing Options 3 and 4, (and likewise when comparing between Options 5 and 6) the principal difference relates to the benefits of controlling mosquito populations (not quantified). Prima facie, Option 6 should be the superior option, provided the costs of controlling the highest tides during the summer solstice season do not outweigh the additional benefits of mosquito control.

Sensitivity analysis was conducted to determine the robustness of the project against adverse changes in key parameters and assumptions. Options 5 and 6 appear to be the most likely options to yield positive economic returns. These options still yield positive economic returns (i.e. $BCR \geq 1.0$) for real discount rates up to 8.5% per annum, or when costs increase by up to 15%, or when benefits are reduced by up to 15% (assuming that tourism benefits are realised by the project).

This analysis suggests that the economic justification for the Project is marginal within a 30 year period. However, if all non-quantifiable benefits were incorporated, and the project was considered over longer timeframes, the economic return of the Project, and the robustness of the economic justification, would improve considerably.

5.1.1.5 Outcomes of Economic Assessment

The Hexham Swamp Rehabilitation Project is expected to generate a range of impacts. Most impacts are expected to be positive. Major negative impacts would include the loss of grazing opportunities for beef cattle on swamplands, however, this has been offset by the purchase of farmlands within Hexham Swamp by HCRCMA or the filling of such lands to prevent inundation. Other potential negative impacts include mosquito nuisance, although as discussed in Section 4.9.3, the major impact on mosquitoes would relate to a change in dominant species, rather than any quantifiable increase or decrease in numbers.

Major positive impacts include the re-establishment of a saline habitat for fish and various plant species. There should be substantial commercial advantage of restoring the habitat. The additional value of commercial fish produced should increase by at least \$300,000 per annum when all eight tidal gates are opened. Also, recreational fishing should benefit to a value roughly equivalent to the commercial fishing benefits (i.e. \$300,000 per year). In addition, regional tourism should benefit. The Wetlands Centre is developing an important educational and recreational facility adjacent to Hexham Swamp. The Project should enhance the Centre's development programmes provided tidal inundation does not significantly interfere with various recreational activities including canoeing.

The economic analysis indicated that Option 6 (the proposed option) would probably yield the highest economic returns, and assuming normal economic parameters, should yield a positive economic outcome, thus offsetting the initial costs of land and easement purchases and on-ground works, within approximately 22 years.

5.1.2 Environmental Benefits and Disbenefits

In addition to the tangible economic benefits and costs discussed in Section 5.1.1, there are also a range of intangible environmental benefits and disbenefits associated with the various options / alternatives. Table 5.2 provides a summary of these intangible environmental considerations, when compared to the do-nothing option (Option 1).

Major environmental benefits are generally associated with improved water quality, reduced sedimentation, re-establishment of estuarine vegetation and habitats, and reduced acid sulfate runoff potential. Major environmental disbenefits are generally associated with reduced freshwater habitat and potential increase in mosquito breeding habitat.

Table 5.2 Summary of Environmental Benefits and Disbenefits (compared to the do nothing option: Option 1)

Option	Environmental Benefits	Environmental Disbenefits
2	- Improved water quality - Reduced sediment accumulation - Improved aquatic fauna habitat - Minor re-establishment of saltmarshes and mangroves - Minor reduction in acid sulfate runoff potential	- Minor reduction in existing freshwater reed habitat - Minor increase in potential mosquito breeding habitat
3	- Improved water quality - Reduced sediment accumulation - Improved aquatic fauna habitat - Re-establishment of saltmarshes and mangroves - Promotion of new aquatic fauna breeding and feeding habitat - Reduction in acid sulfate runoff potential	- Reduction in existing freshwater reed and pasture habitat - Increase in potential mosquito breeding habitat
4	- Improved water quality - Reduced sediment accumulation - Improved aquatic fauna habitat - Re-establishment of saltmarshes and mangroves - Promotion of new aquatic fauna breeding and feeding habitat - Reduction in acid sulfate runoff potential	Reduction in existing freshwater reed and pasture habitat
5	- Improved water quality - Reduced sediment accumulation - Improved aquatic fauna habitat - Re-establishment of saltmarshes and mangroves - Promotion of new aquatic fauna breeding and feeding habitat - Reduction in acid sulfate runoff potential	- Reduction in existing freshwater reed and pasture habitat, except behind bunded areas - Increase in potential mosquito breeding habitat
6	- Improved water quality - Reduced sediment accumulation - Improved aquatic fauna habitat - Re-establishment of saltmarshes and mangroves - Promotion of new aquatic fauna breeding and feeding habitat - Reduction in acid sulfate runoff potential	Reduction in existing freshwater reed and pasture habitat, except behind bunded areas

- Option 2: One gate open
- Option 3: Eight gates open, but with no bunding of selected private properties
- Option 4: Eight gates open – highest tides excluded, and again no bunding of selected private properties
- Option 5: Eight gates open – with bunding of selected properties, but no exclusion of high tides
- Option 6: Eight gates open with bunding and exclusion of the highest tides [**the proposed option**]

5.1.3 Social Benefits and Disbenefits

Social considerations for the various options associated with the Hexham Swamp Rehabilitation Project are integrally linked with the economic and environmental considerations, as the local community appreciates both the existing economic (commercial) value of the land as well as its existing and potential future environmental values.

Several public meetings were held with the local communities to canvass their opinions and concerns regarding the Project. Regarding the options presented in this Chapter, the main issue that differentiates social considerations is the bunding of private lands (as included in Options 5 and 6). Landowners in the Marsden Street area supported the option to retain private ownership of the low-lying land, protecting them from inundation by a low bund adjacent to Ironbark Creek. Therefore, Options 5 and 6 were considered to be more favourable from a social perspective than Options 2, 3 and 4.

5.1.4 Summary of Alternatives

From the assessment of economic, environmental and social considerations, as described in the Sections above, it appears that Option 6 (the proposed option) is superior to the other options on a number of grounds, including social acceptance and maximising environmental benefits and future ecological opportunities. Although not economically positive using known tangible and quantifiable inputs, Option 6 has the greatest potential to yield a net positive economic outcome when intangible benefits are incorporated. Further justification for selecting Option 6 as the preferred approach is given in Section 5.3.1.

5.2 Consistency with Principles of Ecologically Sustainable Development (ESD)

As well as considering the general environmental, social and economic implications, it is important to ensure that the preferred option (Option 6) for the Project is justified in terms of the principles of Ecologically Sustainable Development (ESD).

The principles of ESD have been discussed previously in Section 1.3.3, and are summarised in **Appendix C: Volume 2**. The ESD principles are:

- The precautionary principle;
- Social equity, incorporating inter-generational equity;
- Conservation of biological diversity and ecological integrity;
- Improved valuation and pricing of environmental resources.

Each ESD principle has been considered for Option 6 (the preferred option), as well as the alternative options. The results of the assessment are presented in Table 5.3. From the assessment, it can be concluded that Option 1 (do nothing) is the least consistent with the principles of ESD. This is because all other options are focussed on restoration of former environmental values, which is a key aim of ESD.

Table 5.3 Consideration of ESD Principles

Option 1	Precautionary Principle	Inter-generational Equity	Biodiversity and Ecol. Integrity	Improved pricing and valuation
1 (existing case)	Adopting the do-nothing option can be considered as precautionary. However, given that the Project is for environmental restoration works, such uncertainty should not be used to prevent rehabilitation of the environment when contingency measures can be developed and implemented as necessary.	The do-nothing option would not result in a change to the inter-generational equity, as future generations would experience current day social and environmental conditions.	Construction of the floodgates resulted in dramatic reduction in estuarine habitats within Hexham Swamp. This option (do nothing) would maintain the existing reduced level of diversity (dominantly freshwater) or would result in even less biodiversity as the Phragmites swamp continues to invade freshwater swamps and (degraded) mangrove habitats	This option would not alter the pricing or valuation of environmental resources.
2 (1 gate open)	Opening one floodgate would be consistent with the Precautionary Principle, as it would represent a step towards environmental rehabilitation, but allows for assessment and monitoring of impacts without inducing significant modification to vegetation communities and habitat structure.	The current generation has received improved economic benefit from the Swamp at the expense of environmental values. Opening one gate would restore some of the former environmental values to future generations, while future economic losses have been met by land and easement purchase.	This option would result in the restoration of some of the former estuarine habitat that was lost when the floodgates were first constructed 30 years ago. The swamp would be used more by aquatic fauna, including prawns and juvenile fish.	Adoption of this option would mean that the environmental benefits offset the negative economic results. Based on a liberal assumption for economic tourism and fishery benefits, the environmental benefits would need to total at least \$2.22 million to offset economic losses (refer Table 5.1).
3 (8 gates, no bund)	Option 3 is the least precautionary option, as it involves opening all eight floodgates with minimal contingency measures. Under this option, most existing privately owned lands that would be inundated would need to be purchased (thus adding additional expense to the Project). Nonetheless, this option is still consistent with the Principle as it does not allow scientific uncertainty to delay environmental restoration works.	This option does not involve depletion of natural resources, apart from loss of some low-lying grazing lands. Future generations should expect to have an improved standard of living following implementation of this option due to the improved natural resources and increased biodiversity associated with the rehabilitated swamp area.	Opening all 8 floodgates would result in the restoration of former estuarine habitat within Hexham Swamp. Restoration of former habitats would increase local biodiversity, as it would attract saltwater dependent species to the area which were previously dislodged due to the dominant freshwater reed habitat. The restored habitat would be significant on a local and regional scale, and would supplement rehabilitation on Kooragang Island.	Adoption of this option would mean that the environmental benefits offset the negative economic results. Based on a liberal assumption for economic tourism and fishery benefits, the environmental benefits would need to total just \$60,000 to offset economic losses (refer Table 5.1).

