Appendix P

Quantitative risk assessment for drinking water

Environmental impact statement

ActewAGL

Murrumbidgee to Googong Transfer

Quantitative Risk Assessment for Drinking Water

Final Report, Version 3

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Water Futures

Document History & Status

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1. Executive Summary

1.1. Background

The Murrumbidgee to Googong Raw Water Transfer Project (M2G) project involves drawing water from the Murrumbidgee River source at Angle Crossing on the southern border of the ACT and transferring that water to the Googong Reservoir receiving environment via pump stations, pipelines and the Burra Creek.

This document presents a screening level Quantitative Risk Assessment (QRA) assessing the safety of drinking water harvested from the Googong Reservoir following the introduction of M2G. The analysis considered risks arising during construction and commissioning, risks arising during the initial operation of the scheme (first few years) and risks arising over the long-term (future decades).

The overarching framework applied to the risk assessment was the enHealth *Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards 2002* (enHealth 2002) with particular attention being given to *Chapter 4, Environmental Health Risk Assessment for Water*. The approach involves four steps that are outlined as follows.

1.2. Hazard identification

Hazard identification involves determining which hazards are to be considered in the risk assessment.

The hazards selected for inclusion in this study were the most potent relevant hazards for which there was sufficient data and information to complete a QRA. Most other hazards would present lesser risks than those selected and would, therefore, be adequately managed, if the selected hazards were managed to tolerable levels. Two hazards were selected for assessment via the QRA, as follows.

Oocysts of human infectious genotypes of the enteric protozoan pathogen *Cryptosporidium* spp. were selected to represent faecal-oral enteric waterborne microbial pathogens transferred from the Murrumbidgee River source and passing through the Googong Reservoir receiving environment to the point of water supply offtake.

The cyanotoxin microcystin analogue mLA was selected to represent cyanotoxins arising from cyanobacterial (blue-green algal) blooms arising within the reservoir as a result of phytoplankton proliferation with Googong Reservoir receiving environment influenced by the transferred Murrumbidgee River source water.

In addition, some qualitative consideration was given to other hazards such as taste and odour compounds and other toxins.

1.3. Exposure assessment

Exposure assessment involves predicting exposures to the identified hazards.

1.3.1. Pathogens

Cryptosporidium spp. concentrations measured during the previous three-and-a-half years within the Murrumbidgee River source, including from some storm events samples, were average ≤ 0.2 oocysts per L, ninety-fifth percentile ≤ 0.3 oocysts per L and maximum 4 oocysts per L.

Under scenarios predicted from Googong Reservoir receiving environment modelling by GHD (2009), pathogen concentrations were predicted to be reduced by over 99%, or 2 $\log_{10}$ between the inflow to Googong Reservoir and the offtake point to the Googong Water Treatment Plant (WTP).

Cryptosporidium concentrations would be further reduced by an estimated were estimated 99.99%, or 4 $\log_{10}$, by the conventional coagulation, flocculation, sedimentation and media filtration system at the WTP, when working as intended, based on USEPA (2006) guidance. *Cryptosporidium* is insensitive to chlorine disinfection, hence its selection as the most potent relevant hazard in this context. Viruses and bacteria, for instance, would be reduced significantly by chlorination at the WTP, typically over 99.99%, or 4 $\log_{10}$.

1.3.2. Cyanotoxins

Cyanotoxin concentrations were estimated based on the chlorophyll *a* concentrations predicted to arise within the Googong Reservoir receiving environment by GHD (2009) which were then converted to estimated microcystin concentrations.

Ninety-fifth percentile concentrations of cyanobacteria were predicted to be capable of producing microcystin mLA concentrations of 10.6 µg/L within the surface water in the Burra Creek arm of Googong Reservoir. Note that this would occur approximately 10 km upstream of the offtake tower.

Based on Australian Water Quality Centre research, it was estimated that treatment would be capable of reducing raw water cyanotoxin concentrations by 90% through the action of free chlorination at the Googong WTP. Allowing for treatment by free chlorination, (but not allowing for dilution, avoidance through selective depths offtakes, or treatment by powdered activated carbon at the WTP), treated water cyanotoxin concentrations were estimated to be reduced below 1.1 µg/L in treated water.

1.4. Dose response assessment

Dose response assessment involves estimating the response of the exposed population to the hazard.

1.4.1. Pathogens

In its Surface Water Treatment Rule, the USEPA (2006) used dose response relationships to develop requirements to reduce *Cryptosporidium* concentrations between raw and treated water to meet a target of 10^{-4} annual additional personal infections for a person consuming 2 L of treated water per day. Under this USEPA rule, treatment targets vary with source and are based on arithmetic average measured *Cryptosporidium* concentrations per L over two years. The Murrumbidgee River at Angle Crossing has an arithmetic average *Cryptosporidium* concentration placing it in the USEPA (2006) 'Bin 2' category, which has a *Cryptosporidium* reduction requirement of 99.99%, or 4 $\log_{10}$.

In its Guidelines for Drinking-water Quality, the WHO (2008) used dose response relationships to develop requirements to reduce *Cryptosporidium* concentrations between raw and treated water to meet a target of 1 annual additional personal µDALY (disability-adjusted life year) disease burden. The Murrumbidgee River at Angle Crossing has a ninety-fifth percentile and maximum *Cryptosporidium* concentration that attracts a treatment requirement against WHO (2008) of 3.2 and 4.1. $\log_{10}$ *Cryptosporidium* reduction, respectively.

1.4.2. Cyanotoxins

Dose response relationships for microcystins were derived from animal studies. Based on these toxicological analyses, the Australian Drinking Water Guidelines 2004 (ADWG) provides a lifetime exposure guideline value of 1.3 µg/L for microcystin mLR, which also applies to microcystin mLA.

1.5. Risk characterisation

Risk characterisation involves assessing the acceptability of risks from the identified hazards.

1.5.1. Pathogens

It was assumed that the Googong WTP would be run so as to consistently provide a 4 $\log_{10}$ *Cryptosporidium* reduction performance. Under these conditions, even allowing for no dilution or inactivation within the reservoir, *Cryptosporidium* would be reducible to tolerable levels through the Googong treatment plant, as against the WHO (2008) 1 µDALY or USEPA (2006) 10^{-4} infection annual additional personal health-based targets. The presence of the reservoir provides an additional barrier to *Cryptosporidium* beyond just the WTP so that the system is not 'single barrier'. The reservoir would be expected to provide at least an additional 2 $\log_{10}$ reduction of *Cryptosporidium*, so in total, up to 6 $\log_{10}$ *Cryptosporidium* reduction, with two barriers.

In conclusion, the M2G arrangement was predicted to present a tolerable risk to drinking water consumers from pathogens as judged against the most conservative contemporary benchmarks internationally.

By way of comparison, it was noted that the sum of the pathogen reduction achieved by the Googong WTP and Googong Reservoir combined was similar to that achieved by the Mt Stromlo WTP. The Mt Stromlo WTP achieves approximately 4 $\log_{10}$ *Cryptosporidium* reduction from the filtration system and 2 $\log_{10}$ *Cryptosporidium* reduction from the UV plant, totalling 6 $\log_{10}$ *Cryptosporidium* reduction, with two barriers. The Mt Stromlo WTP draws water directly from the Murrumbidgee River and does not employ a reservoir, giving this direct run-of river source a higher unmitigated risk level than the M2G arrangement. However, both supplies mitigate risks to an equivalent level through the effect of the UV disinfection system for Mt Stromlo WTP or the Googong Reservoir for the Googong WTP and M2G arrangement. It was also noted that storm inflows from the Burra Creek into the Googong Reservoir have similar or higher pathogen concentrations to those that would be harvested from the Murrumbidgee River source. Therefore, with respect to pathogens, the effect of instigating the M2G arrangements would not be expected to result in any change to the current maximum challenge to, nor the operation of, the Googong WTP, such that M2G would present no significant additional risk from pathogens to drinking water consumers.

As a supporting conclusion, the M2G arrangement was predicted to present no additional risk to drinking water consumers from pathogens as compared with current water supply arrangements in the ACT.

1.5.2. Cyanotoxins

It was assumed that the Googong WTP could be run so as to consistently provide 90% reduction of microcystin mLA. Under these conditions, even allowing for no dilution and no inactivation within the reservoir, microcystin mLA would be reducible to 1.1 µg/L through the chlorination taking place at the Googong WTP, a value below the 1.3 µg/L ADWG lifetime exposure guideline value.

In practice, the reservoir dilution effects, and the selective depth offtake options, would be expected to yield significant additional reduction of cyanotoxins. Furthermore, powdered activated carbon could be dosed to provide some additional cyanotoxin reduction or to control cyanotoxins that are not chlorine-sensitive.

In conclusion, the M2G arrangement was predicted to present a tolerable and manageable risk to drinking water consumers from cyanotoxins as judged against the most appropriate guidelines.

The presence of reservoir dilution, selective depth offtake, chlorination and powdered activated carbon provides additional barriers to cyanotoxins so that the system is not single barrier. Furthermore, the highly elevated cyanobacterial concentrations predicted at worst-case would occur approximately 10 km from the offtake point during dry periods, making the risk assessment highly conservative. Therefore, for practical purposes, the effect of the M2G would not be expected to result in any short-term change to the current operation of the Googong WTP and can be considered to represent no significant additional risk.

Over the long-term, an increase in nutrient loads to the Googong Reservoir, estimated to be an approximately 700 kg additional total phosphorus input per year, or approximately 30% above current loads, would be expected to increase the likelihood, severity and duration of problem phytoplankton events within Googong Reservoir. Problem phytoplankton events can yield hazardous levels of cyanotoxins, including saxitoxins and microcystins, as well as taste and odour compounds, such as geosmin and 2-methylisoborneol. The effect of the introduction of the M2G arrangement would not represent a step change in the risk profile of Googong Reservoir since the reservoir already experiences problem phytoplankton events. However, the introduction of the M2G arrangement would lead to a small incremental increase in risks to drinking water quality posed by phytoplankton, and an associated increase in management costs, for the Googong Reservoir and Googong WTP system.

1.5.3. Local impacts

Water flowing via the Burra Creek would not be expected to form algal blooms. The nutrient concentrations in the Murrumbidgee River source are not particularly elevated and are comparable to those found during natural flows within the Burra Creek. Furthermore, the presence of a continuous flow will prevent bloom formation in flowing waters and may in fact reduce bloom formation within this stretch of the river. However, occasional significant phytoplankton blooms (which would consist of various species and types) were predicted to occur in the Burra Creek arm of Googong Reservoir by the GHD (2009) modelling. An ongoing low rate inflow of Murrumbidgee River water to a relatively shallow and quiescent arm of the Googong Reservoir would be different to the normal hydrodynamics of that site. This represents a locally significant step change that does not have major implications for public health or drinking water supply, but that may affect public perceptions, and public perceptions of public health. Locally elevated phytoplankton blooms within the Burra Creek arm of the reservoir could have an unpleasant appearance and odour and could hamper recreational and aesthetic values for the site.

1.6. Conclusions

The introduction of the M2G arrangements represents a tolerable and manageable risk to the quality of the Googong drinking water supply system from both a public health and operational perspective.

1.6.1. Pathogens

Mitigated risks to the drinking water supply arising from pathogens following the introduction of the M2G arrangements were predicted to be reducible to tolerable levels as well as being equivalent to the currently tolerated mitigated risks presented to the current Googong and Mt Stromlo water supply systems. Therefore, risks associated with pathogens arising from the introduction of the M2G arrangements were considered tolerable and equivalent to currently accepted risks.

1.6.2. Cyanotoxins

Mitigated risks to the drinking water supply arising from cyanotoxins following the introduction of the M2G arrangements were predicted to be reducible to tolerable levels, albeit incrementally above currently tolerated mitigated risks within the Googong water supply system. Therefore, risks associated with cyanotoxins arising from the introduction of the M2G arrangements were considered tolerable, manageable and only incrementally elevated compared with currently accepted risks.

1.6.3. Local impacts

Mitigated risks of local impacts from visible, and possibly odorous, algal blooms in the Burra Creek arm of Googong Reservoir need to be considered for their impacts on public perception in the short-term. These risks may not be significant in terms of public health but may affect recreational and aesthetic values locally and may have broader public perception implications.

1.7. Recommendations

1.7.1. Selective pumping

Major spill or contamination events, or highly contaminated fresh runoff from major storms following prolonged dry periods within the Upper Murrumbidgee Catchment, should lead to cessation of pumping. To avoid transferring the five to ten percent of the Murrumbidgee River flows with the highest nutrient and turbidity concentrations, an abstraction shut-off trigger of 100 NTU is recommended. In addition, to avoid transferring unknown contaminants into the Googong Reservoir from the Murrumbidgee River source water, an abstraction shut-off trigger in response to reported spill or contamination events is recommended.

1.7.2. Contingency planning

Over the long-term, the nutrient balance of Googong Reservoir will be altered by the introduction of the M2G arrangements. The effect of increased phosphorus loads is likely to increase the extent, duration and severity of cyanobacterial and other phytoplankton-related problems, such as taste, odour and toxin formation, as well as nuisance issues. Nuisance issues might include local visual amenity and odour impacts as well as operational issues such as filter blocking algae. It is recommended that over the medium-term, planning be undertaken to prepare for incremental increases in management costs for the Googong water supply system arising from M2G.

2. System Description

A concise description of the Murrumbidgee to Googong Raw Water Transfer (M2G) is given in Table 2-1 and illustrated in Figure 2-1 (discharge point) and Figure 2-2 (raw water pumping station abstraction point).

Table 2-1. Concise system description.

Component	Description
Catchment	Water will be drawn from the Murrumbidgee River at Angle Crossing. The catchment as a whole include a range of activities and landuses including native forest, recreation, forestry, extensive grazing, rural residential and urban. A detailed catchment risk assessment has been published previously (Davison and Deere 2006; 2007).
Transport	Transport of the abstracted water will via pumps through a pipeline to Burra Creek and then via Burra Creek to Googong Reservoir. Water will be discharged approximately 7.5 km upstream of the main reservoir body and approximately a further 10.5 km upstream from the dam offtake point, approximately 18 km by water total travel distance.
Storage	Storage of the abstracted water will be within the Googong Reservoir.
Treatment	Treatment of the water will be at the currently existing facilities at Googong Water Treatment Plant (as described in the current version of ActewAGL's HACCP Plan). Treatment begins with conventional coagulation, flocculation, sedimentation and media filtration. Disinfection is undertaken using free chlorination. There is the option to dose powdered activated carbon to reduce concentrations of taste and odour compounds and cyanotoxins.
Distribution	Distribution of the treated water is via a closed distribution system of pipes, pumps and closed storages, as described in the current version of ActewAGL's HACCP Plan.

Figure 2-1. Map showing discharge point of the Murrumbidgee River source water into Burra Creek as well as the offtake tower that supplies water from the Googong Reservoir to the Googong Water Treatment Plant (base map: © Google maps).

Figure 2-2. Map showing the abstraction point at Angle Crossing were water will be drawn from the Murrumbidgee River for pumping to the Burra Creek discharge point (base map: © Google maps).