Option 1	Precautionary Principle	Inter-generational Equity	Biodiversity and Ecol. Integrity	Improved pricing and valuation
4 (8 gates, no bund, but high tide exclusion)	This option would be more precautionary than Option 3, as uncertainties associated with mosquito breeding in infrequently inundated depressions would be avoided.	Same as Option 3 above	This option is essentially the same as Option 3 above, except that exclusion of the highest tides would limit breeding of mosquitoes and other species dependent on shallow ponded waters.	Same as Option 3 above
5 (8 gates, with bund)	This option would also be more precautionary than Option 3, as a bund is proposed to protect private properties in the Marsden Street area from saltwater inundation. The option allows for the rehabilitation of the swamp without compromising the rural-residential value of the area.	This option involves the construction of a bund to protect privately owned lands from saline inundation. The bund protects the interests of the current and future generations, ensuring that the privately owned lands are able to be utilised in the same manner as currently used.	Bundling off some of the swamp to saline inundation would reduce the potential for rehabilitation of former habitats. However, the area that would not be inundated is small compared to the area that will be rehabilitation by opening the gates.	Adoption of this option would mean that the environmental benefits offset the negative economic results. Based on a liberal assumption for economic tourism and fishery benefits, the project would be economically positive within 22 years (refer Table 5.1), and as such, would not require the intangible environmental benefits to be considered as part of the economic justification for the works.
6 (8 gates, with bund and high tide exclusion)	This option is the most cautious option, being more conservative than Option 3, Option 4 and Option 5, as it incorporates contingencies associated with mosquito control and saline inundation of private rural-residential lands.	Same as Option 5 above	Once again, this is essentially the same as Option 5 above, but without the shallow ponded saltwater habitats that are favourable to mosquitoes.	Same as Option 5 above

Option 2 (one gate open) is considered to be consistent with all four principles of ESD, however, when compared to the remaining options, Option 2 does not provide the same degree of biodiversity and ecological integrity.

Options 3, 4, 5 and 6 are considered to equally consistent with the ESD principles. For Options 3 and 4, the slightly less precautionary approach (due to the fact that no bund is constructed in the Marsden Street area) is counterbalanced by the slightly better biodiversity and ecological integrity (due to a greater area being rehabilitated).

For Options 3, 4, 5 and 6, the staged opening of the floodgates provides further precaution to the Project, which will enable adaptive management of the inundation through regular monitoring of the water levels and inundation extents throughout the swamp.

5.3 Project Justification

5.3.1 Preferred Option

The various options were considered from an economic, environmental and social perspective (i.e. the Triple Bottom Line).

- **Economics: Options 5 and 6** was the most favoured options, as they provided positive economic return (within a period of 22 years, based on normal economic assumptions and inclusion of tourism and recreational fishing benefits).
- **Environmental / ESD:** Options 3, 4, 5 and 6 all provided significant environmental benefits, however, **Options 4 and 6** may be slightly more preferred due to their mosquito management strategy.
- **Social: Options 5 and 6** were preferred, as they incorporated the construction of a bund in the Marsden Street area, which enables local landholders to retain their land and retain existing usage of this land in the future.

Based on the above, Option 6 was considered to be the best option, and as such, has been adopted as the preferred approach for rehabilitation.

In comparing Options 2 and 6, there appears to be advantages (quantifiable and non-quantifiable) to open all eight gates in the long run, despite the difficulties with predicting the precise impact of opening the gates. However, in order to minimise the risk of unforeseen and undesirable side effects, it is proposed to open the gates in a step-wise manner, enabling the potential impacts of the opening to be closely monitored and effectively managed. This process is described in detail in Section 2.4, and starts with the opening of just one gate.

The initial one gate opening would allow for a period of monitoring and calibration such that the impacts of opening further gates can be predicted with greater precision than currently is the case. Such monitoring would provide opportunities for advancing wetland science and community education and, as such, would provide a benefit in itself.

A comprehensive monitoring program is an integral part of the proposal. The program would comprise of monitoring of fauna, flora, water quality, groundwater, wetlands hydraulics and extent of inundation to ensure that:

- Tidal inundation does not extend to privately owned land;
- Rehabilitation occurs in an orderly and manageable fashion;
- Total conservation value is maintained or improved, but not diminished.

Further details of the monitoring program are provided in Section 6.9.

5.3.2 Consequences of the Do-Nothing Option

The consequences of selecting Option 1 (the do-nothing option) have been described in Section 4 and Section 5.1 as a benchmark for assessment of the proposed works and alternative options. In summary, Option 1 (doing nothing) would result in the following consequences:

Advantages of doing nothing:

- The incidence and extent of tidal inundation would remain as under current conditions, allowing farming to continue within the study area;
- Mosquito nuisance would remain at current levels;
- Species found within the study area which are listed under *the Threatened Species Conservation Act 1995* would continue to be able to utilise Hexham Swamp under existing conditions until these would change as a consequence of ecological succession processes.

Disadvantages of doing nothing:

- Water quality within Ironbark Creek and its tributaries would continue to be degraded, with elevated nutrient levels and primary productivity;
- Sediment would continue to be trapped within Hexham Swamp, slowly infilling the channels and waterways of the swamp;
- Ecological succession would continue to alter the existing habitats, resulting in increased homogeneity and paucity in species diversity, thus diminishing the value of the Hexham Swamp Nature Reserve;
- Fisheries and tidal water habitat values would continue to be lost, contravening the intent of the SEPP 14 designation of Hexham Swamp;
- Opportunities for improved fire control would be lost;
- Weeds such as alligator weed would continue to pose control problems;
- Visual enhancement, recreational and tourism opportunities would be lost;
- Scientific and educational opportunities would be lost;

- Doing nothing would contravene the intent of the NSW Wetlands Management Policy and Action Plan, the Hexham Swamp Nature Reserve Plan of Management and the Ironbark Creek Total Catchment Management Strategy.

Based on the above information, it is considered that the 'do-nothing' option (Option 1) does not provide an environmentally positive outcome for Hexham Swamp. Given that rehabilitation of degraded wetlands, their habitats and processes is one of the key principles of the NSW Wetlands Management Policy, it is recommended that opening of the Hexham Swamp floodgates proceed (using the preferred option [Option 6]), in a staged manner, to enable effective monitoring, and future adaptive management of the inundation extents.

5.3.3 Likelihood of Successful Rehabilitation

Each ecosystem is a unique combination of a large number of highly variable environmental factors including physical parameters (*eg* temperature, radiation), chemical characteristics (*eg* nutrients and metals) and biological factors (*eg* flora, fauna, and microbes). To predict what would occur to a stable ecosystem as a result of a particular stressor is difficult in the context of this complexity, and predictions of environmental impacts in natural ecosystems therefore usually consist of educated estimates. To predict what would happen in an ecosystem already in a state of flux, however, such as the Hexham Swamp system, is considerably more difficult.

Not only is the Hexham Swamp ecosystem unique and in flux, there is also little experience in Australia with estuarine wetland rehabilitation. Most of the wetland literature focuses on North American examples, where emergent wetlands associated with open (pond) water appear to provide the best opportunity for success (Brooks 1993). A very successful restoration program was conducted by the California Coastal Conservancy (Josselyn and Chamberlain 1994). However, on the whole, wetland rehabilitation is a relatively recent phenomenon and long term results of wetland rehabilitation (particularly with respect to wetland functioning) are still scarce.

Within NSW, the only major wetland rehabilitation project undertaken in recent years is the Yarrahapinni Wetland Rehabilitation Project. This project involved the rehabilitation of approximately 600 hectares of degraded estuarine wetland habitat located behind flood mitigation structures at Yarrahapinni Wetland, near Stuarts Point on the mid north coast of N.S.W. The overall aims of the Project were to rehabilitate the wetland, enhance fishery habitats, and raise community awareness of the value and importance of estuarine wetlands. The first floodgate was opened in the Yarrahapinni Wetland in May 2001, with saltwater from Anderson Inlet entering the wetlands (officially) for the first time in 30 years.

Due to a range of issues including a lack of funding, and support by local landholders, the floodgates did not remain open for long, and have since been re-closed. Despite the lack of duration of saline intrusion, anecdotal reports indicated that mobile aquatic fauna, such as fish and prawns, returned to the wetland almost instantly, while estuarine vegetation such as mangroves, were starting to re-establish prior to reversion back to a freshwater system (pers comm. J Schmidt, DIPNR: J Duggen, UNE, 2004).

There are also numerous examples of successful establishment of intertidal wetland vegetation. Successful mangrove establishment has, for example, been achieved on Kooragang Island, adjacent

to the study area (Streever 1997). However, how this has affected wetland functioning is yet to be determined.

With regard to the Hexham Swamp Rehabilitation Project, it is likely that the opening of one gate will result in rapid re-utilisation of the waterway channels by mobile aquatic fauna, such as fish and prawns. Changes in aquatic vegetation would be slower to respond to the modified floodgate conditions, and may not actually eventuate until more floodgates are opened. Vegetation changes would be focussed initially on narrow riparian areas fringing the tidal waterways. Given the partial salt-tolerance of Phragmites, extensive succession to saltmarsh throughout the tidal inundation area may not be fully achieved for a number of years following opening of all eight floodgates.

6 SUMMARY OF MITIGATION MEASURES

This Section of the EIS provides a compilation of mitigation measures that will be required to minimise detrimental effects on the environment associated with opening of the floodgates at the downstream end of Ironbark Creek in Hexham Swamp. These measures form an integral part of the proposal and responsibility for undertaking the required works would lie with the Hunter – Central Rivers Catchment Management Authority.

Due to an inability to accurately predict impacts that would arise from opening of the gates, monitoring will be the only means to assess the impacts of tidal restoration and wetland rehabilitation. The preferred option allows for incremental opening of the gates in the future. Monitoring will assist not only in assessing the impacts of such staged gate openings, but can also provide valuable information on:

- the time required for the system to stabilise; and
- the impacts likely to arise from further opening of the floodgates (if desired) through extrapolation of results from intermediate stages of gate opening.

Details of the monitoring recommended for this project is also outlined in this Chapter.

6.1 Wetland Hydraulics

6.1.1 Impacts

Opening of the floodgates at the mouth of Ironbark Creek will result in widespread tidal inundation of Hexham Swamp, particularly during large (solstice) tides. Changes to the hydraulics of the wetland will be the primary consequence of opening the floodgates. All other impacts will be the result of the change to wetland hydraulics.