3. Water Quality Data Analysis

3.1. Reference sites

Recent data from ActewAGL's water quality monitoring program was assembled by Teresa Morey's team. Long-term data was downloaded from the ACT Government web site directly. The quantity and quality of water quality data was excellent for both the Googong Reservoir and the Murrumbidgee River. Water sampling site MUR 213, and Lobbs Hole flow gauging station site 410761, were considered to be those most representative of water quality and flow rate, respectively, at the *abstraction point* (Figure 3-1). Googong Dam sampling site GOO 724 (6 km upstream of offtake, most upstream sampling point inundated in recent years) was considered representative of water quality at the probable *receiving environment* (Figure 3-1). Site GOO 729 (Burra Ck arm) was theoretically more suitable than GOO 724, but GOO 729 lacked data for prolonged recent dry years, hence GOO 724 was analysed in the most detail.

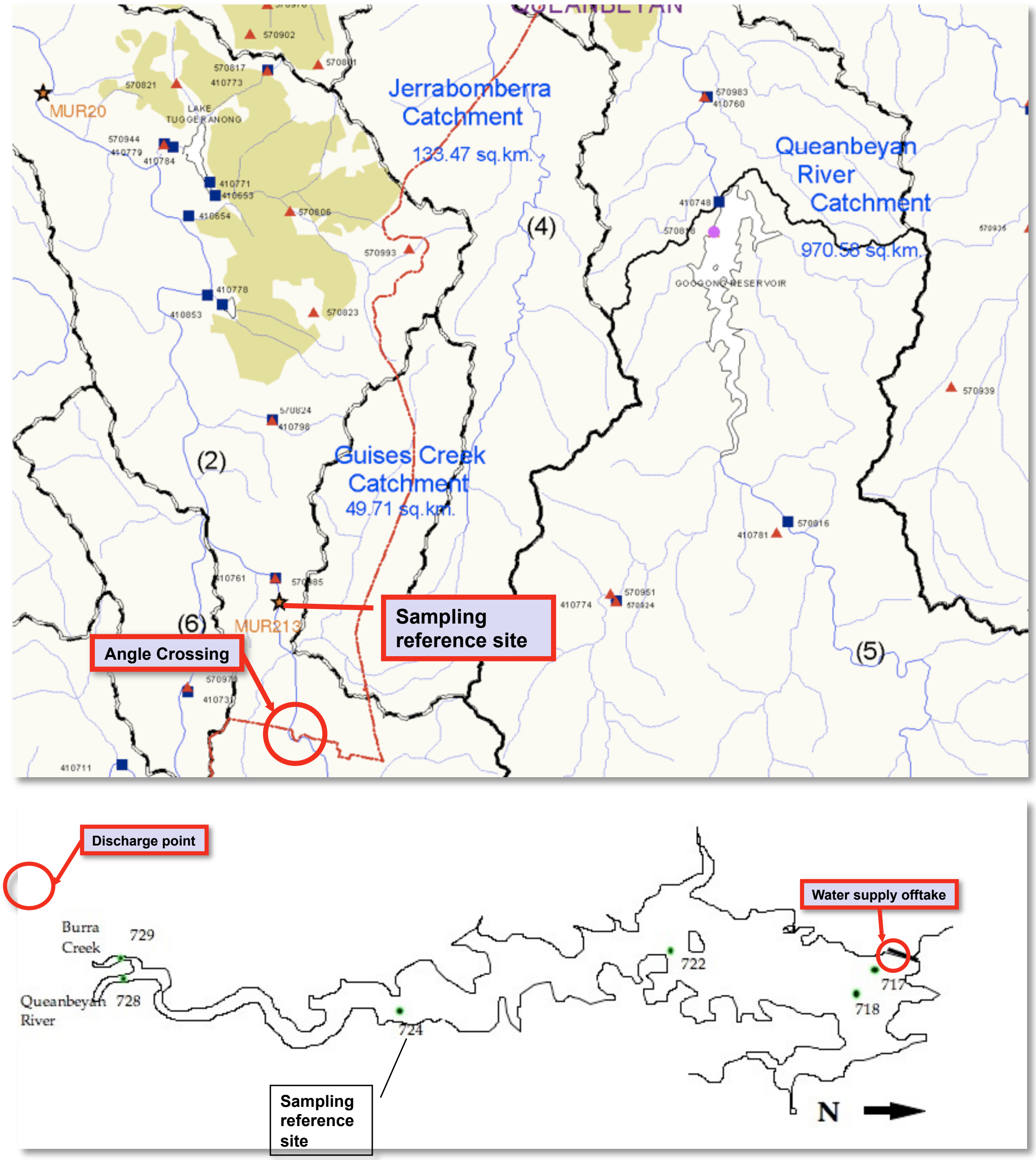

Figure 3-1. Illustration of sampling sites used in the data analysis. The upper map plot shows the catchment sampling sites whilst the lower sketch plot shows the Googong Reservoir sampling sites.

3.2. Summary of water quality data

Summary tables and plots relating to the assessed water quality data are given in Sections 7 and 8 (river) and Section 9 (reservoir). Summary statistics are given as tables in Section 7 whilst plots are given as time series and trendlines in Sections 8 and 9. Analysis of the water quality data revealed several important features. Over the past ten years, for most parameters for which trends were assessed, the water quality appears to be becoming less favourable to drinking water supply in both the Murrumbidgee River source and the Googong Reservoir receiving environment. The most marked adverse changes in water quality, where concentrations were increasing over time, for the Murrumbidgee River source were:

- total algae;
- total phosphorus;
- total nitrogen;
- turbidity;
- reactive phosphorus;
- chlorophyll *a*; and
- ammonia.

The most marked adverse changes in water quality, where concentrations were increasing over time, for the Googong Reservoir receiving environment were:

- faecal coliforms;
- total algae;
- total cyanophyta;
- total phosphorus;
- total nitrogen;
- turbidity;
- chlorophyll *a*; and
- ammonia.

This observation had several implications. Firstly, the water quality data analysis was largely limited to data from just the past ten years. Some scattered data from 1976 onwards was reviewed by was not used to contribute to the statistical analysis and trend analysis. Secondly, and more importantly, it is likely that Googong Reservoir will experience increased adverse phytoplankton events over the longer term, even without the input of the Murrumbidgee River. Finally, the use past events is of limited value in predicting future risks in a situation where the water quality appears to be changing.

For most parameters for which comparisons were made, the water quality was less favourable to drinking water supply in the Murrumbidgee River source than in the Googong Reservoir receiving environment as measured with respect to the average (Figure 3-2) or ninety-fifth percentile (Figure 3-3) values. The most marked and important adverse differences in water quality, where concentrations were greater for the Murrumbidgee River source than the Googong Reservoir receiving environment, are illustrated most readily with reference to Figure 3-4, and were:

- faecal coliforms (river over twenty-fold higher than reservoir);
- total phosphorus (river over three-fold higher than reservoir);
- turbidity (river over ten-fold higher than reservoir); and
- reactive phosphorus (river over two-fold higher than reservoir).

This observation means that prima facie the addition of the Murrumbidgee River source water to the Googong Reservoir receiving environment will not be favourable, and may lead to an increased risk of adverse water quality within Googong Reservoir.

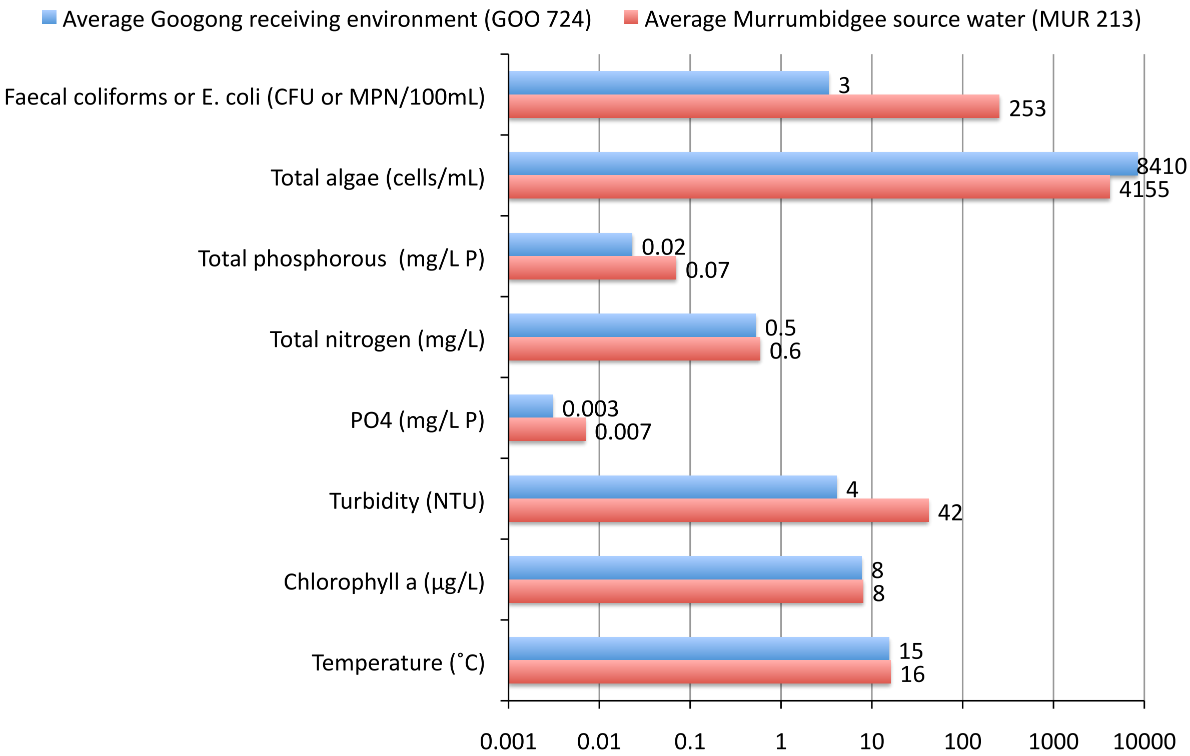

Figure 3-2. Comparison of the arithmetic mean ten-year average concentrations of selected determinands in the Murrumbidgee River source with the Googong Reservoir receiving environment.

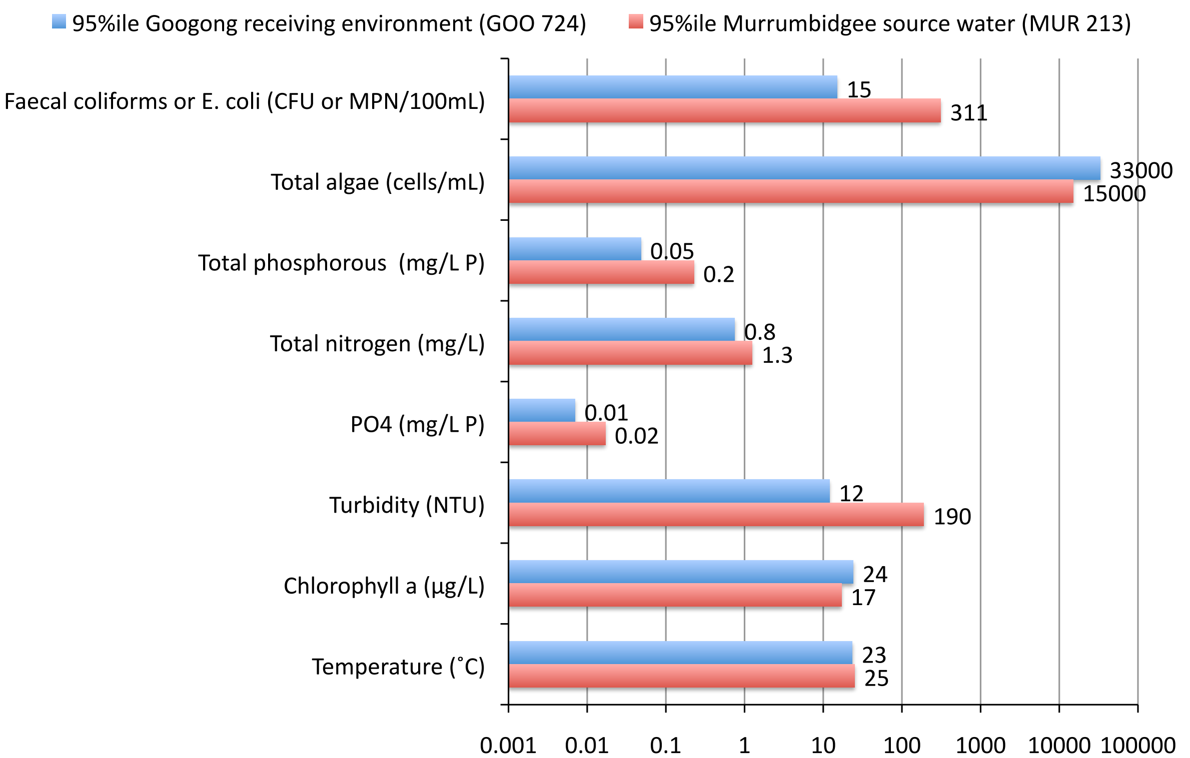

Figure 3-3. Comparison of the ninety-fifth percentile ten-year concentrations of selected determinands in the Murrumbidgee River source with the Googong Reservoir receiving environment.

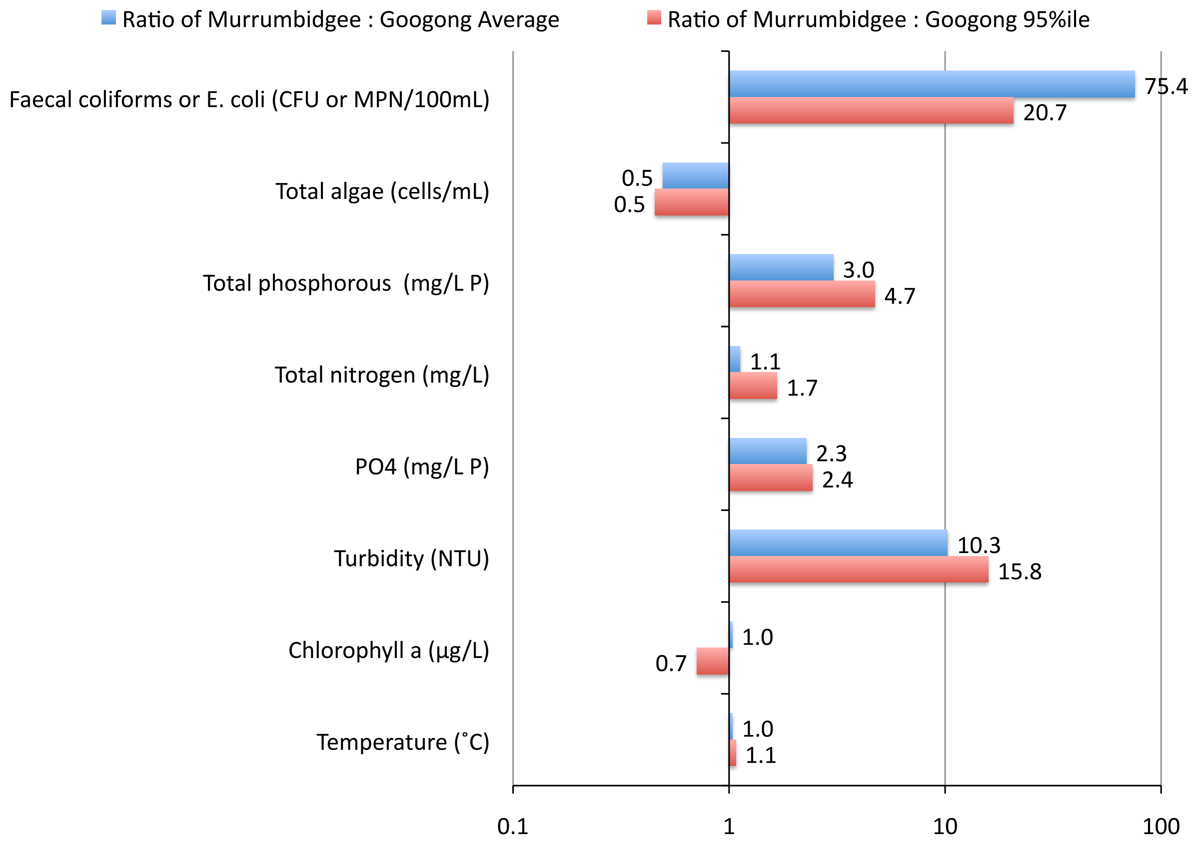

Figure 3-4. Comparison of the ratios of the ninety-fifth percentile and average ten-year concentrations of selected determinands in the Murrumbidgee River source with the Googong Reservoir receiving environment.

4. Hazard Identification and Risk Analysis

4.1. Hazard identification

Hazard identification involves determining which hazards and hazardous events are to be considered.

4.1.1. Overview

There are hundreds of water quality hazards for which health-based guidelines have been developed and that are listed within the *Australian Drinking Water Guidelines 2004* (ADWG). Listing within the ADWG implies that there is prior experience of the listed characteristic being problematic in water supply. Theoretically, all such hazards are worthy of consideration in a Quantitative Risk Assessment (QRA), as are any other hazards that might be present in the Murrumbidgee River, or that might arise in the Googong Reservoir as a result of the introduction of the M2G arrangements.

In practice, very few hazards are likely to be present at concentrations of relevance to health in the Murrumbidgee River, or within the Googong Reservoir arising as a result of the introduction of the M2G arrangements. Furthermore, of the hundreds of hazards identified in the ADWG, a small number of the most prevalent and hazardous substances can be considered as the 'limiting hazards'. Risks from limiting hazards, and actions taken to mitigate those risks to tolerable levels, correspond to risks from, and actions required to manage, all other relevant hazards to tolerable levels. The limiting hazards identified for consideration within this QRA were identified as follows.

4.1.2. Analysis of previous risk assessments

Based on previous catchment inspection work, a concise summary of the hazards arising in the source water (Murrumbidgee River) is given in this section. The analysis extracts some key points from previous reports produced for ActewAGL to inform catchment management planning for the ACT's Murrumbidgee River sources (Davison and Deere 2006; 2007) and the Googong Reservoir (Contos et al 2007). The previous reports should be referred to for further information. As part of this prior work, a detailed sanitary survey was undertaken using a helicopter over flight and photography to observe and record the condition of the catchment in 2006, and ground surveys were undertaken during 2007.

The level of grazing animal access to the river was extensive and it would be expected that in both dry and wet weather flows microbial pathogens and indicators would be present at potentially significant concentrations, particularly during any calving or lambing periods. From a water quality protection perspective, the grazing land was found to be poorly managed. Containment of the large pollution sources, such as wastewater, extractive industry dams and stormwater, appeared to be good during dry weather conditions. Therefore, water quality risks were predicted to be very much more pronounced during higher rather than lower flows.

There were a number of road crossings in the catchment. In terms of risk, the further downstream, the more road crossings there are and the greater the potential for spills to occur. Spills can be of any substance and can occur in any weather with no warning.

The upper Murrumbidgee River catchment is primarily an 'extensive grazing' catchment. If poorly managed, such catchments typically yield moderately high particulate phosphorus and turbidity as well as often moderate, and occasionally high, microbial indicators and bacterial and protozoan pathogens.

From a water quality hazard perspective, qualitatively, the upper Murrumbidgee River catchment to Angle Crossing is reasonably comparable to the Googong Reservoir catchment, particularly to the Burra Creek catchment. Measured pathogen, microbial indicator and nutrient concentrations have previously been compared and were found to be reasonably comparable for the Burra Creek arm of the Googong Reservoir and the Murrumbidgee River. Therefore, the M2G scheme does not present a fundamentally different water quality range, nor new type of hazard, beyond those experienced by Googong Reservoir historically.

4.1.3. Pathogens

Enteric pathogens are singled out as the most important hazards in water supply in the introductory material given in the ADWG and the WHO *Guidelines for Drinking-water Quality 2008* (GDWQ). The first priority in this QRA was to consider enteric pathogens. There are hundreds of enteric pathogens, but for the purposes of risk assessment, it is possible to consider three reference pathogens (WHO 2008). The hazards to be considered are human infectious genotypes of *Cryptosporidium* spp. oocysts (representing protozoan pathogens), *Campylobacter jejuni* (representing bacterial pathogens) and human rotavirus (representing viral pathogens).

With respect to the M2G, the hazard identification can be further narrowed down by consideration of the barriers in place. Infectious oocysts of *Cryptosporidium parvum* or *C. hominis* (referred to hereon simply as *Cryptosporidium*) is in practice the limiting hazard for pathogens. *Cryptosporidium* will arise from both stock and human faecal pollution sources, whereas important enteric viral hazards will only arise from human faecal pollution sources, making *Cryptosporidium* more likely to be found at hazardous concentrations in what is, largely, a grazing-impacted rather than human-impacted catchment. Furthermore, of the protozoan parasites of relevance to water supply, *Cryptosporidium* is more resistant to environmental and treatment effects than other hazards, such as cysts of *Giardia* spp. Finally, *Cryptosporidium* oocysts are only removed by one barrier in the Googong water supply system: the water filtration plant, whereas bacteria and viruses, and to some extent *Giardia*, are inactivated by chlorine. Free chlorine is a highly effective disinfectant for bacteria and viruses in filtered water making *Cryptosporidium* oocysts far more likely to present risks to health than viral or bacterial pathogens in the Googong water supply system.

This singling out process does not mean that there are not other hazards presenting additional risks. However, the identification of the limiting hazards is useful in assessing risks since, once managed to tolerable levels, other relatively smaller risks will also be tolerably controlled. In this case, if risks arising from *Cryptosporidium* oocysts were adequately managed through source control and filtration mitigation measures, then due to the presence of the additional chlorine barrier for the other waterborne enteric pathogens, risks from these other pathogens would be more than adequately managed.

In conclusion, human infectious genotypes of *Cryptosporidium* spp. oocysts (referred to hereon simply as *Cryptosporidium*) were considered to be the limiting microbial hazard identified for analysis in the risk assessment.

4.1.4. Chemicals

Chemical hazards are generally of secondary consideration for surface water supply (ADWG, GDWQ). In groundwater supplies, arsenic, fluoride, uranium and nitrate are sometimes found at hazardous concentrations. However, for large surface water reservoirs with long residence times receiving relatively small inflows, the effects of sedimentation, dilution, adsorption, volatilisation, photolysis and biotransformation collectively reduce most foreseeable chemical and physical hazards to below levels of health significance. Furthermore, the catchment of the Angle Crossing abstraction point is in NSW. Under the Department of Environment and Climate Change (DECC) and subordinate local government obligations, NSW has active Hazardous Waste Tracking systems for hazardous chemical management as well as systems for the control of agricultural chemicals (in this largely agricultural and non-industrial catchment) through the *Pesticides Act 1999* (NSW).

In general, within Australia it is rare, if not unheard of, for most chemical and physical hazards to be present at concentrations of health concern in surface waters supplies drawn from large reservoirs. Occasionally potentially hazardous chemicals are detected, but typically below lifetime exposure guideline values. Even where guideline values are exceeded, the exceedance is typically only moderate in magnitude and short in duration, not representing significant health risks when compared with lifetime exposure guideline values.

A review of extensive water quality test results from the Murrumbidgee River, including metal scans and various organics scans, did not reveal any hazards at concentrations of concern. Furthermore, there is no evidence from catchment surveys of other high output sources of chemicals of concern in the catchment. Therefore, no other hazards were considered to be likely to reach hazardous concentrations, either acutely hazardous concentrations for short periods, or chronically hazardous concentrations for long periods. It is true that additional inputs of hazards substances such as turbidity, colour and nutrients will be introduced into the Googong Reservoir by the M2G arrangements. However, given the dilution effects anticipated, and the fact that these substances aren't in themselves harmful, these characteristics were not included in the QRA.

A notable exception to the above conclusions is cyanotoxins. It is not uncommon for cyanotoxins to reach in excess of lifetime exposure health-related guideline values in Australian surface water reservoirs, including Googong Reservoir. Therefore, cyanotoxins were considered in this study. Within the broad set of cyanotoxins, within Australia, the most commonly identified, most toxic and best characterised and most amenable to consideration in a QRA are the microcystins, of which mLR and mLA are the most toxic. The cyanotoxin mLA is somewhat less readily removed by treatment than mLR and was, therefore, considered the limiting hazard for cyanotoxins.

It is noted that other toxins, such as saxitoxins might be more prevalent within Googong Dam than microcystin since *Anabaena* spp. has been a common component of the phytoplankton. In addition, cylindrospermopsin is increasingly being reported within Australia. However, there is relatively less data and information about these toxins compared with microcystins with which to conduct a risk assessment. It was considered that, provided risks arising from mLA could be mitigated to tolerable levels, risks from other toxins were considered to be potentially controllable to tolerable levels. In that sense, mLA is fulfilling the same role here for cyanotoxins as the reference pathogens, such as *Cryptosporidium* spp. oocysts, fulfilled for the pathogens.

In conclusion, microcystin mLA was considered to be the limiting chemical hazard identified for analysis in the risk assessment.

4.1.5. Hazardous events

The construction phase of the project will have strict requirements placed upon it to control local water quality impacts. The strictness of the controls on local water quality impacts will more than adequately mitigate downstream impacts, such as effects on the currently used downstream Cotter Pump Station abstraction point, and effects on the initial stages of the M2G project.

There are no specific very high hazard sources in the immediate vicinity of the proposed abstraction point. Inputs are largely diffuse and limited to wool and beef grazing, some small sewage treatment plants many km upstream of the offtake point, some small unsewered townships and some low-density water-based recreational activity and vehicular access. These inputs are not anticipated to significantly change in the foreseeable future.

The review of water quality monitoring data from the Murrumbidgee River source and from the Googong Reservoir receiving environment of the M2G demonstrates a gradual deterioration in water quality over the past ten years. Water quality at the Angle Crossing abstraction point is not considered to present any higher unmitigated risk to water quality than is the current abstraction from the Cotter Pump Station site or the current Googong Water Treatment Plant challenges arising due to the current Burra Creek inflow.

Major spill or contamination events, or highly contaminated fresh runoff from major storms following prolonged dry periods within the Upper Murrumbidgee Catchment, should lead to cessation of pumping until water safety can be established. Risks from such events were not assessed since this is a standard precaution in selective water supply abstraction which is assumed to apply, making assessment of such events unnecessary. However, trigger values for ceasing to pump were considered and are given in concluding sections of this report.

Short-term hazardous events, such as construction phase, were considered to present no significant risks to drinking water quality due to the restrictions placed upon them to protect local water quality objectives.

Long-term hazardous events were considered to be consistent with current hazardous events occurring within the Upper Murrumbidgee Catchment, making recent experiences with testing and harvesting water from this catchment likely to be representative of the future situation.

4.2. Pathogen exposure assessment

Comparison of risks with qualitative and quantitative benchmarks was used to assess the existing mitigation measures to enable the need for any additional controls to be assessed and the quantitative capability of additional controls (if considered necessary), to be recommended. The pathogen risk is strongly determined by riverine inflows and pumped inputs (Brookes, et al., 2004, 2005; Hipsey et al., 2004, 2005, 2007). This risk can be mitigated by knowing where the riverine inputs intrude into the reservoir, the dilution during travel and by selection of an offtake outside of this zone. Depending upon the size of the reservoir and the flow rate of the input, the pathogen risk may present a challenge at the offtake on timescales of hours to several days. However, the M2G inflow is relatively small compared to the volume of the Googong Reservoir. As a result, modelling of pathogens in Googong Reservoir undertaken for ActewAGL indicates that, using conservative assumptions, there would be estimated to be > 2-log reduction in infectious *Cryptosporidium* oocyst concentrations between the inflow to Burra Creek and the water supply offtake (GHD, 2009).

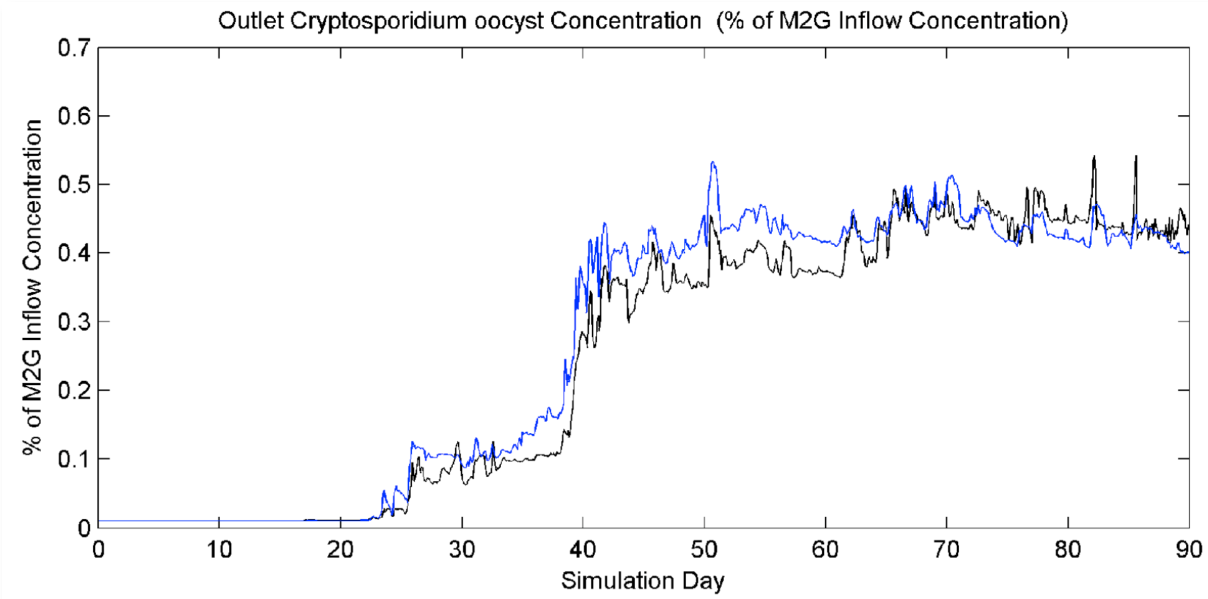

Figure 4-1. Outlet *Cryptosporidium* concentrations conservatively estimated under cool period winter conditions as a percentage of the inflow concentration for 80% and 40% storage volumes (black and blue plot lines, respectively). Note that the outlet *Cryptosporidium* concentration does not rise above 1% of the inflow concentration – a > 2-log reduction. Figure extracted from GHD (2009).