Given the large number of variable that affect the conveyance of overland flows across the swamp, including the topography of the ground surface and existing density of wetland vegetation, the exact extents of tidal inundation are not known. However, sophisticated numerical modelling has been used to gain a better appreciation of the likely areas of inundation, and hence, the need for mitigative measures where future tidal inundation is not desired.

6.1.2 Mitigation Measures

It is proposed to construct a number of low level earth bunds to limit the tidal inundation, thus protecting private properties and assets, as follows:

- 700 metre long bund between the Marsden Street ridge and the Shortland WWTW (this will prevent saltwater inundation of approximately 20 private properties located along Marsden Street, Alister Street and Mawson Street, Shortland). The land on which the bund is to be constructed is owned by Hunter Water;
- 230 metre long bund around the BAL radio masts located immediately adjacent to the Ironbark Creek floodgates. The land on which most of the bund will be constructed will be purchased by HCRCMA from BAL;

- Small terminal bunds in front of culverts under the historic Richmond-Pelaw Railway line to prevent saltwater intrusion onto private farming lands on the northern side of this railway line. These bunds will only be constructed on an as-required basis, and will be located on land associated with the rail line, which is owned by Rio Tinto (CNA).

It is also proposed to fill a small number of private properties to prevent saltwater inundation on these lands. Properties where fill is proposed are:

- Cook: Marsden St Shortland (Lot 20 DP16703), comprising approximately 550 m³ of clean imported fill, to be placed on the low-lying riverine terrace adjacent to Ironbark Creek at a typical depth of about 0.3 metres;
- Dombkins: Marsden St Shortland (Lot B DP350274), comprising approximately 250 m³ of clean imported fill, to be placed on the low-lying riverine terrace adjacent to Ironbark Creek at a typical depth of about 0.3 metres;
- Puliueva: Marsden St Shortland (Lot A DP350274), comprising approximately 200 m³ of clean imported fill, to be placed on the low-lying riverine terrace adjacent to Ironbark Creek at a typical depth of about 0.3 metres;
- Watts: Harges Ave Maryland (Lot 28 DP864756), comprising approximately 450 m³ of clean imported fill, to be placed on low-lying swampy ground just within the property boundary.

Tidal inundation is also proposed to be limited by the installation of pre-fabricated one-way flap-gates on the downstream ends of formal drainage lines. Locations where these structures will be installed include pipe culverts discharging into Ironbark Creek from Newcastle Council land (Lot 24 DP599877), the drain between the aforementioned Council lot and Tacon's property (Lot 52 DP593732), which discharges into Dark Creek, and at the culverts under the access road to the R&H Transport depot and associated downstream channel that drain the 2HD ponds.

With the possible exception of the small bunds under the abandoned Richmond-Pelaw rail line, all mitigative works described above will be carried out prior to commencement of the staged floodgate opening program.

6.1.3 Monitoring of Hydrology and Inundation Extents

Monitoring would involve:

- continuous recording of water levels at discrete locations throughout the swamp; and
- mapping of maximum inundation extents via aerial reconnaissance.

Water levels

Water levels within Hexham Swamp are currently being monitored by Manly Hydraulics Laboratory (MHL) as part of pre-opening baseline surveys. Water levels are monitored at four (4) water quality monitoring sites within the swamp (refer Section 3.4.2.1), as well as at two (2) water level only sites (refer Figure 6.1). It is proposed to continue monitoring of water levels at these six (6) sites following opening of the floodgates (including all stages of opening, starting with one gate open).

The results of the monitoring of intermediate stages will be used to help improve predictions of changes to inundation extents within Hexham Swamp under ultimate conditions. Improved results of predictive modelling would be used to 'fine-tune' the proposed floodgate management strategy.

Water level monitoring at Mullaness Plumbing (refer Figure 6.1) satisfies the requirements of Environment Australia in their decision that the Project is not a controlling action under Part 3 of the EPBC Act 1999.

Inundation Extents

Monitoring the maximum extents of inundation is considerably more difficult than monitoring water levels within the main waterways of Hexham Swamp. The simplest means of assessing inundation is via aerial reconnaissance. Therefore, it is proposed to conduct aerial surveys of the swamp (via helicopter would be the most advantageous) coinciding with maximum solstice tide inundation. The effectiveness of this survey would be compromised if antecedent rainfall produces localised ponding of water within the swamp. Therefore, such aerial surveys should only be undertaken if no significant rainfall precedes the solstice tides.

Mapping of peak tidal inundation via aerial reconnaissance would potentially be facilitated by installation of survey stakes throughout the swamp, which are distinguishable from the air. These stakes would be used as reference markers, against which the extents of inundation would be recorded.

6.2 Water Quality

6.2.1 Impacts

Water quality impacts resulting from the proposal are likely to be largely short term, while the magnitude of impacts will depend on the amount of tidal flushing restored and the timeframe of the restoration. Potential adverse water quality impacts from the proposal are considered to be as follows:

- the potential for minor water quality degradation of the Hunter River due to the reduced capture and retention of pollutants within the swamp generated from the Ironbark Creek catchment. Retention of nutrients and other pollutants that have been washed off the catchment tends to lead to eutrophication within the swamp, characterised by high primary productivity (eg algae blooms).

With increased tidal interaction between the swamp and the Hunter River, the nutrients would be more likely to be advected to the river before they could be taken up by primary producers, such as algae. Once in the river, the pollutants would be more dispersed and diluted, where they would be less likely to result in eutrophication problems, particularly given the higher suspended sediment concentrations of the river (refer Section 3.4). Also, the reduction of pollutant loads from the Hexham Swamp / Ironbark Creek catchment is being addressed by NCC and the HCRCA through implementation of the Ironbark Creek Total Catchment Management Strategy (ICTCMC, 1996) and the Newcastle Stormwater Management Plan (NCC, 1999);

- vegetation die-off may degrade water quality. As the organic matter decomposes, it would contribute to the detrital BOD of the waterway and would consume dissolved oxygen, potentially resulting in anoxic conditions. However, as discussed in Section 4.4, it is likely that the majority of the existing reed vegetation (especially *Phragmites australis*) would not die-off suddenly as a result of the re-introduction of saltwater into the swamp. Research by Greenwood and experience at Yarrahapinni Wetland (pers comm. John Duggen, UNE, 2004) indicate that *Phragmites* are semi-tolerant of saline water.

Nonetheless, as reported by DLWC (1997), a fish kill and an algal bloom did occur in Hexham Swamp following opening and immediate re-closure in 1997 due to vandalism of the gates (refer Section 3.4.1.11). This suggests that there may still be an initial die-off of some aquatic vegetation (eg *Typha*) following initial saline penetration, which would impart an oxygen demand on the system. The fish kill was significantly exacerbated by the fact that the gates were immediately re-closed following the vandalism event. If the gates were to remain open following initial saline penetration of the swamp, it is likely that the tidal flushing processes would have abated the short-term high oxygen demand and the fish kill may have been averted;

- advection of poor water quality (possibly contaminated with metals and organics) from the former tip site into the Hunter River. The extent of leachate from the tip site is still somewhat indeterminate, and is subject to planned remediation of the site by Newcastle City Council. However, given the significantly larger volume of the Hunter River compared to Hexham Swamp, it is considered that there is much greater capacity in the river to assimilate the tip site leachate, compared to the swamp. From a holistic viewpoint, dispersing the contaminant over a larger volume would be preferable to keeping it concentrated within an isolated, but detrimentally affected sub-environment.

6.2.2 Mitigation Measures

Although it appears that the water quality of the Hunter River would be poorer following opening of the floodgates, it is considered the degree of impact on the river would be relatively minor in the context of the whole river environment. In contrast, however, the water quality of Hexham Swamp itself is likely to improve significantly, due to the greater tidal exchange that it would receive with the Hunter River.

Based on the predicted water quality impacts, it is considered that there are no specific mitigative measures that need to be implemented to address the possible water quality impacts associated with the Project. However, it is recommended that the former Astra Street tip be remediated to minimise its impact on Hexham Swamp and the wider Hunter River estuary environment. Although such remediation is considered beyond the scope of this proposal, support should be given to NCC in preparing a long term management and remediation strategy for the site, in response to the recent listing of the former tip as a contaminated site by DEC (EPA) (refer Section 3.6.1).

6.2.3 Monitoring of Water Quality

As mentioned in Section 6.1.3, a baseline water quality monitoring program is already underway at four (4) locations within Hexham Swamp (refer Figure 6.1). The program involves automated collection of a range of water quality parameters every 15 minutes.

Water quality monitoring at these same locations will continue throughout the proposed staged opening of the floodgates. Analysis of the data will be used to quantify changes in water quality within the swamp and within the river following successive openings the floodgates, as described in Section 2.4.