4.3. Pathogen dose-response and risk characterisation

4.3.1. Australian Drinking Water Guidelines approach

The *Australian Drinking Water Guidelines 2004* (ADWG) are relatively non-prescriptive and do not set out quantitative treatment requirements for public water supplies to remove pathogens. The ADWG promote a catchment to tap multiple barrier risk management system including the following:

- A catchment protection program informed by event-based monitoring and sanitary surveys to achieve the control of human and animal wastes.
- Filtration of water from unprotected catchments to respond to risks from *Cryptosporidium*.
- Adequate disinfection to inactive pathogens wherein a turbidity of < 1 NTU is desirable at the time of disinfection if disinfection is required.
- If chlorine is used, the pH should be appropriate and the total chlorine residual after 30 min should be at least 0.5 mg/L.

The M2G arrangements would conform to the ADWG. The ADWG refer to the need to match the specific treatment requirements to the level of source water contamination and the ADWG make references to USEPA publications implying that these are the appropriate source of information for doing this. Therefore, in addition to recommending compliance with the ADWG, recommended pathogen removal/inactivation targets that would reduce risks to acceptable levels were based on the following guidance, being the most stringent of the international benchmarks of relevance to the current situation:

- World Health Organization (WHO) *Guidelines for Drinking-water Quality 2008* (GDWQ): Recommended concentration associated with a 1 µDALY (disability-adjusted life years) additional annual per person disease burden risk given 2 L of water consumed per person per day for the three reference pathogens *Cryptosporidium*, *Campylobacter* and rotavirus.
- United Stated Environmental Protection Agency (USEPA) *Long-term 2 Enhanced Surface Water Treatment Rule 2006* (LT2) and *Surface Water Treatment Rule 1989* (SWTR): Recommended log removals based on their four-tier *Cryptosporidium* risk classification and the requirement for three and four log removal of *Giardia* and viruses respectively.

The Drinking Water Inspectorate (DWI) for England and Wales *Water Supply (Water Quality) Regulations 2000* (DWI) benchmark of 1 infectious *Cryptosporidium* oocyst per 10 L is less stringent than the US and WHO guidelines given above and, therefore, was not considered in this analysis. The treatment recommendations of the Guidelines for Canadian Drinking Water Quality (1996) (Health Canada 2004a, b) and the NZ Ministry of Health *Drinking Water Standards New Zealand 2007* are more or less identical to the USEPA regulations in this respect.

4.3.2. WHO Guidelines for Drinking-water Quality approach

Pathogen removal/inactivation recommendations against the WHO *Guidelines for Drinking-water Quality 2008* (GDWQ) were made by comparing observed oocyst counts with GDWQ guideline values (Table 4-1). The calculation was made assuming ninety-fifth percentile and maximum previously observed levels of challenge, optimal water treatment plant (WTP) operations and dilution and inactivation in reservoir as modelled by GHD (2009).

With the M2G arrangements in place, provided the Googong WTP performed optimally, additional treatment was not predicted to be necessary to conform to the GDWQ recommendations. The 4 $\log_{10}$ reduction predicted through water treatment coupled with the 2 $\log_{10}$ reduction predicted through reservoir attenuation provides more than the recommended 3 to 4 $\log_{10}$ reduction required under the GDWQ system. Specifically, 6 $\log_{10}$ reduction was predicted, equivalent to that estimated to be achieved by the Mt Stromlo WTP. In addition, the reservoir provides 2 $\log_{10}$ reduction, an additional barrier, equivalent to that provided by UV at Mt Stromlo WTP.

Microbial water quality results are notoriously variable. Therefore, an important caveat in interpreting this assessment is that the conclusions are based on a reasonable but not exhaustive dataset. Different river flow and catchment antecedent conditions from those preceding the sampling days, or possible spills from faecal and sewer waste containment systems and sewage conduits, may give rise to very different outcomes.

Another limitation of this assessment is that it assumes treatment systems are working and that dilution and inactivation effects are as expected. In practice, multiple barriers are recommended in safe water supply management (ADWG). Therefore, options that are predicted to only just reach the recommended log reduction capability are not considered to comply with the intent of the ADWG in this regard. The ADWG recommend 'multiple barriers' to protect from risks associated with microbial pathogens. Therefore, it is recommended that one or more additional barriers, such as selective pumping avoiding extremely contaminated runoff, be used to help mitigate such risks. However, unlike the Mt Stromlo situation, where UV disinfection was required, for the M2G arrangements, additional treatment at Googong WTP, such as using UV or ozone disinfection, does not appear to be required. Ideally, experience with field operation of the system would be gained to be fully confident in that assessment. Modelling and monitoring can be used to validate the dilution and time delay within the reservoir over time. With good dilution and prolonged time periods in the reservoir, pathogens are effectively inactivated, obviating the need for additional disinfection. Avoiding abstraction during periods where short-circuiting might occur within the reservoir could help further extend the value of the reservoir as a barrier.

Table 4-1. Predicted capability of current dilution and treatment systems to reduce 95th percentile and maximum observed *Cryptosporidium* spp. oocyst challenge concentrations to tolerable levels.

Concentration of hazards						Log_{10} reductions					
Raw[1]			GDWQ Target			Target	Filter[2]	Cl_2	Dilution and inactivation[3]	Total	Safety Margin
#	Vol	Unit	#	Vol	Unit						
3.1 (95%ile)	10	L	6.3	20,000	L	3.0	4.0	0	2.0	6.0	3.0
40.0 (maximum)	10	L	6.3	20,000	L	4.1	4.0	0	2.0	6.0	1.9

[1]Based on measured *Cryptosporidium* spp. oocyst concentrations in the Murrumbidgee River at Angle Crossing (MUR 213) (Table 7-1).

[2]Based on LT2 log reduction credit process.

[3]Estimated from GHD 2009.

4.3.3. USEPA Surface Water Treatment Rule approach

The log removal/inactivation requirements under LT2 for *Cryptosporidium* are very detailed. Two years of fortnightly pathogen monitoring to gather 48 samples is required to inform the process. A four-level rating scale is used in which arithmetic mean oocyst concentrations of ≥ 3/L are 'Bin 4', ≥ 1 to < 3/L are 'Bin 3', ≥ 0.075 to <1/L are 'Bin 2' and < 0.075 are 'Bin 1'. Bins 1 to 4 attract total $\log_{10}$ treatment removal/inactivation requirements of 2.5 to 3, 4, 5 and 5.5 respectively. For the Murrumbidgee River source at Angle Crossing, monitoring of *Cryptosporidium* spp. oocysts over three-and-a-half years, gathering 93 samples, including from storm events, has reported an average oocyst concentration of < 0.18/L, which is within the 'Bin 2' category.

LT2 and its predecessor rules provide 'log credits' for particular treatment processes. By comparing treatment capability with treatment recommendations, additional treatment requirements can be defined (Table 4-2). In practice, the correct point for monitoring against LT2 would not be Angle Crossing but the Googong Reservoir raw water intake itself. Therefore, it is difficult to directly apply the LT2 to the Googong system and some assumption about the probable log reduction across the Googong Reservoir would need to be made and combined with log reduction credits for the Googong water treatment plant. Such an assessment does not suggest that the M2G would be theoretically unacceptable provided the Googong Treatment Plant operated optimally.

It is possible for the Googong Treatment Plant to achieve the required 4 $\log_{10}$ reduction credit required for raw water in the LT2 Bin 2 category. The credit can be achieved by gaining 3.5 $\log_{10}$ for the WTP and 0.5 $\log_{10}$ for the catchment, or 4 $\log_{10}$ for the WTP. However, as noted for the assessment against the GDWQ, the extent to which a reliance on optimal operation and multiple barrier safety could be placed on the reservoir is yet to be determined. The nature of any recommendation depends crucially on the effectiveness of the Googong Reservoir as a barrier. Since a 2 $\log_{10}$ removal/inactivation capability is assumed for the Googong Reservoir (based on GHD 2009), it is likely that the existing treatment system could adequately mitigate the *Cryptosporidium* risk to comfortably comply with LT2 recommendations.

Table 4-2. Log reduction under the LT2 system.

Process step	**Log credit**	**Summary of requirements** (the full USEPA rules should be consulted for full details)	**Reference**
Cryptosporidium oocysts (4 $\log_{10}$ required for most probable 'Bin' classification)			
Catchment protection	0.5 $\log_{10}$	○ State must approve a Watershed Control Plan ○ Identify 'area of influence' ○ Identify potential and actual sources and relative impact ○ Analyse effectiveness and feasibility of control measures ○ Set goals and specific actions to reduce sources ○ Identify watershed partners and their roles ○ Identify resource requirements and commitments ○ Include a schedule and plan with deadlines for actions ○ Submit annual status report to the state ○ Sanitary survey every 3 years	LT2ESWTR p 685 (pdf 33) and p 778 (pdf 126)
Conventional filtration	3.0 $\log_{10}$	○ Combined filter effluent in ≥ 95% of measurements ≤ 0.3 NTU in each month; Sampling rate at least 4-hourly ○ Monitor individual filter effluent on line and report every 15 mins and follow up exceedances > 0.5 NTU	LT2ESWTR p 678 (pdf 26)
Chlorine disinfection	0	○ Not effective	LT2ESWTR p 663 (pdf 11)
Combined filter performance credit	0.5 $\log_{10}$	○ ≥ 95% of measurements ≤ 0.15 NTU in each month ○ Sampling rate at least 4-hourly	LT2ESWTR p 685 (pdf 33)
Individual filter performance credit	0.5 $\log_{10}$	○ ≥ 95% of measurements ≤ 0.15 NTU in each month and no two sequential samples > 0.3 NTU ○ Sampling rate at least every 15'	LT2ESWTR p 685 (pdf 33)
Total process	3.0 $\log_{10}$	○ Filtration process only	
Total process	3.5 $\log_{10}$	○ Filtration combined with watershed control program credit or one of the filter performance credits	
Total process	4.0 $\log_{10}$	○ Filtration combined with both of the filter performance credits or the watershed control program credit and one of the filter performance credits	
Total process	4.5 $\log_{10}$	○ Filtration combined with watershed control program credit and both filter performance credits	

4.3.4. Summary of pathogen-related recommendations

In summary, the following conclusions arise from the quantitative analysis of risks associated with pathogens:

- The Googong Treatment Plant includes a free chlorination disinfection process. Therefore, due to its resistance to this disinfectant, infectious *Cryptosporidium* spp. oocysts were identified as the limiting hazard from a microbial risk perspective.
- Microbial monitoring provided samples that were used to provide statistics for oocyst concentrations in the raw water.
- Comparing measured oocyst concentrations with drinking water quality and treatment recommendations from the WHO GDWQ and USEPA LT2 identified that, provided the Googong WTP was performing optimally, risks were likely to be tolerable for the M2G.

4.4. Cyanotoxin exposure assessment

The concentrations of N, P and cyanobacteria that might be pumped into Googong from the Murrumbidgee River are not particularly high in comparison to current inputs. Therefore, the concentrations *per se* are not a cause for concern for the reservoir. However, the additional loading of these hazards, and the ongoing baseflow loading of these hazards, might be a cause for concern, depending on how much water was being pumped and what happened in the receiving environment.

As a general principle, from a water quality perspective, water should enter the reservoir as far as practically possible from the point of water extraction. This will reduce, to some degree, the impacts of contaminants that may be detrimental to water quality. However, nutrients derived from the catchment contribute to the entire nutrient load and support the growth of phytoplankton, particularly cyanobacteria, within the reservoir. This cyanobacterial risk is somewhat independent of the point of inflow but highly dependent upon river water quality and pumped volume.

Nutrient inputs that control cyanobacterial growth may be important over longer timeframes than are relevant to pathogens. This is because of the time that is required for phytoplankton cells to encounter nutrients, incorporate them and for this to be evident as growth of the population. This may occur locally near the site of nutrient input but there are a number of physical processes that can mix and transport nutrients and cells throughout the reservoir within these time frames. These physical processes include wind driven mixing, differential heating and cooling (Monismith et al., 1990), intrusions driven by the mixer and mixing due to the inflows themselves.

From a quantitative perspective, there are not specific guidelines that can be used to simply assess tolerability, as there were for pathogens, above. Rather, the main questions that need to be addressed with respect to the cyanobacteria populations in Googong reservoir with additional piped Murrumbidgee River water are:

- Will there be more problem phytoplankton events (e.g. blooms) than at present?
- Will the problem phytoplankton events be worse, potentially?

Although the Burra Creek inflow to the Googong Reservoir is contaminated with nutrients at similar levels to the Murrumbidgee River, it is important to note that the Burra Creek is not a continuous input. The additional water delivered into the reservoir from the Murrumbidgee River will typically be of poorer water quality than the ambient reservoir water that receives the input. Phosphorus pumped into the reservoir will be in both particulate and dissolved form. The dissolved form and a proportion of particulate bound phosphorus will be available for algal growth. The inorganic particulate phosphorus and phosphorus bound with algal cells will tend to sediment from the water column and contribute to sediment-phosphorus.

Two scenarios need to be considered when assessing a piped inflow into Googong Reservoir:

- The short-term nutrient and phytoplankton response assessing how the phytoplankton grow in response to the additional nutrients.
- The longer-term response assessing nutrient accumulation in the reservoir as a result of increasing the nutrient load due to pumping.

This second scenario may take years or even decades to become problematic but is useful for setting catchment nutrient export targets in the future. Of relevance to both scenarios, selective pumping of river water may allow the avoidance of the extreme high concentrations, thereby reducing the nutrient load to the reservoir.

4.5. Cyanotoxin dose-response and risk characterisation

4.5.1. Longer-term risks

The magnitude of the cyanobacterial population that could be maintained in the reservoir will be determined by the nutrient availability, particularly phosphorus. The nutrient sources supporting the phytoplankton blooms are derived from reservoir sediment, upstream catchments and the piped river water. The relative contribution of each source to the total nutrient pool has not been rigorously determined; however the Murrumbidgee pipeline will contribute additional *loads* of nutrients to the reservoir.

The Googong Reservoir receiving environment has higher concentrations of inorganic nitrogen (NH_3, NOx) than the Murrumbidgee River source but the river has slightly more organically bound nitrogen (TKN). The concentrations are seasonally variable but there appears to be sufficient nitrogen to support phytoplankton growth. In either case, nitrogen is unlikely to be limiting, and in any case is not so well conserved and accumulated as phosphorus within reservoirs, making phosphorus the more important nutrient in this case.

The Murrumbidgee River water has higher concentrations of phosphorus than the ambient reservoir water. The Murrumbidgee River has higher maximum, median and average concentrations of total phosphorus than the reservoir sites. Median reactive phosphorus (FRP) concentrations are similar between the reservoir and the Murrumbidgee River (0.002 µg/L and 0.003 µg/L, respectively). However, the river water has a higher average FRP concentration than the reservoir (0.007 versus 0.002 µg/L), presumably due largely to periodically high concentrations associated with elevated flows. Overall, it is anticipated that the net outcome of pumping Murrumbidgee River water into Googong Reservoir is elevated *concentrations* of nutrients in the reservoir at times, and a higher total nutrient *load* overall.

The maximum carrying capacity or eventual population yield of the reservoir will ultimately be limited by nutrient availability. Nutrient concentrations from the river and flux from sediments will increase the available nutrient pool and so increase the standing biomass of phytoplankton. Concentrations for total phosphorus can be used to derive an approximate cyanobacterial yield for a mono-specific bloom of different species of cyanobacteria.

An assumption was made in this case that the entire amount of filterable reactive phosphorus were bioavailable. It was assumed that 1 µg of phosphorus can support 1 µg of chlorophyll *a*. Assuming a chlorophyll *a* concentration per cell of 1 pg, the theoretical yield of *Anabaena circinalis* can be determined for any given phosphorus concentration. This maximum carrying capacity (population density in terms of cells mL^{-1}) can also be translated into an estimate of geosmin concentration that could occur. This was done using recent extensive work by Peter Hobson (Australian Water Quality Centre) to collect accurate cell geosmin content data for natural populations of *Anabaena circinalis.* This was done specifically to provide data for the purposes of this type of risk assessment. Populations of *A. circinalis* cells were collected from both Yan Yean Reservoir, Victoria and Happy Valley Reservoir, Adelaide, during significant blooms earlier in 2006.

In Yan Yean a cell concentration of 1,300,000 cells mL^{-1} yielded a geosmin concentration of 67,000 ng L^{-1}. This converts to a mean chlorophyll *a* per cell 0.8844 pg $cell^{-1}$ and mean geosmin per cell of 0.0455 pg $cell^{-1}$. In Happy Valley Reservoir the mean chlorophyll *a* per cell was 1.1780 pg $cell^{-1}$ and the mean Geosmin per cell was 0.0409 pg $cell^{-1}$ in April 2006. Based upon these relationships 5,000 cells mL^{-1} would yield 205 ng L^{-1} of geosmin.

For this risk assessment the slightly higher values for Yan Yean were used (0.0455 pg geosmin $cell^{-1}$). The predicted geosmin concentrations for different starting concentrations and different growth rates are presented in Table 4-3. Note that tens of ng/L can be perceived by drinking water consumers.

The estimates for geosmin based upon the new data from *Anabaena* populations in Australian Reservoirs suggests that the maximum geosmin associated with a potential bloom of 20,000 cells mL^{-1} is around 900 ng L^{-1}. This is an extremely high concentration and would cause concern to ActewAGL, particularly if these high concentrations existed near the off-takes for local supply.

Table 4-3. Cell concentration of *Anabaena circinalis* and predicted total geosmin concentration. The Geosmin is based upon the intracellular concentration in a healthy population.

Cell density (cells mL^{-1})	Possible geosmin concentration (ng L^{-1})
100	4.6
500	22.8
1,000	45.5
5,000	227.5
10,000	455.0
20,000	910.0

These estimates for geosmin represent the total geosmin pool, i.e. both intra and extra cellular. In reality there would be turnover and loss as the population grows and the actual concentration in the river would be expected to be lower due to these losses. The significant losses are considered to be from biodegradation and volatilization.

Similar derivations can be carried out for other bloom forming species such as *Cylindrospermopsis raciborskii*. Less data is available for conversion of phosphorus into chlorophyll concentrations, however using cell toxin quota data the following estimates can be derived. Using a cylindrospermopsin (CYN) cell content of 31 fg CYN $cell^{-1}$ (Hawkins *et al*, 2001), and a relationship of 0.17 µg CYN per µg Chlorophyll *a* (Saker *et al*, 1999), it is possible to derive the value for chlorophyll cell content of 0.182 pg Chlorophyll *a* $cell^{-1}$. Based upon the same relationship of chlorophyll to phosphorus assumed for *Anabaena*, it is possible that 20 µg L^{-1} bioavailable phosphorus could give rise to approximately 110,000 cells mL^{-1} of *Cylindrospermopsis raciborskii*, which would translate into 3.4 µg L^{-1} of cylindrospermopsin toxin.

The FRP in the Murrumbidgee is typically less than 10 µg/L but this could host populations of 10,000 cells/mL. Indeed total algal counts and total cyanobacteria counts for Googong Reservoir show seasonally high numbers exceeding this. Contributing to elevated cyanobacterial numbers is the fact that they can float which can result in very high surface concentrations. Typically, chlorophyll *a* peaks at 10 µg/L within the reservoir now.

An additional loading of P was estimated based on some assumptions about the quantity of water to be pumped in from the Murrumbidgee River (Table 4-4). Total annual P loading was expected to increase by 30% under the pumping option considered. Note that the *concentration* of nutrients might not significantly change in the short term, but the *total load* to the reservoir will increase due to the increased total volume of water added. The Googong Reservoir has a water quality that now just exceeds the trigger levels for lakes and reservoirs in South-east Australia for its nutrients status (ANZECC/ARMCANZ 2000). Therefore, increasing pumping from the river can be expected to lead to increasing problems with cyanobacteria in future years. The loading will probably increase the risk of more frequent, more lengthy and more intense, blooms of cyanobacteria, and become worse over time. In terms of the effect on assets, Googong Reservoir is going to have its useful working period reduced and/or treatment augmentations at Googong WTP may need to be brought forward. It should be noted that the impacts are somewhat irreversible in the short-term once effects become evident.

Table 4-4. Approximation of additional nutrient loads into Googong Reservoir.

Input	Inflow (ML)	Basis of estimate	Mean total phosphorus concentration (mg/L)	Mean total P load to Googong (kg/yr)	Additional load to Googong (percentage)
Murrumbidgee River	10,000	Estimated and including Tantangara component (source: Bulk Water Alliance)	0.07	700	30%
Queanbeyan River	39,580	Annual mean inflow from 1990 to 2007 (source: ActewAGL)	0.04	1,583	
Burra Creek	3,110		0.10	311	
Other inflows	11,430		0.04*	457	

*Not based on data but assumed to be the same as the Queanbeyan R.

At present, the sporadic and relatively low magnitude of risks related to cyanobacteria in Googong Reservoir mean that additional treatment barriers may prove unnecessary provided it is accepted that from time to time avoidance of abstraction from the dam may have to occur during bloom periods. The use of mixing of the reservoir, and the avoidance of nutrient peaks through selective pumping from the river, may also assist in significantly delaying, possibly avoiding, the point at which enhanced treatment is required.

There is a trade-off between yield of water abstracted and quality. However, it is unlikely to be acceptable to pump the most turbid water arising after peak storm events within the Murrumbidgee. An example of a turbidity spike in a peak storm hydrograph from the Murrumbidgee is given in Figure 4-2.

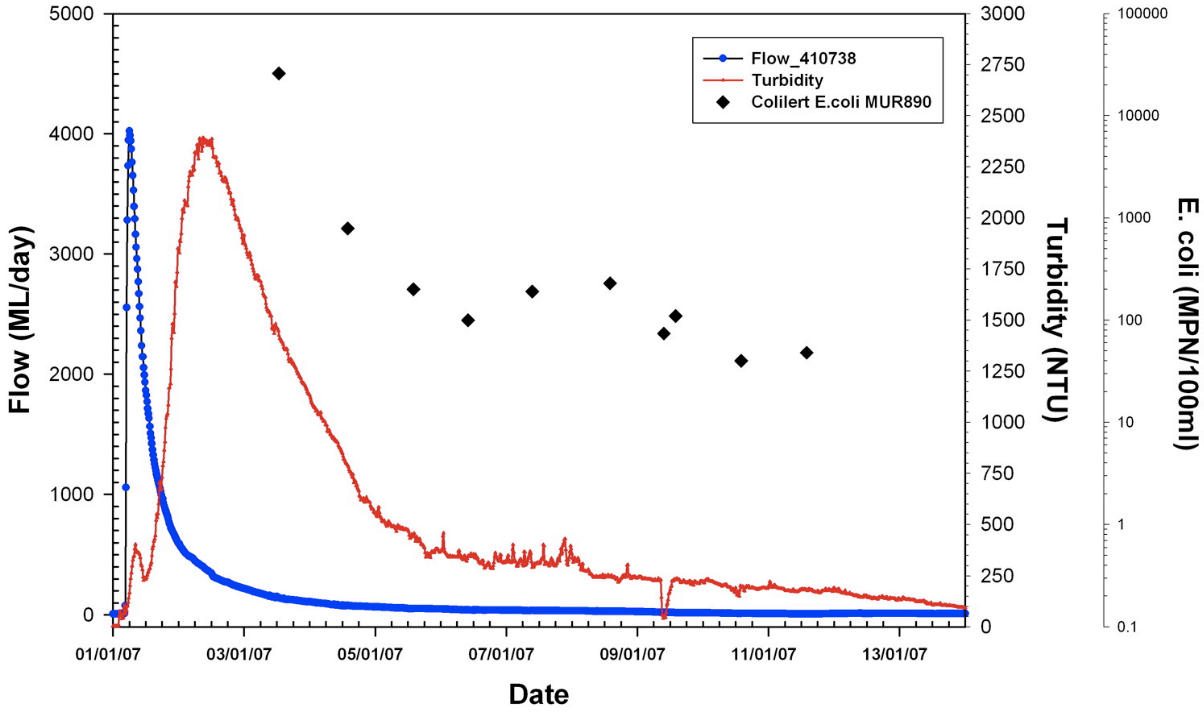

Figure 4-2. Analysis of the large event of 1 January 2007. Flow rate is the key, lead indicator of adverse water quality contamination as assessed using all other measures (turbidity and *E. coli* shown).

The management objective is to control phytoplankton carrying capacity within the Googong Reservoir. However, phytoplankton measurements taken within the reservoir are a lag indicator which can only detect problems after they have arisen. Furthermore, phytoplankton do not typically reach levels of concern within the river source making phytoplankton unsuitable as an indicator to help support decision-making regarding pumping of water into the reservoir.

The principal limiting factor for phytoplankton carrying capacity in this context is phosphorus. However, phosphorus is also a reasonably slow indicator to measure as laboratory testing is required. In contrast, turbidity can be readily measured on line. Data for the past ten years from the Murrumbidgee River at MUR213 reveal that turbidity and total phosphorus are well correlated (Figure 4-3). Therefore, turbidity is a suitable trigger for driving abstraction decisions to avoid the worst of the nutrient loads.

In setting a turbidity trigger value to drive pumping decisions from the Murrumbidgee, a review of local data reveals that the river runs for prolonged periods at a turbidity in the low tens of NTU, but only rarely exceeds 100 NTU (Figure 4-4). The ninety-fifth percentile turbidity within the river over the past ten years is 190 NTU (Table 7-1), the ninetieth percentile is 71 NTU and over the past 33 years the ninety-fifth percentile is 52 NTU. It is recommended that a turbidity trigger of 100 NTU is used as the shut-off point, after which pumping from the Murrumbidgee River should cease Such an arrangement would avoid the approximately 5% to 10% of flow with the highest nutrient concentrations whilst allowing for a high yield from the source. Recent on line monitoring data from the site reveals that turbidities above 100 NTU are unlikely to be sustained (Figure 4-5).

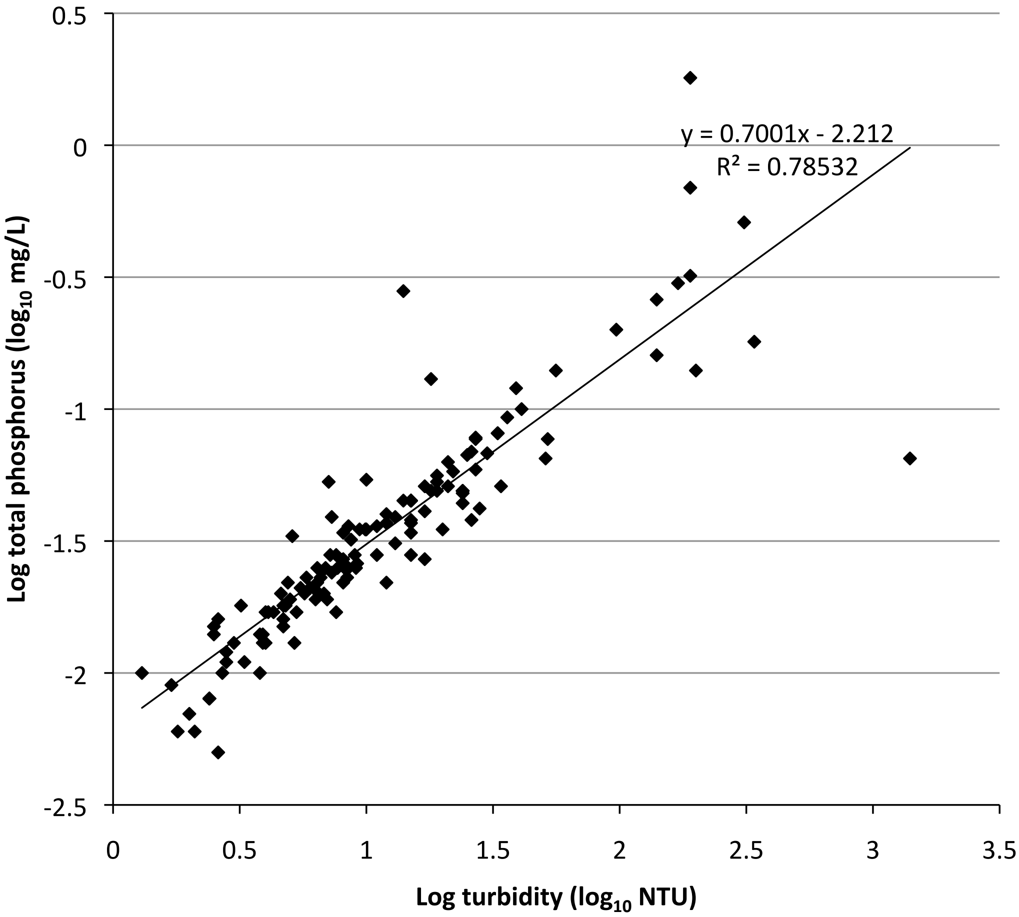

Figure 4-3. Scatter plot of turbidity versus total phosphorus data at MUR213 Murrumbidgee river source.

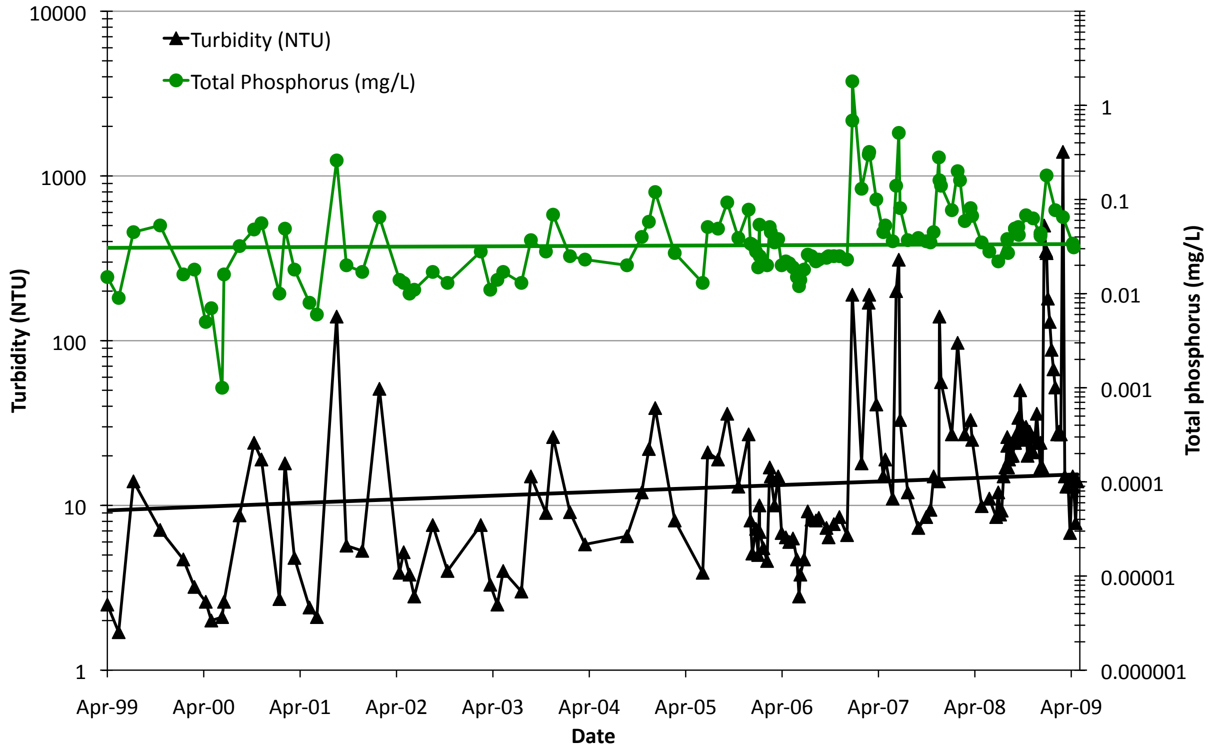

Figure 4-4. Ten-year time series and trendlines of total phosphorus and turbidity at MUR213 Murrumbidgee river source.