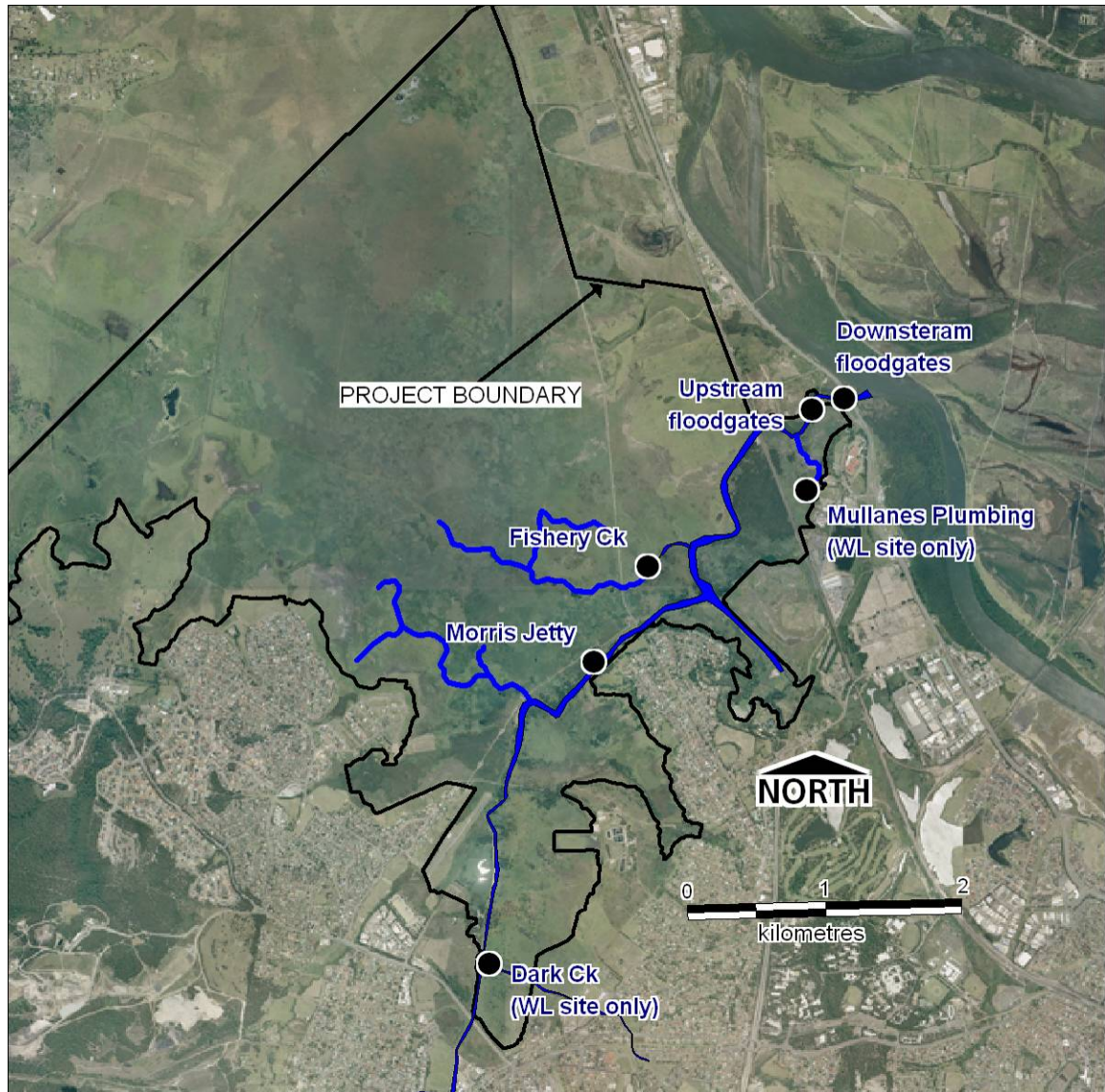


Figure 6.1 Water Level and Water Quality Monitoring Sites (by MHL)

In addition to the permanent water quality / water level recorders positioned within the main waterways, water quality will be monitored using hand-held instrumentation at a series of predefined locations on a periodic basis. This additional monitoring program will continue to HCRCMA monitoring carried out to date (refer Section 3.4.2.2), utilising the same sampling sites (see Figure 3.12) at a frequency of 2 months. At least one additional site will be included, however, at the 2HD swamp ponds, in accordance with Environment Australia schedule regarding the decision that the Project is not a Controlled Action (under Part 3 of the EPBC Act 1999). The 2HD ponds will be

monitored for salinity to ensure that opening the floodgates does not impact on the habitat and breeding values of the endangered Green and Golden Bell Frog population located in the ponds. Given that a one-way tidal gate will be installed on the culverts immediately downstream of the ponds, it is unlikely that the ponds will be affected by saline intrusion. Nonetheless, monitoring will be undertaken to ensure protection of the ponds and the frog population.

6.3 Sediments and Groundwater

6.3.1 Impacts

The change in wetland hydraulics is predicted to increase the mean water level in Ironbark Creek, and consequently, should increase the typical groundwater level at locations within the swamp that are relatively close to the creek (and it may be many years before the full effects on groundwater are developed). Groundwater levels in the more extreme sections of the swamp are unlikely to be affected by the change in channel hydraulics.

Sediments would not be affected by the proposed changes to the wetland, apart from a potential increase in detrital organic load to bed sediments within the waterways following die-off of saline intolerant vegetation species.

Increased tidal currents within the Ironbark Creek / Hexham Swamp waterways is likely to mobilise some bed and bank sediments, causing localised pockets of erosion. Areas considered to be most susceptible to erosion would be the most downstream sections of Ironbark Creek, where tidal discharges (and prisms) are greatest. Minor erosion of channel beds may reverse some of the exacerbated sedimentation that has occurred within Hexham Swamp over the past 30 years. Erosion of channel banks, however, would potentially degrade riparian habitats and introduce new sediment loads to the waterways.

With respect to acid sulfate soils (ASS), the predicted increase in groundwater levels should increase the saturation of potential ASS within the swamp, which would reduce the potential for this soil to oxidise and hence produce acidic runoff.

6.3.2 Mitigation Measures

No specific mitigative measures are recommended for sediments and groundwater in Hexham Swamp. The impact of elevated groundwater levels on infrastructure within the swamp is mitigated through specific works to the assets at risk (refer Section 6.8). Meanwhile, the potential increase of organic loading to bed sediments would be addressed to some degree by the staging of the works, which would limit saltwater inundation, and the degree of salt-intolerant vegetation affected.

Staging of the works would also minimise the potential for bank erosion of the waterways, as salt-tolerant vegetation would have an opportunity to re-establish within the riparian zone before peak tidal currents are experienced (with all eight floodgates open). It is also possible that active replanting of eroded or unvegetated banks could be carried out as part of the proposal, although this would have some associated disbenefits, as described in Section 6.4.2. In some circumstances, formal bank stabilisation works may be necessary in order to protect assets that are located immediately behind channel banks that experienced exaggerated recession.

No physical disturbance of soils within Hexham Swamp are proposed as part of this Project, with all proposed bunds and filling utilising clean imported fill. Consequently, no acid sulfate soil will be disturbed, and a formal Acid Sulfate Soils Management Strategy will not be required.

Swamp soils are prone to consolidation, which means that saltwater exclusion bunds and areas of filled floodplain may settle over time. To address this issue, it is recommended that periodic ground surveys of the bunds and filled areas be carried out (eg 2 years initially, then at 5 yearly intervals). If significant consolidation of the soil is recorded and the objectives of the works are compromised, then further 'topping up' of the bunds and/or filled areas should be undertaken to maintain design levels, again using clean imported fill.

6.3.3 Monitoring of Groundwater and Bank Erosion

Groundwater monitoring within Hexham Swamp has been carried out in the past for a range of projects (refer Section 3.5). Given that groundwater conditions are likely to influence wetland vegetation, it is considered that periodic and systematic monitoring of groundwater will be carried out to quantify groundwater changes. Monitoring will be undertaken throughout the staged opening process, as well as after the ultimate floodgate condition has been adopted, in order to determine the rate of change of groundwater conditions. Monitoring will include measurements of groundwater level, as well as pH and salinity / conductivity and will be undertaken at fixed piezometers. Locations for the monitoring will be based on previous works (RCA, 1998), and will cover a range of areas within the swamp (eg, Bores BH1, BH2, BH6, BH7, BH8 and BH9, as well as other areas that were not previously included in groundwater assessments, eg behind the proposed Marsden Street bund, shown as BH10 – refer Figure 6.2). Piezometers were previously established at sites BH1, BH2 and BH7 by RCA (1998).

Monitoring of groundwater levels within the swamp will provide an opportunity to modify the floodgate management regime should the new groundwater levels prove to be significantly detrimental to the swamp habitats or the surrounding private properties. If opening the floodgates unduly increases groundwater levels in the swamp (above and beyond the normal variation in groundwater level due to dominant rainfall / drought seasonality), then mitigation could be achieved by only partially opening one or more floodgates. By retaining some of the existing one-way nature of the gates, tides would exit the swamp quicker than they could enter it, which would depress the mean tide water level relative to the adjacent Hunter River (as is experienced presently). Changes to the floodgate operation will also have repercussions of the extents of saltwater inundation of surface water. Therefore, future decisions regarding management of the floodgates would need to consider all hydraulic processes, including surface water and groundwater, and the associated implications for chemical and biological processes occurring within the swamp.

Periodic monitoring of bank condition within the waterways of Hexham Swamp will also be carried out. The monitoring will be undertaken prior to and following specific stages of the works to determine if increased tidal currents are impacting on bank stability. Where necessary, impacted banks could be actively revegetated, or structurally protected using a range of hard and soft engineering techniques. Monitoring for bank erosion will be undertaken throughout the major waterways of the Hexham Swamp and would be best done from the water at low tide. Particular attention will be given to the downstream end of Ironbark Creek, where tidal currents would be highest and where major infrastructure is located. Given that the same tidal currents would have been

conveyed through the swamp channels prior to construction of the gates, it is not expected that bank erosion would be significant within the swamp following opening of the gates.

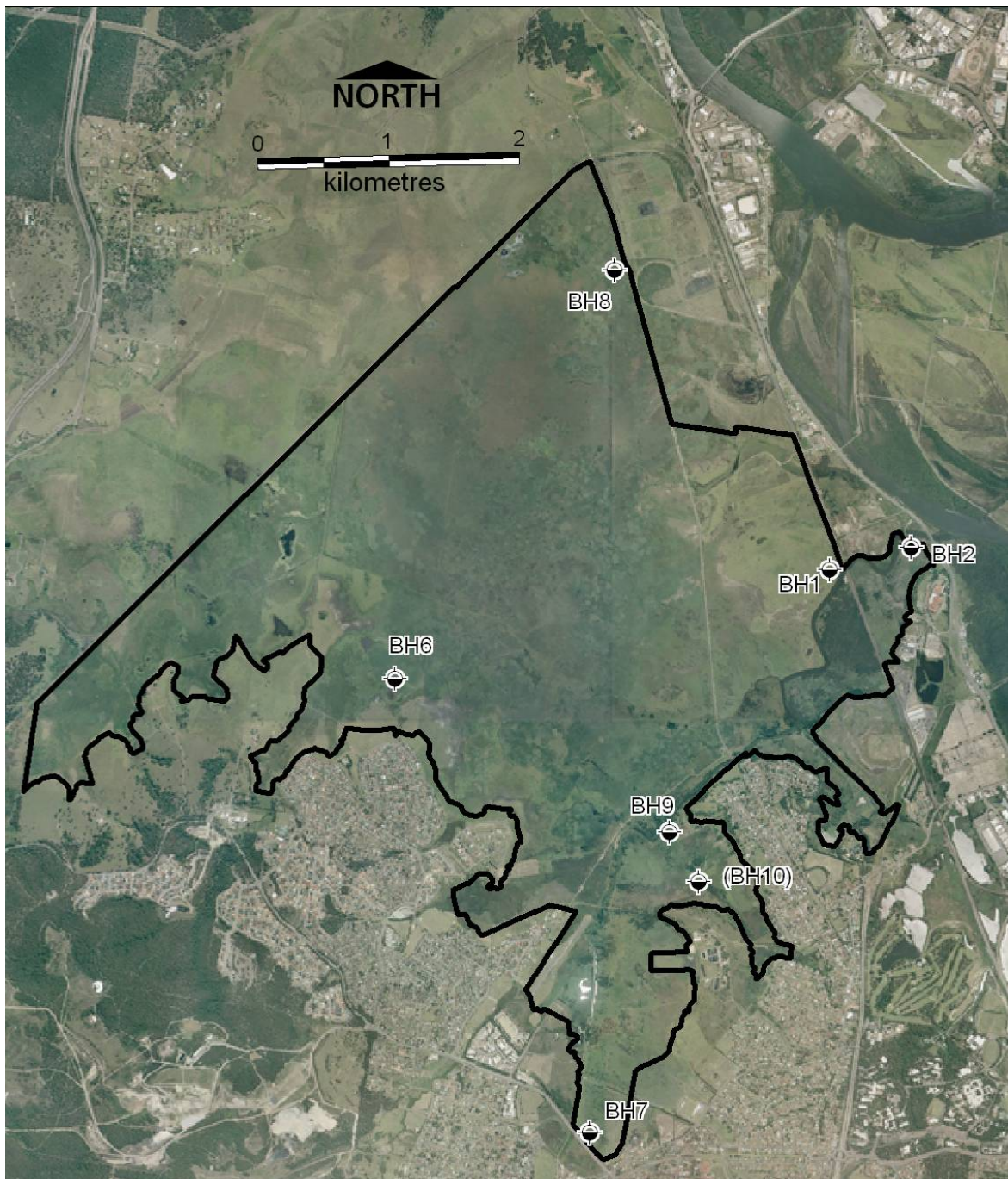


Figure 6.2 Groundwater monitoring locations

6.4 Vegetation

6.4.1 Impacts

Altered hydraulics of the wetland will re-introduce saline water to the area, which will result in significant changes to existing predominantly freshwater-based vegetation within Hexham Swamp. Although not predicted to occur instantaneously with the saltwater inundation, the proposal would have the greatest impact on existing *Phragmites* swamp habitat, although some areas of *Typha* swamp, other freshwater swamps and she-oak forests would also be affected (refer Section 4.4).

While the vegetation change is considered to be a positive environmental benefit and one of the main objectives of the project, the saltwater inundation may potentially impact on the threatened freshwater species *Zannichellia palustris*. *Z.palustris* is a submerged aquatic plant species listed as endangered under the *Threatened Species Conservation Act 1995*, which has been occasionally observed within some of the waterway channels within Hexham Swamp. While it is uncertain that the proposal would be deleterious to the growth and reproduction of the *Z.palustris* population within Hexham Swamp, it is considered prudent to undertake management measures to minimise the risk of local extinction of this species. These measures are described in Section 6.4.2.

6.4.2 Mitigative Measures

Given that an altered vegetation structure of Hexham Swamp is one of the primary objectives of the proposal, few mitigative measures are required to manage the transition from freshwater to estuarine vegetation. The main strategy that would be adopted to manage this transition is the staging of the floodgate openings. By opening the floodgates in an incremental manner, it is considered that only limited sections of the wetland vegetation would be stressed and in transition at any one time. This would also limit the detrital organic loading rate to the swamp and its waterways, which would help control water quality impacts.

With regard to *Z.palustris*, it is recommended that the initial opening of one floodgate be carried out during spring or early summer to maximise the dispersion of *Z.palustris* propagules (seeds and/or vegetative parts) throughout the waterways of Hexham Swamp by the increased tidal currents and extents. In addition, it is recommended that research be conducted on the habitat requirements of *Z.palustris* to determine tolerance limits to environmental disturbances and to design suitable transplantation techniques. Such a project would require a substantial literature survey, followed by experimental work to test the effect of various habitat conditions on plant growth and reproduction. Appropriate treatments would include varying amounts of salinity, nutrients, water flow, light, and competition from other plants.

Although active planting of estuarine plant species adapted to enhanced tidal conditions would potentially shorten the vegetation transition period within Hexham Swamp following opening of the floodgates, it is recommended that such planting not be undertaken on a large scale unless absolutely necessary for the following reasons:

- The area affected by increased tidal inundation due to opening of a single floodgate is not large and would not present significant environmental problems (eg enhanced erosion, decrease in water quality, etc.). Banks of creeks and channels are generally well vegetated by species (mangroves) already adapted to enhanced salinities, suggesting that bank erosion is not likely to

cause significant problems overall. It is expected that, where suitable species are absent, such species would naturally establish within sufficient time before erosion becomes problematic. This would be further facilitated by the staged or incremental nature of proposed openings, which would increase channel flows slowly, thus enabling estuarine vegetation sufficient time to establish and limit the erosion potential. Any active revegetation works would most likely be unnecessary. It is, however, recommended that banks be monitored and be actively revegetated should natural revegetation not occur within a sufficient timeframe;

- Active revegetation programs would interfere with the natural rehabilitation processes, thus diminishing the opportunities to study natural rehabilitation processes. The results of such studies are invaluable for assessing the impacts of enhanced tidal inundation. This would provide opportunities to improve predictions about impacts arising from opening subsequent floodgates at Ironbark Creek or about impacts from tidal wetland rehabilitation works elsewhere.

6.4.3 Monitoring of Vegetation

An ongoing vegetation monitoring program has already been initiated by the Hunter and Central Rivers Catchment Management Authority, involving two monthly recordings at 16 sampling locations both within Hexham Swamp and in similar habitats outside the Swamp (ie reference sites). Five to six sites are located within the area likely to be affected by a single gate opening. A map showing the location of each site is provided in Figure 6.3.

The present monitoring program is limited to publicly owned land in the south and east of the swamp, however, the program would be expanded to other land within the study area, following finalisation of land purchase in the near future, by the HCRCMA. In addition, the sampling quadrats would be enlarged to minimise data noise when evaluating time series due to inexact relocation of the small plots presently used. Monitoring sites would, furthermore, be marked with a peg (eg star picket) to facilitate relocation of the site and fixed using a global positioning system. Subsequent to the opening of the floodgates, the sites would be monitored on a monthly basis for a year, after which time the frequency would be reviewed.

Caution must be taken to closely monitor the area at the edge of tidal inundation and other downstream areas for exotic plant establishment. The increased flushing of areas currently infested by alligator weed may provide potential for spread of this weed.

6.5 Aquatic and Terrestrial Fauna, except Mosquitoes

6.5.1 Impacts

Impacts on aquatic and terrestrial fauna will be based on changes to habitats and vegetation communities within Hexham Swamp, and are summarised in Table 4.7. Impacts are likely to include an increase in fish and mobile aquatic fauna, an increase in wader population, a decrease in waterfowl population and a potential decrease in herpetofauna.

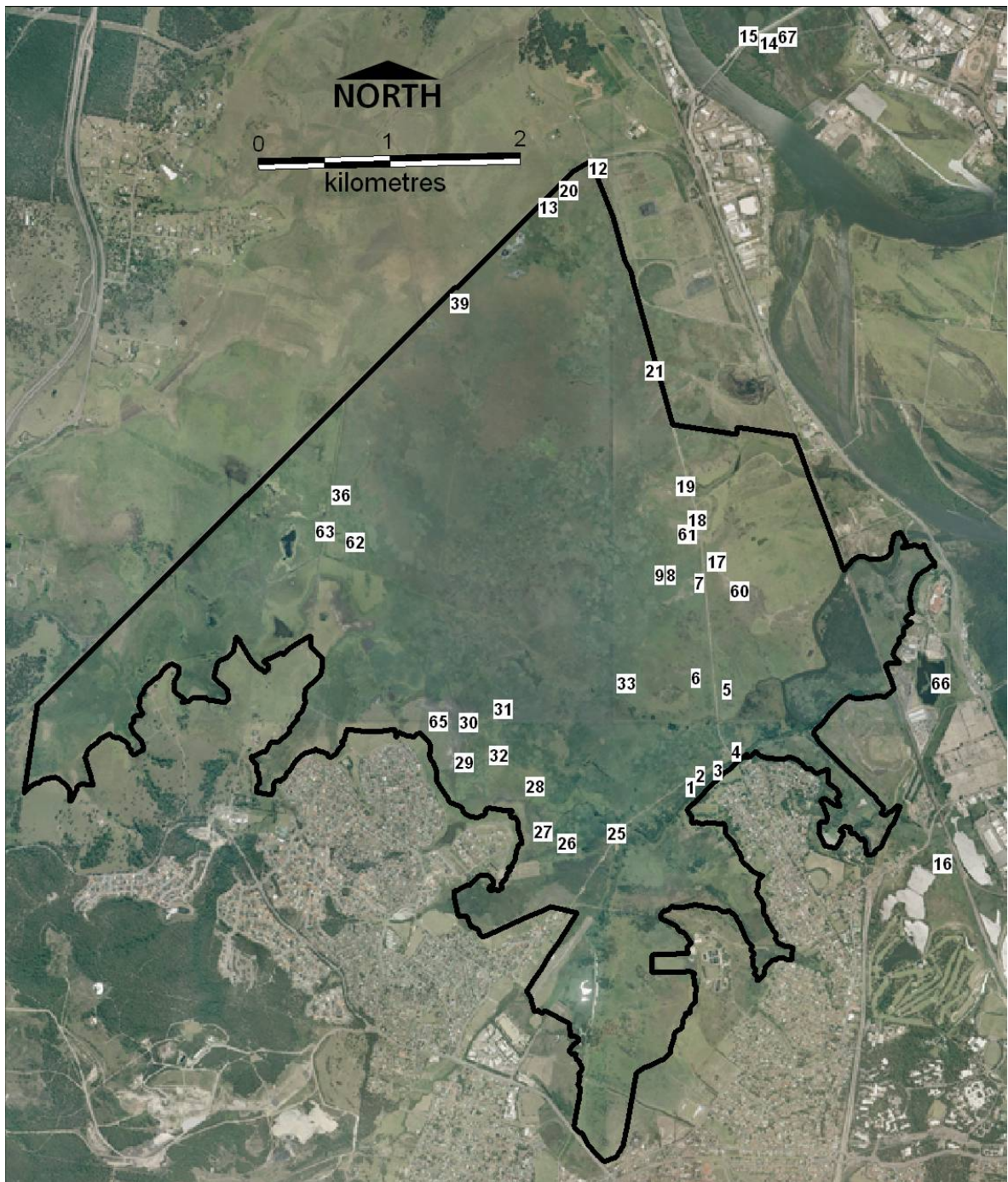


Figure 6.3 Vegetation monitoring locations (existing and future)

6.5.2 Mitigative Measures

Long-term impacts on fauna communities cannot be mitigated without compromising the goals of the proposal. Some long-term impacts, such as an increase in the wader bird population, are actually key objectives of the proposal, and consequently do not require mitigation.