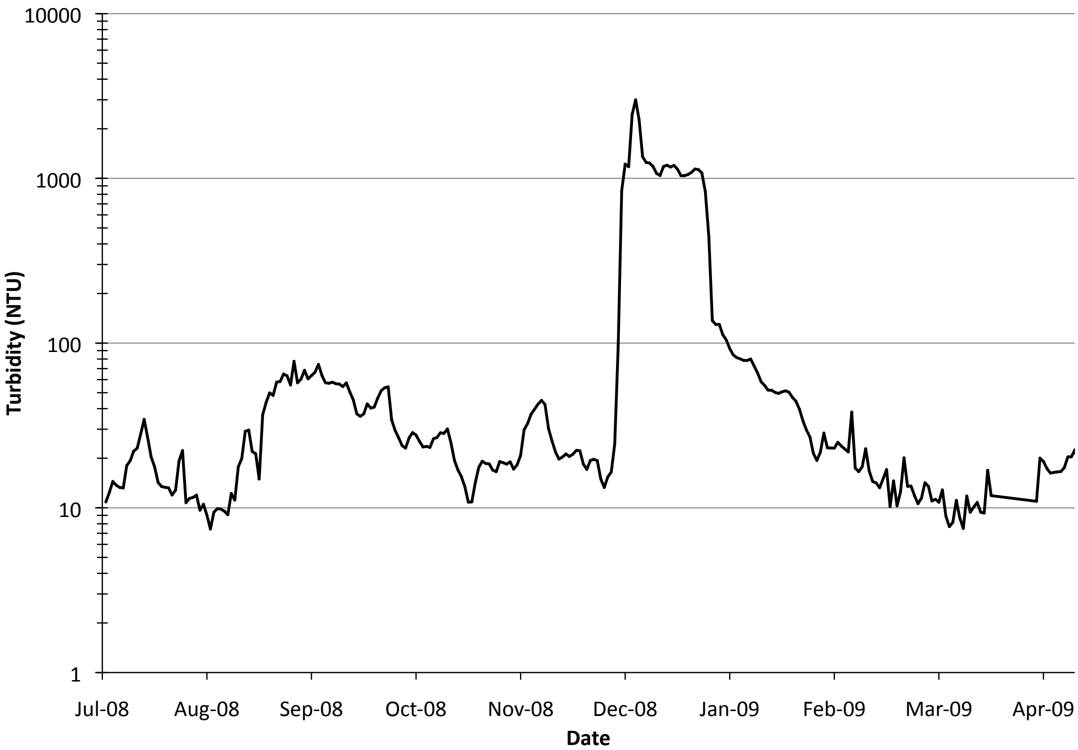

Figure 4-5. Recent on line turbidity data from Lobbs Hole gauging Murrumbidgee river source.

4.5.2. Shorter-term risks

The results of modelling by GHD (2009) indicated that the predicted short-term peak cyanobacterial chlorophyll *a* concentration in the Burra Creek arm of the Googong Reservoir could be significantly elevated beyond the levels predicted without such an inflow and could reach as high as 18 µg/L (Figure 4-6).

Assuming a ratio of chlorophyll *a* to microcystin of 1.7 (based on Long *et al* 2001), this equates to a predicted mLA concentration of 10.6 µg/L, if the bloom were in fact toxic. If this toxin were to leach from the cyanobacterial cells, e.g. following death of the bloom, and short-circuit through to the water supply offtake undiluted, then chlorination would be required to attenuate the toxin present.

It is not known at the time of writing what the actual C•t for free chlorination is at Googong WTP, but assuming a free chlorine C•t of 100 mg•min/L (e.g. ≥ 1 mg/L for ≥ 100 mins contact time between chlorine dosing and water reaching the first customer), a 90% reduction in mLA concentration in treated water would be expected (Newcombe G, pers. comm.). The result would be a predicted final concentration of mLA in the treated water of 1.1 µg/L. The ADWG guideline value for microcystins is 1.3 µg/L, making the water safe to consume.

In practice significant dilution and attenuation of toxin would take place between the Burra Creek arm of Googong Reservoir and the offtake point so that the actual concentration of microcystin in the treated water would be considerably lower than estimated here if the other assumptions used are valid.

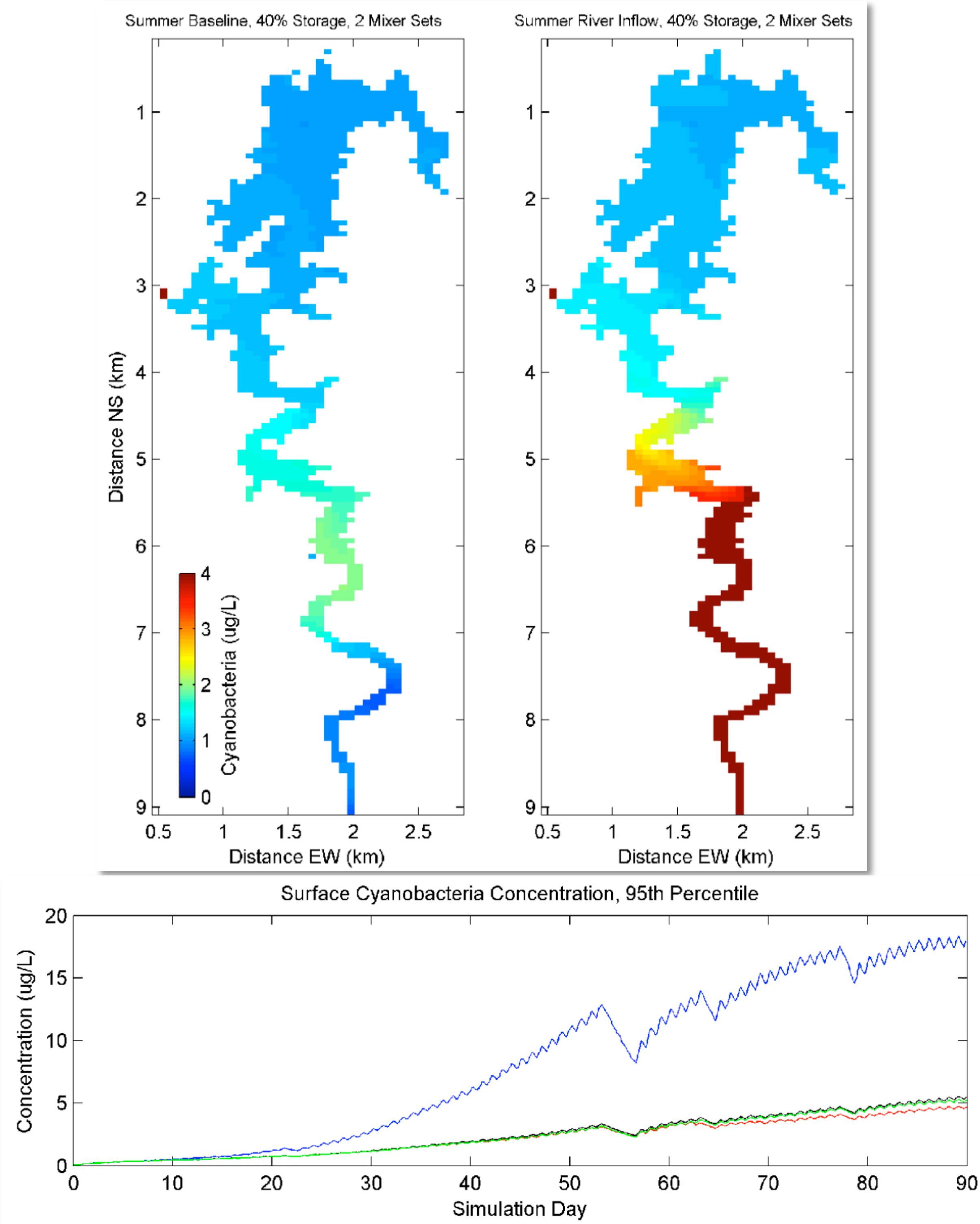

Figure 4-6. Predicted typical (upper map plot) and 95%ile (lower graph plot) cyanobacteria concentration expressed as chlorophyll a concentrations (µg/L). The upper map plot compares the current situation (left hand image) with the predicted situation following the introduction of the M2G (right hand image). The lower graph plot shows results for the Burra Creek arm of Googong Reservoir during summer as the blue plot line. Figures extracted from GHD (2009).

4.5.3. Summary of cyanobacteria-related recommendations

In summary, the following conclusions arise from the quantitative analysis of risks associated with cyanotoxins and related risks:

- The nutrient concentrations in the Murrumbidgee River are reasonably similar to Burra Creek inflows and somewhat above Queanbeyan River inflows. Therefore, the M2G presents relatively similar inputs, in terms of concentrations, to those already experienced in the Googong Reservoir.
- The concentrations of nutrients in the Murrumbidgee River are not in and of themselves a major source of difference and possible future risk. The immediate receiving environment is far enough from the water supply offtake that short-term localised effects are unlikely to be a source of significant drinking water quality concern. Some local nuisance concerns may, however arise.
- The load of total nutrients entering Googong Reservoir could foreseeably increase by 30% on an average annual basis under the M2G. Over time, the effect of these increased nutrient loads, particularly the phosphorus loads, is likely to increase the extent, duration and severity of cyanobacterial and other phytoplankton-related problems, such as taste, odour and toxin formation, as well as nuisance issues. Operational nuisance issues of concern might include filter-blocking algae that shorten filter run times.
- Locally, at the point where the Murrumbidgee River water reaches the backwater of the Burra Creek arm of Googong Reservoir, public nuisance issues. Such issues might include visual amenity impacts, local odour effects and impacts on the ability of persons to recreate within the dam water.
- Over time, the increased load of nutrients and corresponding trophic response will lead to an increased need for mixing, additional treatment and, in some cases, avoidance of abstraction from Googong Reservoir relative to the current situation. In the longer-term, whether or not additional treatment is required depends on how long the dam can be offline and on how effective artificial destratification is at keeping phosphorus within the sediment.

5. Summary

5.1. Key findings

- The M2G arrangement was found to be acceptable and manageable from a drinking water quality perspective:
    - The scheme does not present a foreseeable risk of a short-term acute pathogen-related outbreak or incident arising.
    - Any of the foreseen water quality problems associated with cyanobacteria can be managed adaptively over the long-term.
    - Therefore, the option can proceed, if managed.
- The M2G arrangement may, in the medium-term, lead to increased use of reservoir management actions (e.g. mixing) to respond to increased nutrient loads beyond the extent to which this would occur otherwise.
- The M2G arrangement may, in the longer-term, lead to the need for additional water treatment beyond what would be required otherwise if problems related to cyanobacteria become more persistent.
- Whether or not the M2G creates the need for additional water treatment, or reduced source availability, and the extent of increased management actions, depends on how effective the reservoir is as a water quality barrier, how effective selective pumping can be given the importance of the source for quantity, and how critical the reservoir is as an on line source.

5.2. Key recommendations

There were three different types of risks identified within the risk assessment: i) public health risks; ii) operational risks and iii) broader community risks. All three should be considered in forward planning, as follows:

- With respect to the public health risks associated with the drinking water supply, the M2G arrangement should proceed and presents acceptable and manageable risks to drinking water quality. The scheme presents tolerable mitigated risks to the quality of the Googong drinking water supply system from a public health perspective.
- With respect to source water operational risks, operational actions should be implemented to help set selective river abstraction windows that balance water quality and yield considerations. Risks associated with both cyanobacteria and pathogens can be reduced through selective pumping from the river. The selective pumping would seek to avoid phosphorus concentration peaks, such as during periods of highly turbid water, at above 100 NTU. In practice, this is only likely to mean avoiding the first few days of most smaller turbid flow events and at most a few weeks following major storm events. In addition, pumping should cease following any major contaminant spill events within the Upper Murrumbidgee River catchment.
- With respect to water supply operational risks, contingency planning should be undertaken in the medium-term to prepare for possible longer-term issues. Considerations include increases in the extent of mixing being required as well as possible reductions in supply availability due both to increased problems with cyanobacteria and potential reduced tolerance of treatment problems likely to be associated with a perceived higher risk source.
- With respect to the broader community risks, predicted increases in the presence of visible algal blooms in the Burra Creek arm of Googong Reservoir need to be considered for their impacts on public perception. For instance, a public education strategy, and the preparation of public and media advisory information, might be useful to help reduce manage expectations and perceptions regarding these risks.

6. References

ACT Government (2004) Think water, act water. Volume 1: Strategy for sustainable water resource management in the ACT, April 2004. Publication No. 04/0364 ISBN 0 642 60273 5

ADWG: see NHMRC/NRMMC (2004)

ANZECC (2000): see ANZECC/ARMCNZ (2000)

ANZECC/ARMCNZ (2000) Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1, The Guidelines. National Water Quality Management Strategy Paper No. 4. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zeland. Canberra: Government of Australia.

Antenucci, J., Brookes, J.D. and Hipsey, M. (2005). A simple model for quantifying Cryptosporidium transport, dilution, and potential risk in reservoirs. Journal of the American Water Works Association 97 (1) 86-93

Brookes, J.D. Hipsey, M.R. , Linden, L., Regel, R.H., Burch, M.D. and Antenucci, J.P. (2005). Investigation of the relative value of surrogate indicators for detecting pathogens in lakes and reservoirs. Environmental Science and Technology 39(22): 8614-8621

Brookes, J.D., Antenucci, J., Hipsey, M. Burch, M.D. Ashbolt, N. and Fergusson, C. (2004). Pathogen transport, distribution and fate in lakes and reservoirs. Environment International 30:741-759

Contos A., Davison, A., and Deere, D. (2007) Googong Catchment Water Quality Risk Management Report. Report by Water Futures Pty Ltd for ACTEW.

Davison, A and Deere, D. (2006) Murrumbidgee Risk Assessment. Project Report. Report by Water Futures Pty Ltd to ActewAGL.

Davison, A. and Deere, D. (2007) Managing the Murrumbidgee as a Raw Water Source. Catchment Cryptosporidium Source Control Plan (CSCP) by Water Futures Pty Ltd for ActewAGL.

DWI (2000) Water Supply (Water Quality) Regulations. Drinking Water Inspectorate, Department for Environment, Transport and the Regions for England and Wales, 2000.

enHealth (2002) Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards. enHealth Council, Australia.