Short-term impacts to faunal communities (eg. as a result of habitat changes) may be managed to some degree by adopting a staged approach to floodgate opening.

Staged opening of the floodgates would enable faunal assemblages within the swamp to “acclimatise” to the new hydraulic / salinity regime and minimise the potential for significant fauna deaths as:

- some salt intolerant aquatic species may move into adjacent freshwater areas; and
- adverse water quality effects (eg. due to decaying vegetation) are likely to be lesser than if all gates were opened at once.

6.5.3 Monitoring of Fauna

Baseline terrestrial fauna monitoring has already commenced within Hexham Swamp (Winning 1998, see Section 3.8.6) and will be continued following opening of the floodgates. Locations of terrestrial fauna monitoring in Hexham Swamp are presented in Figure 6.4.

Monitoring of changes in terrestrial fauna populations will be beneficial to the outcomes of the project. There would also be benefits in investigating opportunities to involve community groups (eg. Hunter Bird Observers Club) considering that monitoring will need to be widespread (ie. over broad areas of swamp) and occur at least seasonally, but preferably monthly. Emphasis will be placed upon fauna of conservation value especially the Green and Gold Bell Frog and migratory wader species (eg. those listed under JAMBA/CAMBA). The existing population of Green and Golden Bell Frogs in the 2HD ponds (refer Figure 6.4, site K) will be monitored to determine any impacts on the population resulting from opening of the floodgates, as per Environment Australia requirements.

Aquatic fauna monitoring will also be carried out to cover aquatic faunal communities over a broad range of habitats at:

- sites along the length of Ironbark Creek. These sites should, as far as practical, be linked to water quality monitoring sites (refer Figure 6.1); and
- several sites located throughout the wetland areas.

Sampling will target both the juvenile and adult stages of fish and prawns, and be undertaken at regular intervals to account for seasonal variability. Reference localities would be required in the monitoring program (eg. to assess when restoration of prawn populations is “complete”) and would be selected on the basis of results from a pilot study program. The specific details of the environmental monitoring program would need to be determined through pilot surveys and would be subject to discussions with relevant Approving Authorities.

Benthic macroinvertebrate monitoring is already underway within Hexham Swamp (Bio-Analysis, 2005), and will be continued following opening of the floodgates. Monitoring at reference sites is also being undertaken, and is considered an essential component of determining impacts of opening the floodgates. Reference sites for benthic macroinvertebrate monitoring are located at Mosquito Creek on Kooragang Island, and Dunnes Creek in the Tomago Wetlands.

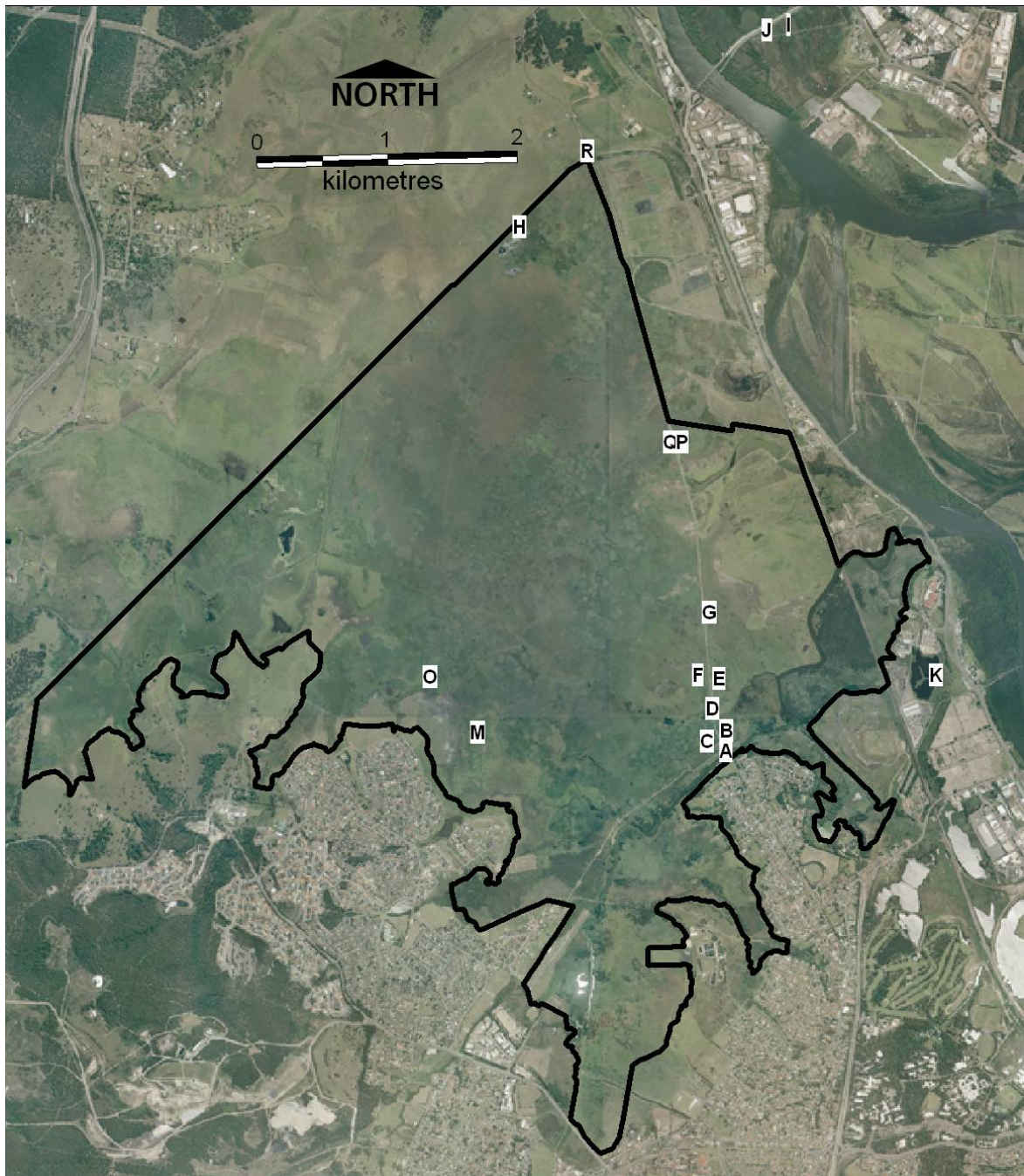


Figure 6.4 Terrestrial fauna monitoring sites in Hexham Swamp

6.6 Mosquitoes

6.6.1 Impacts

Predicted impacts on mosquito populations as a consequence of the proposal are discussed in 4.9.3. While the proposal is likely to result in a potential significant increase in saltwater species within Hexham Swamp, this would be offset by a potential significant decrease in freshwater species. Regardless of the change, Hexham Swamp would still be minor contributor to the total mosquito

population of the Lower Hunter River, given the very large mosquito habitats on Kooragang Island and within the Tomago wetlands.

6.6.2 Mitigation Measures

Measures to mitigate any impacts on mosquitoes (and their associated impacts on the general population of the Newcastle area) consist of management of the floodgate operation or physical controls. These measures were described in detail in Section 4.9.3.4, and are summarised below.

6.6.2.1 Floodgate Management

The proposal for Hexham Swamp involves restricting the penetration of king tides into the swamp during the summer solstice period. Restrictions on this tide will be achieved by lowering one or more floodgates, thus inhibiting tidal ingress through the structure.

Restricting the king tide will eliminate the creation of extensive areas of stagnant ponds (given that subsequent tides would not be able to flush or drain the ponds). These ponds would otherwise become ideal habitat for mosquitoes. As mosquito breeding only occurs during the summer months, control of the floodgates to restrict king tides will only be required during the summer solstice period. Saltwater ingress associated with the winter solstice would be free to inundate existing swamplands and rejuvenate saltmarsh production, thus maximising the benefits of the Project.

If proposed floodgate management is ineffective at managing mosquito numbers within the swamp (i.e. ensuring that there are not significant increases in mosquito numbers), then the ingress of large spring tides (i.e. 1.8m +, as predicted at Fort Denison) will also be restricted during the summer mosquito breeding season (i.e. December to March) through strategic floodgate operation. Beyond this, physical controls will need to be adopted, as described in Section 6.6.2.2.

6.6.2.2 Physical controls

Physical controls will be adopted if monitoring shows that opening of the floodgates has had a significant impact on the overall size of the mosquito population within Hexham Swamp, and management of the floodgate system (i.e. excluding king tides and large spring tides during summer breeding months) has been ineffective at mitigating these impacts.

A number of physical management strategies are available, and have been described previously in Section 4.9.3.4. The preferred technique would be aerial application of the larvicide *B.t.i.* As *B.t.i.* has a small window of opportunity for application, aerial spraying would need to be coordinated with field-based larvae monitoring. Also, application of *B.t.i.* to Hexham Swamp alone would do little for addressing the biting mosquito problem experienced in the wider Newcastle area. Therefore, management of Hexham Swamp using physical controls would need to be carried out as part of a wider regional management program, as discussed in Section 6.6.3.

6.6.3 Regional Mosquito Management Initiatives

As discussed in Section 4.9.3.4, a regional mosquito management program is currently being developed, aimed at integrating management efforts throughout the Lower Hunter and mid North Coast area.

In addition to the mitigation measures described above in Section 6.6.2, future management of mosquito populations within Hexham Swamp following opening of the floodgates will be consistent with the recommendations and strategies outlined in the regional management document that is currently in preparation.

6.6.4 Monitoring of Mosquitoes

Regular monitoring will be undertaken in and around Hexham Swamp, as well as other prime mosquito habitats in the Lower Hunter (i.e. Kooragang Island and Tomago Wetlands) to examine the impacts of enhanced tidal inundation, and the effectiveness of any management strategies implemented. Monitoring is already being carried out on behalf of the HCRCMA to provide baseline data on mosquito numbers – sites for existing mosquito monitoring are shown in Figure 6.5. This data collection will be continued throughout the staged opening process, with particular emphasis on periods when the floodgates are being actively managed to minimise the king tide inundation, and thus minimise the potential for increased saltmarsh mosquito breeding habitat.

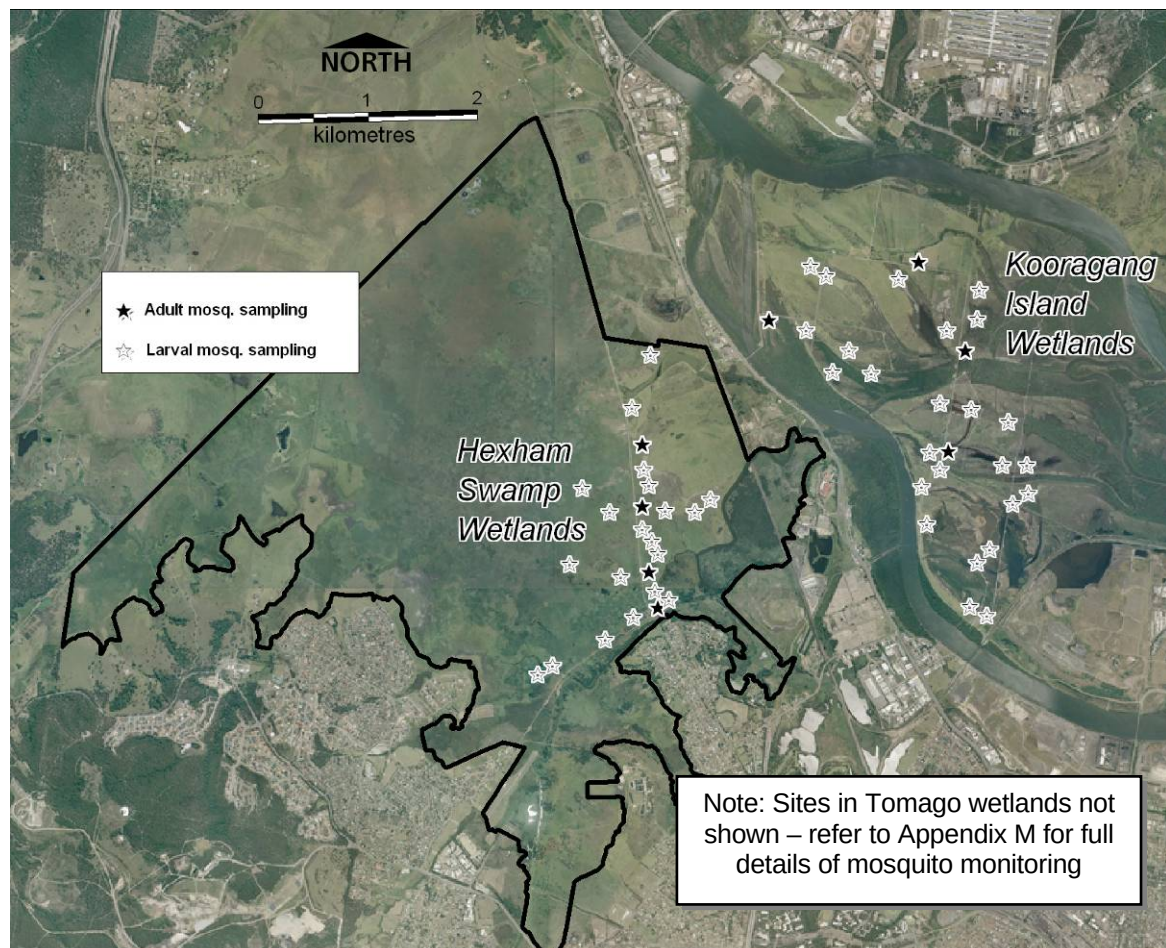


Figure 6.5 Locations of Mosquito Monitoring Sampling Sites (existing and future)

6.7 Noise

6.7.1 Impacts

The construction of the earthen bunds will have an acoustic impact on nearby residences, particularly along Marsden Street, with some exceedance of noise criterion as specified in the EPA's Environmental Noise Control Manual (ENCM). The predicted noise level would generally be less than about 55 dB, which is considered typical for construction activities of the type proposed near Marsden Street.

6.7.2 Mitigation Measures

Given that the construction of the bund was specifically requested by the residents of Shortland through a public consultation process, it is considered that the general community would be mostly accepting of the short-term increase in noise associated with the bund construction.

Nonetheless, mitigation measures will be adopted and will include the use of sound controlled equipment, where possible, and on-site practices that minimise the generation of excessive noise (eg not dropping excavator buckets on the ground).

Consultation with the local residents along Marsden Street will also be carried out, informing them of the details of the proposed works, including construction duration, work hours and contact details to lodge complaints regarding noise.

6.7.3 Noise Monitoring

If a noise complaint is received regarding the construction of the earthen bunds associated with this Project and further liaison with the complainant cannot resolve the issue, then specific noise monitoring of the works will be carried out at the residence of the complainant to determine the actual noise level experienced at the residence. Such monitoring would only be carried out on an as-required basis, and would only be necessary during the construction stage for the Project.

6.8 Services and Infrastructure

6.8.1 Impacts

The proposed changes to the hydraulics of Hexham Swamp will have a range of impacts on the existing services and infrastructure, which have been fully documented in Section 4.17. These impacts mostly relate to increasing groundwater levels and some minor overtopping of access tracks and other facilities within the swamp.

6.8.2 Mitigation Measures

Mitigation of the impacts on services and infrastructure relates to carrying out physical works to the affected facilities within the swamp. This includes localised raising of low sections of access track (adjacent to the Hunter Water pipeline, the main northern railway and within The Wetlands Centre), and raising and resurfacing of the private Wallsend airstrip. Details of the proposed works / mitigation measures are presented in Section 2.5.

6.8.3 Monitoring of Services and Infrastructure

Monitoring of services and infrastructure will not be required except to identify specific localised areas where mitigative works need to be carried out. It is recommended that monitoring of saltwater inundation in the vicinity of the infrastructure be carried out at the time of peak tidal ingress into the swamp following incremental gate opening regimes. It is likely that the monitoring will show that specific mitigative works may not be required until after multiple gates are opened.

6.9 Proposed Environmental Monitoring Program

The proposed environmental monitoring program will quantify the extent and nature of any environmental changes attributable to the proposed opening of the floodgates. The environmental monitoring program will aim to determine environmental changes resulting from incremental gate openings and how these changes compare to the existing (pre-opened) condition, as well as a nearby unrestricted estuarine waterway that has similar physical/biological characteristics (ie. a “reference” or control site) as necessary. A comparison with a suitable control will enable assessment of the extent and magnitude of the swamp restoration process and when a “natural” situation has been achieved. The program will also incorporate a baseline data collection phase to assess pre-gate opening conditions (note that much as the baseline data collection has already been carried out and is continuing to be collected, as described in Chapter 3).

The monitoring program will be designed in conjunction with administering authorities once the gate opening strategy has been confirmed. It is envisaged that the monitoring program will include:

- replicated sampling;
- impact and reference sites; and
- defined acceptable levels of environmental change.

Table 6.1 indicates recommended monitoring parameters, techniques and frequencies to form the basis for future design of a monitoring program. Each type of monitoring (ie. water quality, fish, birds, etc) will require a different approach with respect to selection of sample sites (including reference sites) and frequencies, although all opportunities should be investigated to integrate sampling so as to maximise data and minimise monitoring costs. This is also particularly relevant to integrating with existing monitoring/survey programs (eg. HBOC surveys, DPI-Fisheries, etc).

The Hunter Central Rivers CMA will be responsible for full implementation of the monitoring program.

If not already underway, all elements of the monitoring program will commence 12 months prior to the opening of the first floodgate, in order to establish baseline ‘pre-opening’ conditions. Assuming that opening of the first floodgate will occur in spring / early summer 2006, all proposed monitoring will be underway by November / December 2005.