GDWQ: see WHO (2008)

GHD (2009) ActewAGL Report for Googong Reservoir Hydrodynamic Modelling DRAFT Scenario Modelling Report January 2009.

Health Canada (2004a) Guidelines for Canadian Drinking Water Quality: Supporting Documentation — Protozoa: Giardia and Cryptosporidium. Water Quality and Health Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.

Health Canada (2004b) Guidelines for Canadian Drinking Water Quality: Supporting Documentation — Enteric Viruses. Water Quality and Health Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.

Hipsey, M., Antenucci, J. Brookes, J.D., Burch, M., Regel, R and Linden, L. (2004). A three-dimensional model for Cryptosporidium dynamics in lakes and reservoirs. International Journal of River Basin Management 2 (3): 181-197.

Hipsey, M.R., Antenucci, J.P., Brookes, J.D. (2007) A generic, process-based model of microbial pollution in aquatic systems. Water Resources Research (accepted 18 September 2007)

Hipsey, M.R., Brookes, J.D., Regel, R., Antenucci, J.P., and Burch, M.D. (2005). In situ evidence for the association of Total Coliforms and Escherichia.coli with suspended inorganic particles in an Australian Reservoir. Water, Air and Soil Pollution. 170 (1): 191-209.

Monismith, S.G., Imberger, J. & Morison, M.L. 1990. Convective motions in the sidearm of a small reservoir. Limnology and Oceanography 35: 1676-1702

Long, B.M., Jones, G.J. and Orr, P.T. (2001) Cellular microcystin content in N-limited *Microcystis aeruginosa* can be predicted from growth rate. Appl. Environ. Microbiol. 67(1):278-83.

NHMRC/NRMMC (2004) Australian Drinking Water Guidelines National Water Quality Management Strategy. National Health and Medical Research Council and Natural Resource Management Ministerial Council. Canberra: Government of Australia. ISBN Online: 1864961244.

Peter R. Hawkins, Elizabeth Putt, Ian Falconer, Andrew Humpage. 2001. Phenotypical Variation in a Toxic Strain of the Phytoplankter, Cylindrospermopsis raciborskii (Nostocales, Cyanophyceae) During Batch Culture. Env. Tox. 16, 460-467

Saker, M.L., B.A. Neilan, and D.J. Griffiths. 1999. Two Morphological Forms of Cylindrospermopsis raciborskii (Cyanobacteria) Isolated from Solomon Dam, Palm Island, Queensland. Journal of Phycology, 35(3):599-606.

Thebault, J-M and Qotbi, A. (1999) A model of phytoplankton development in the Lot River (France). Simulations of scenarios. Wat. Res. 33(4):1065-1079.

USEPA (1991) Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public water Systems Using Surface Water Sources. United Stated Environmental Protection Agency, March 1991.

USEPA (2006) Long-term 2 Enhanced Surface Water Treatment Rule. United Stated Environmental Protection Agency, 5th January 2006.

WHO (2008) Guidelines for Drinking-water Quality. Third Edition. Incorporating first and second addenda. Volume 1. Recommendations. Geneva: World Health Organization.

7. Water Quality Data Summary Tables

Table 7-1. Water quality statistics (from 19/02/98 to 12/05/09) for MUR213 Angle Crossing raw water source.

Analyte \ Statistic	Count	Minimum	Median	Mean	95th percentile	Maximum	Ten-year simple trend
Faecal coliforms or *E. coli* (CFU or MPN/100mL)	170	1	22	253	311	15,000	Decreasing
Cryptosporidium (oocysts/L)	93	0.04	0.08	0.18	0.31	4.0	N/A
Giardia (cysts/L)	54	0.04	0.09	0.12	0.31	0.6	N/A
Total algae (cells/mL)	86	360	1,720	4,155	15,000	46,656	Increasing
Total cyanophyta (cells/mL)	10	1	250	611	2,217	2,990	N/A
Total phosphorous (mg/L P)	132	0.001	0.032	0.070	0.227	1.800	Increasing
Total nitrogen (mg/L)	132	0.150	0.345	0.588	1.245	16.000	Increasing
TKN calculated (mg/L)	60	0.190	0.400	0.538	1.100	3.800	N/A
NH_3 (mg/L N)	132	0.001	0.005	0.012	0.040	0.220	Increasing
NO_X (mg/L NOX)	132	0.001	0.003	0.031	0.140	0.650	N/A
PO_4 (mg/L P)	59	0.001	0.003	0.007	0.017	0.170	N/A
Turbidity (NTU)	170	1	13	42	190	1,400	Increasing
Total organic carbon (mg/L)	111	1	4	17	18	1,200	Increasing
Chlorophyll (µg/L)	110	1	6	8	17	71	Increasing
Temperature (˚C)	172	5	17	16	25	28	Increasing

N/A: not assessed

Table 7-2. Water quality statistics (17/12/97 to 06/05/09) for site GOO724 Googong Dam 6 km from offtake.

Analyte \ Statistic	Count	Minimum	Median	Mean	95th percentile	Maximum	Ten-year simple trend
Faecal coliforms or *E. coli* (CFU or MPN/100mL)	75	< 1	< 1	3	15	47	Increasing
Total algae (cells/mL)	755	< 1	2220	8410	33000	230000	Increasing
Total cyanophyta (cells/mL)	449	< 1	1959	10582	45767	228000	Increasing
Total phosphorous (mg/L P)	326	0.006	0.019	0.023	0.048	0.130	Increasing
Total nitrogen (mg/L)	326	0.320	0.500	0.524	0.750	1.100	Increasing
TKN calculated (mg/L)	322	0.300	0.500	0.485	0.700	0.800	N/A
NH_3 (mg/L N)	326	0.001	0.016	0.027	0.083	0.110	N/A
NO_X (mg/L NOX)	326	0.001	0.020	0.038	0.150	0.400	N/A
PO_4 (mg/L P)	316	0.001	0.003	0.003	0.007	0.010	Decreasing
Turbidity (NTU)	851	0.5	2.4	4.1	12.0	67.0	Decreasing
Chlorophyll (µg/L)	665	0.4	5.1	7.7	24.0	98.0	Increasing
Temperature (˚C)	1773	4.8	15.9	15.4	23.3	26.4	N/A

N/A: not assessed

8. Water quality data time series – river source

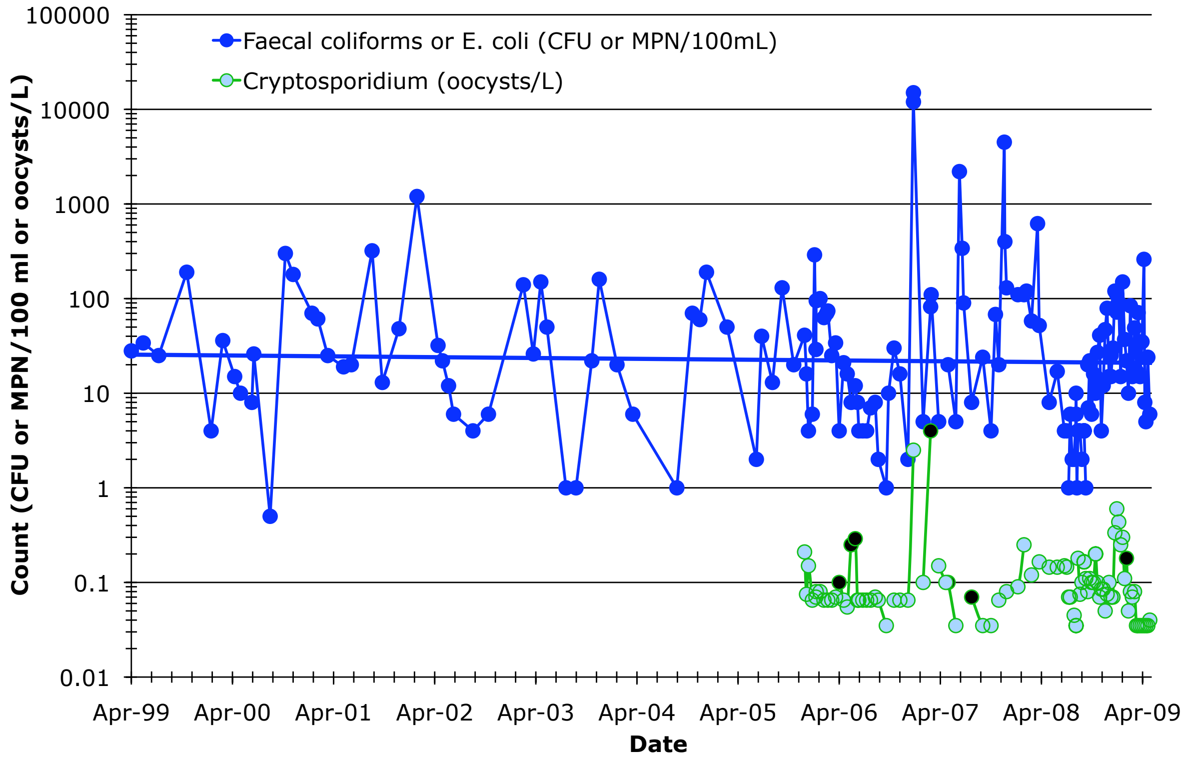

Figure 8-1. Ten-year time series and trendline for microbial count data at sampling site MUR213 Murrumbidgee River source. For *Cryptosporidium*, black symbols are detects whilst others are non-detects at half detection limit.

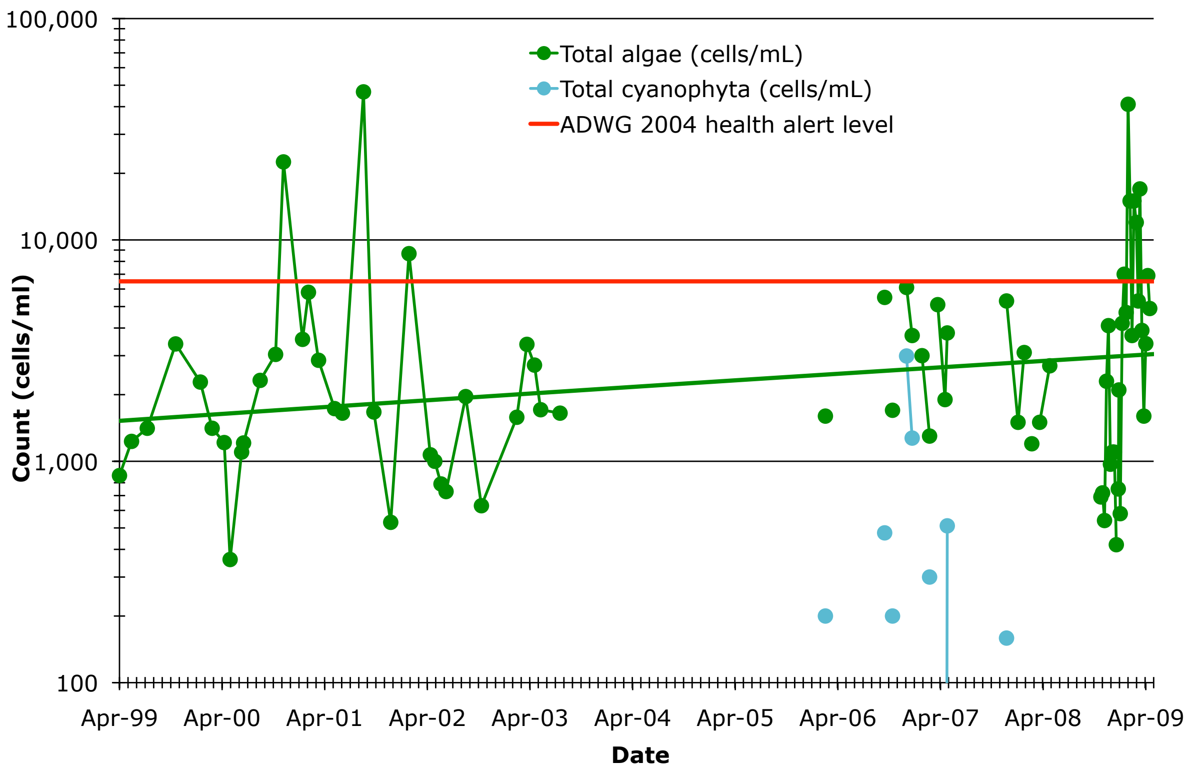

Figure 8-2. Ten-year time series, trendline and cyanobacterial health alert level (6,500 cells/ml) for phytoplankton count data at sampling site MUR213 Murrumbidgee River source.

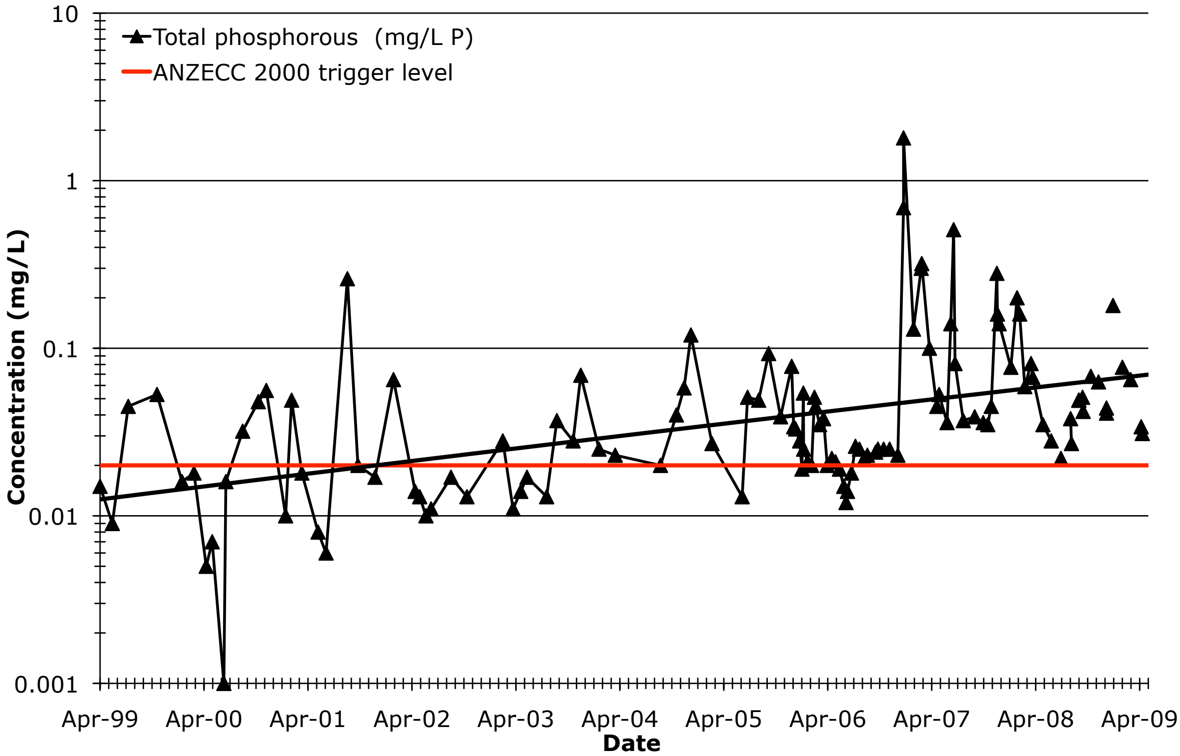

Figure 8-3. Ten-year time series, trendline and ANZECC trigger value (20 µg/L) for total phosphorus data at sampling site MUR213 Murrumbidgee River source.