Table 6.1 Proposed Monitoring Program Components

Type	Parameters	Techniques	Frequency	Locations
Wetland Hydraulics	Water levels	In-situ logging with automated water level recorders	Continuous monitoring (eg every 15 minutes) using automatic loggers for duration of floodgates opening process	As per current water level / water quality probes deployed by MHL (refer Section 3.4.2.1 and Figure 6.1)
	Inundation spatial extents	Aerial reconnaissance (helicopter) and associated mapping	Coinciding with peak of summer and winter solstice tides	Generally across whole swamp, with reference made to surveyed stakes
Water Quality	Dissolved oxygen, salinity, pH, turbidity, temperature, ORP	In-situ monitoring using hand held instrumentation.	Bimonthly for at least 12 months after initial one gate opening, with at least two surveys following rainfall (>25mm), then subject to review	As per current in-situ monitoring by HCRCMA (refer Section 3.4.2.2), plus 2HD ponds
		In situ logging with water quality probes.	Continuous monitoring (eg. every hour) using automatic loggers for at least 12 months after initial one gate opening, then subject to review	As per current water quality probes deployed by MHL (refer Section 3.4.2.1)
	Nutrients (total and dissolved), suspended solids, chlorophyll a	Sample collection and laboratory analysis (NATA certified).	Bimonthly for at least 12 months after initial one gate opening, with at least two surveys following rainfall (>25mm), then subject to review	As per current in-situ monitoring by HCRCMA (refer Section 3.4.2.2)
	Faecal coliforms, metals (Al, Cd, Cr, Cu, Fe, Pb, Zn, Ni), ASS indicators	Sample collection and laboratory analysis (NATA certified).	Bimonthly, for at least 12 months after initial one gate opening, with at least one survey following rainfall (>25mm), then subject to review	As per current in-situ monitoring by HCRCMA (refer Section 3.4.2.2)
Groundwater	Groundwater levels, pH, salinity	In-situ monitoring at piezometers	Bimonthly, for at least 12 months after initial one gate opening, with at least two surveys following rainfall (>25mm), then subject to review	As per RCA (1998) using Bores BH1, BH2, BH6, BH7, BH8 and BH9, and new site BH10 – refer Figure 6.2
Aquatic Fauna (macrobenthos)	Species distribution, diversity and abundance.	Grab and quadrant sampling.	Quarterly for at least 12 months after initial one gate opening, then subject to review.	As per existing baseline monitoring being carried out by Danny Roberts on behalf of HCRCMA
Aquatic Fauna (fish)	Species distribution, diversity and abundance.	Netting and trapping.	Monthly for at least 12 months after initial one gate opening, then subject to review.	As per previous fish surveys carried out by DPI-Fisheries

Type	Parameters	Techniques	Frequency	Locations
Vegetation	Community type, species distribution, condition.	Aerial photography and quadrats.	Monthly for at least 12 months after initial one gate opening, then subject to review.	As per current base-line vegetation survey being carried out by Geoff Winning (refer Figure 6.3)
Birds	Species distribution, diversity and abundance.	Point counts.	Quarterly for at least 12 months after initial one gate opening, then subject to review.	As per current base-line survey being carried out by Geoff Winning
Amphibians	Species distribution, diversity and abundance.	Transects and point counts.	Quarterly for at least 12 months after initial one gate opening, then subject to review.	As per current base-line survey being carried out by Geoff Winning, including 2HD ponds
Mosquitoes	Species distribution, diversity and abundance	Trapping	Monthly during summer months, for duration of floodgates opening process	As per base-line monitoring program being carried out by Entomology Dept, Westmead Hospital on behalf of HCRCMA
Noise	L _{Aeq} (15 minutes)	Automatic noise level recorder / logger	As required, subject to noise complaints and unsuccessful resolution with complainant(s)	At residence(s) of complainants or adjacent properties

Key issues to be considered in designing the monitoring program are discussed in the following Sections.

6.9.1 Monitoring Program Design Considerations

Cost Effectiveness

A monitoring program should aim to be cost effective. That is, the program must be designed so that it assesses those variables (parameters) that respond to environmental changes attributable to the floodgate opening in a manner that is distinct and easily separated from naturally occurring changes. A precise judgement can then be made as to whether or not a positive or negative environmental impact has occurred, or is likely to occur. The level of change to be detected needs to be balanced against the costs associated with monitoring.

Threshold Level of Change

Initially, in designing a monitoring program it is necessary to determine the level of change in a parameter that is considered a significant environmental change or impact. The level of change sought will vary depending upon the components of the environment to be monitored. Such levels need to be assessed based on an understanding of the susceptibility of the flora and fauna communities under consideration to the various impacts.

Equally important are the conservation values of such communities. The derivation of what level of change is sought to be detected is generally the result of a subjective process involving the

perceptions of various management agencies and their ultimate management goals. This level of change should be determined as part of designing a cost effective monitoring program.

Natural Variability

It is also important to consider the natural levels of temporal and spatial variation of those parameters proposed for monitoring. To detect a change in a parameter due to the floodgate opening clearly, more samples would be required for a parameter that undergoes large natural changes than would be needed for a parameter which is relatively stable (both in time and space). An understanding of the natural levels of variation is therefore required to determine the intensity of sampling required to account for this natural variation. This ensures that the design of the monitoring program is rigorous enough to detect a pre-determined level of change.

Determination of levels of natural variability is particularly difficult in estuarine areas, such as in Ironbark Creek, where significant variation occurs on a number of temporal and spatial scales. That is, seasonally, monthly (spring and ebb tides), weekly (tidal range variation) and daily (flood/ebb tide). Some broad indications could be obtained from the results of studies conducted in previous studies, however, to be cost effective and detect an environmental impact, information should be derived from site specific pilot data collection.

Pilot studies are also important in defining a monitoring program design so as to avoid the collection and processing of unnecessary, excessive data or the collection of unreliable data, in terms of determining potential environmental impacts.

Pilot Study

It will be important for the monitoring program to be designed, taking into account data describing existing natural spatial and temporal variability. Administering authorities could use this information to determine a threshold for the cost effective, detectable level of change for the monitoring program.

Monitoring Frequency

The frequency of monitoring needs to take into account the magnitude and time scale of potential impacts and the likely response characteristics of the variables being measured. Environmental impacts resulting from floodgate opening are most likely to relate to an increase in inundation extents, an increase in salinity and associated flow-on effects (eg. changes to vegetation/fauna communities). Potentially influenced communities are likely to respond differently (ie. rapid or slow) and hence different frequency may be needed for different attributes and communities.

Monitoring frequency will need to take into account the form of natural influences in ambient temperatures, tidal regimes, weather patterns and, in particular, events such as major floods. Flood events occur periodically and need to be incorporated as specific, but not predefined, monitoring periods.

Reference sites

If the monitoring program is to determine whether the anticipated changes in the environmental characteristics of the swamp (eg. enhanced prawn abundance) due to the floodgate opening result in a “natural” estuarine system, it is necessary to sample at a number of reference sites. That is,

monitoring at reference sites would provide an assessment of the success and extent of swamp rehabilitation.

Reference (or control) sites may not be required for some parameters. For example, if all eight floodgates were opened, a marked reduction in salt-intolerant fauna species (eg. frogs) would occur. Whilst this change could be monitored within the swamp, there would be few benefits in monitoring at reference sites as the pre-gate-opening habitat would be so markedly changed.

Reference sites have already been established as part of existing base-line monitoring for a number of parameters (particularly those being monitored by Winning).

7 SUMMARY OF EIS REQUIREMENTS AND PROJECT APPROVALS

7.1 Check-List of Director-General Requirements

The Director General of the Department of Infrastructure, Planning and Natural Resources has specified a number of issues and requirements that need to be considered and addressed during the completion of the Environmental Impact Assessment. Table 7.1 summarises the requirements of the Director-General and indicates how the relevant issue has been considered, and in what section of this EIS document it is addressed.

Table 7.1 Director-General Requirements Check-List

Issues	Consideration given	Relevant EIS Section
<u>Issues of Key Environmental Planning Importance</u>		
Flora and fauna impacts	Significant changes to the flora and fauna of Hexham Swamp can be expected due to changes in wetland hydraulics, salinity and fauna passage	Existing conditions see Sections 3.7, 3.8, and 3.9 Impacts see Sections 4.4, 4.6 and 4.9.
Surface and groundwater impacts	Significant changes to surface water inundation can be expected, while a net increase in groundwater will also result	Existing conditions see Sections 3.3 & 3.5.1.3 Impacts see Sections 4.1 and 4.3.2.
Soil quality, particularly with regard to Acid Sulfate Soil (ASS), erosion and stabilisation	Soil characteristics will not be significantly affected. No disturbance of existing soils are proposed, thus ASS should not be of concern	Existing conditions see Sections 3.5 and 3.6. Impacts see Section 4.3.
Hydrological impacts, particularly with regards to potential flooding and local drainage regimes	Impacts of proposal on existing flooding conditions would be minor, while tidal flushing and drainage of the swamp will improve dramatically	Existing conditions see Section 3.3. Impacts see Section 4.1.
<u>Issues of Environmental Planning Importance</u>		
Noise impacts	Localised, short-term noise impacts may be experienced during the construction of the Marsden Street bund and filling on private lands	Existing conditions see Section 3.10. Impacts see Section 4.10.
Air quality impacts	No significant impacts on air quality are expected	Impacts see Section 4.11.

Issues	Consideration given	Relevant EIS Section
Heritage impacts, including Aboriginal objects	No significant impacts on the heritage aspects of Hexham Swamp, including the Aboriginal heritage, with the exception of an identified artefact site along proposed Marsden Street bund alignment	Existing conditions see Section 3.15. Impacts see Section 4.14.3.
<u>Other Important Issues</u>		
Traffic impacts	No significant impacts on local traffic around Hexham Swamp are expected	Impacts see Section 4.12.
Visual impacts	The proposal is likely to provide positive benefits to the visual amenity by increasing diversity and open water to the landscape	Existing conditions see Section 3.12. Impacts see Section 4.13.
Statutory Instruments, including SEPP-14, Hunter REP, Newcastle LEP and relevant DCPs	Due consideration has been given to all Environmental Planning Instruments	See Sections 1.3, 2.7 and 4.14.1.
Hexham Swamp Nature Reserve Plan of Management	Due consideration has been given the aims and objectives of the Plan of Management	See Sections 2.7.5.3 and 4.14.2.
<u>Consultation</u>	Consultation has been carried out with community, relevant stakeholders and private landholders in and around Hexham Swamp	See Section 2.7.5.6 and Appendix B: Volume 2 for details and responses
<u>Commonwealth EPBC Act 1999</u>	Referral has been made to the Commonwealth Department of Environment and Heritage	See Section 2.7.5.1 and Appendix B: Volume 2 for details

7.2 Summary of Approvals and Permits Required

The following approvals are required in relation to the Proposal:

- (1) development consent is required from Newcastle City Council pursuant to SEPP 14;
- (2) consent to destroy Aboriginal artefacts located in the vicinity of the proposed Marsden Street bund pursuant to the *National Parks and Wildlife Act 1974*;
- (2) consent to carry out works on public roads under the *Roads Act 1993*; and
- (3) a flood work approval is required under the *Water Management Act 2000*.

The Proposal is therefore integrated development under the EP&A Act.

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