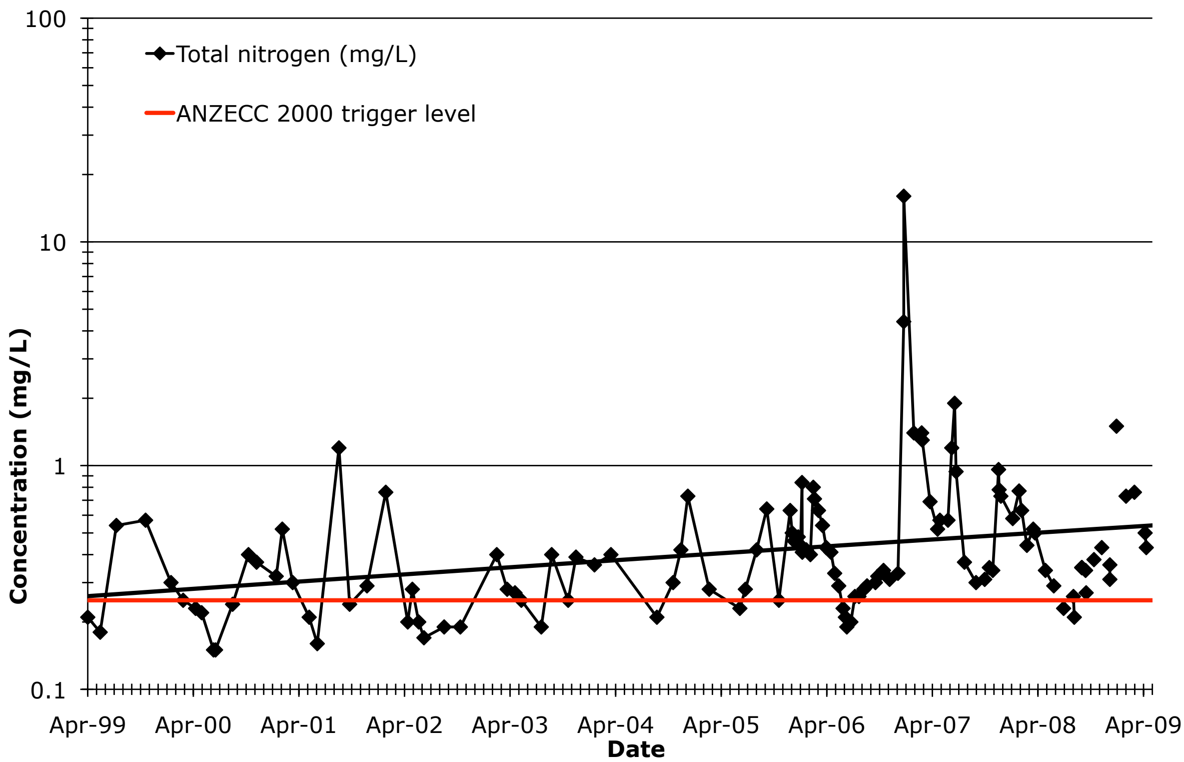

Figure 8-4. Ten-year time series, trendline and ANZECC trigger value (250 µg/L) for total nitrogen data at MUR213 sampling site MUR213 Murrumbidgee River source.

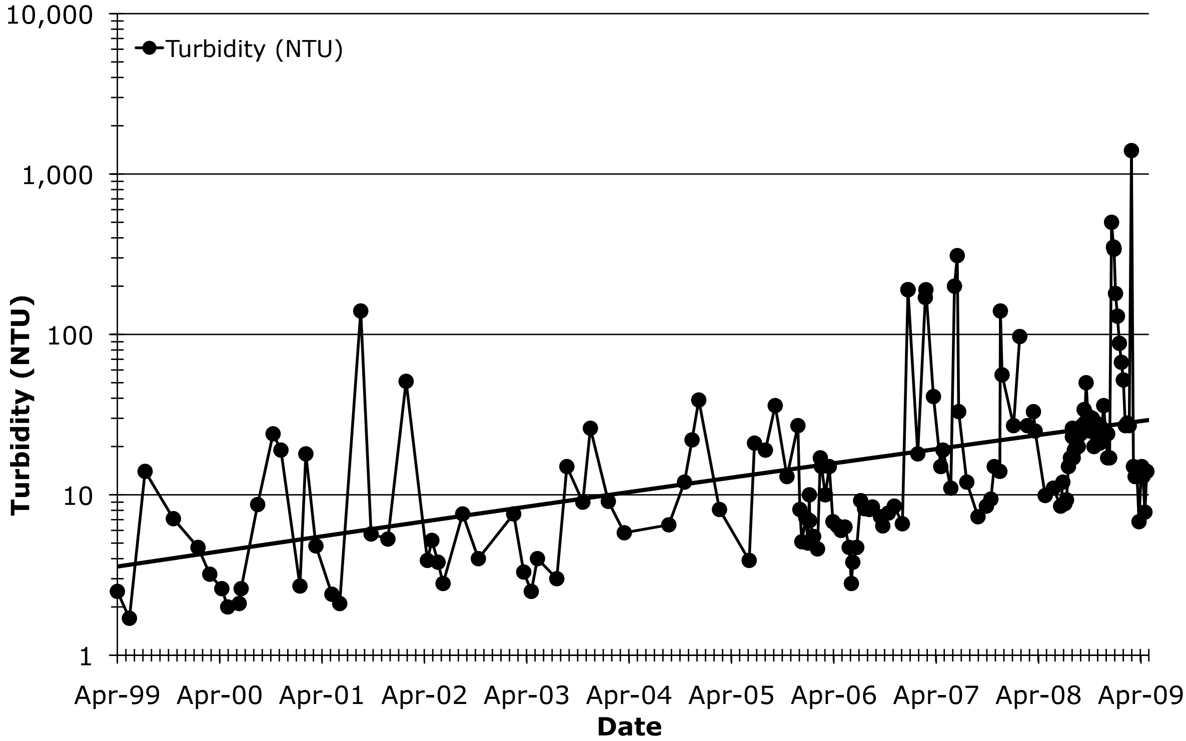

Figure 8-5. Ten-year time series and trendline for turbidity data at sampling site MUR213 Murrumbidgee River source.

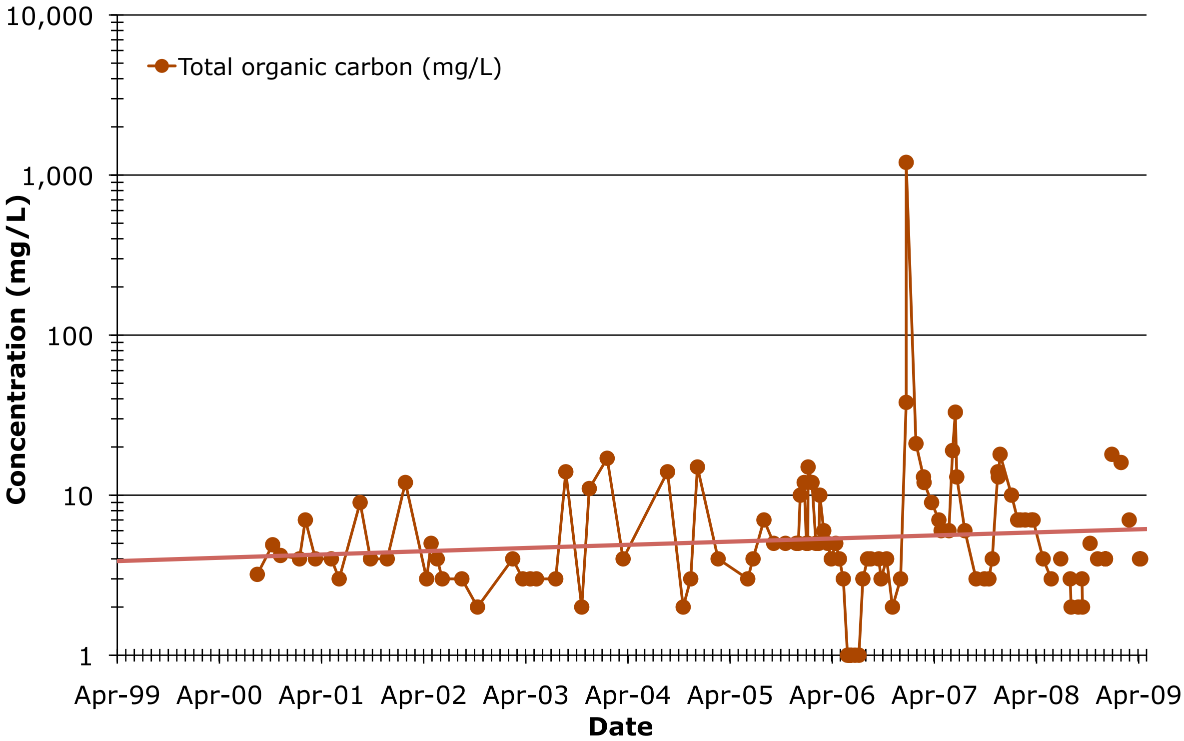

Figure 8-6. Ten-year time series and trendline for total organic carbon data at sampling site MUR213 Murrumbidgee River source.

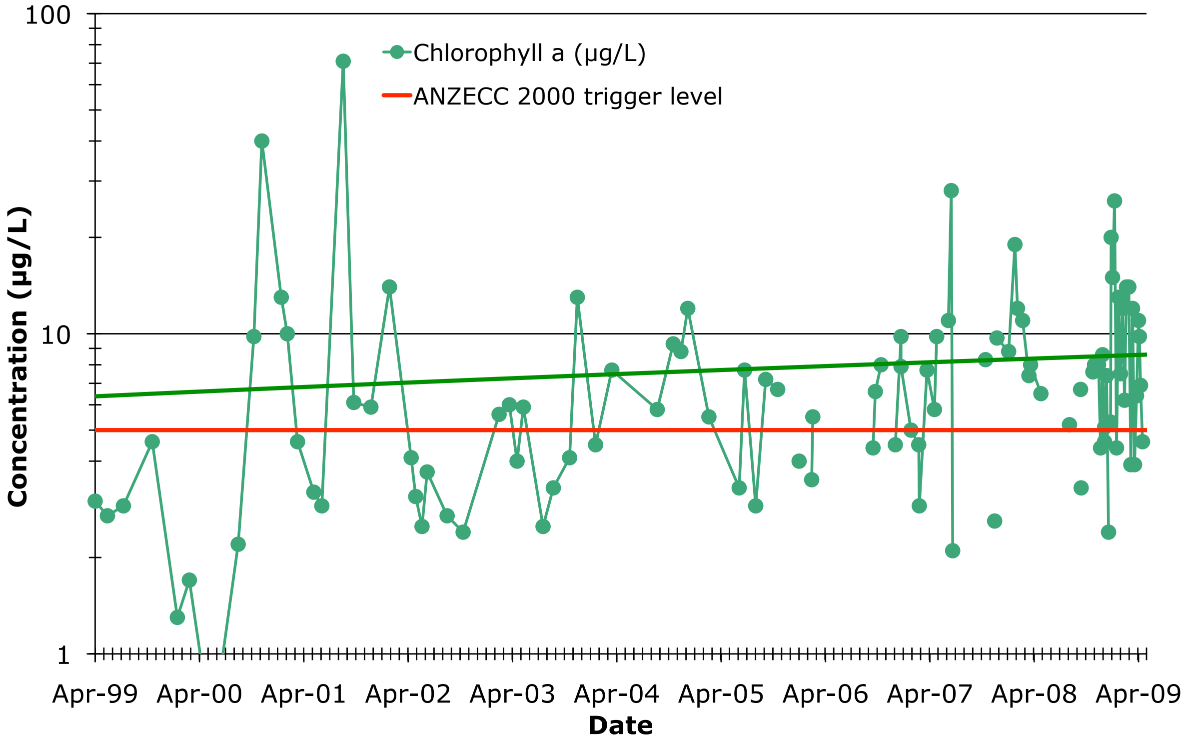

Figure 8-7. Ten-year time series, trendline and ANZECC trigger value (5 µg/L) for chlorophyll *a* data at sampling site MUR213 Murrumbidgee River source.

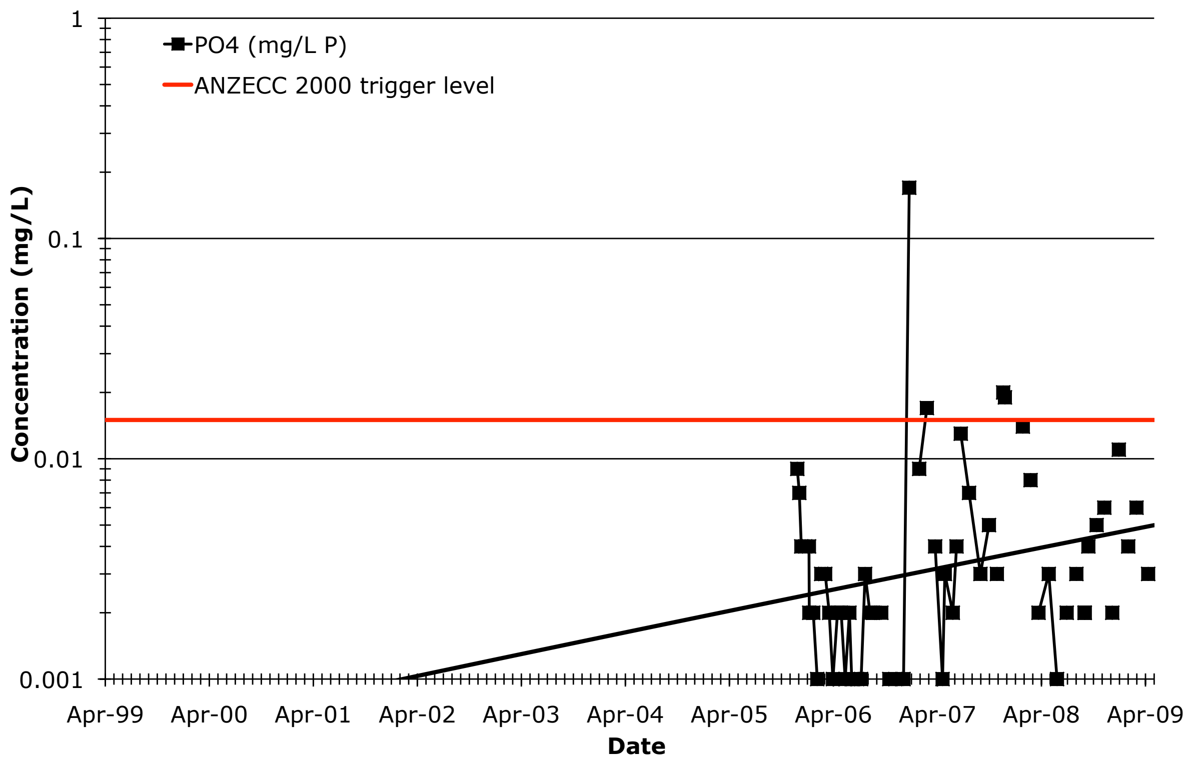

Figure 8-8. Ten-year time series, trendline and ANZECC trigger value (15 µg/L) of reactive phosphorus data at sampling site MUR213 Murrumbidgee River source.

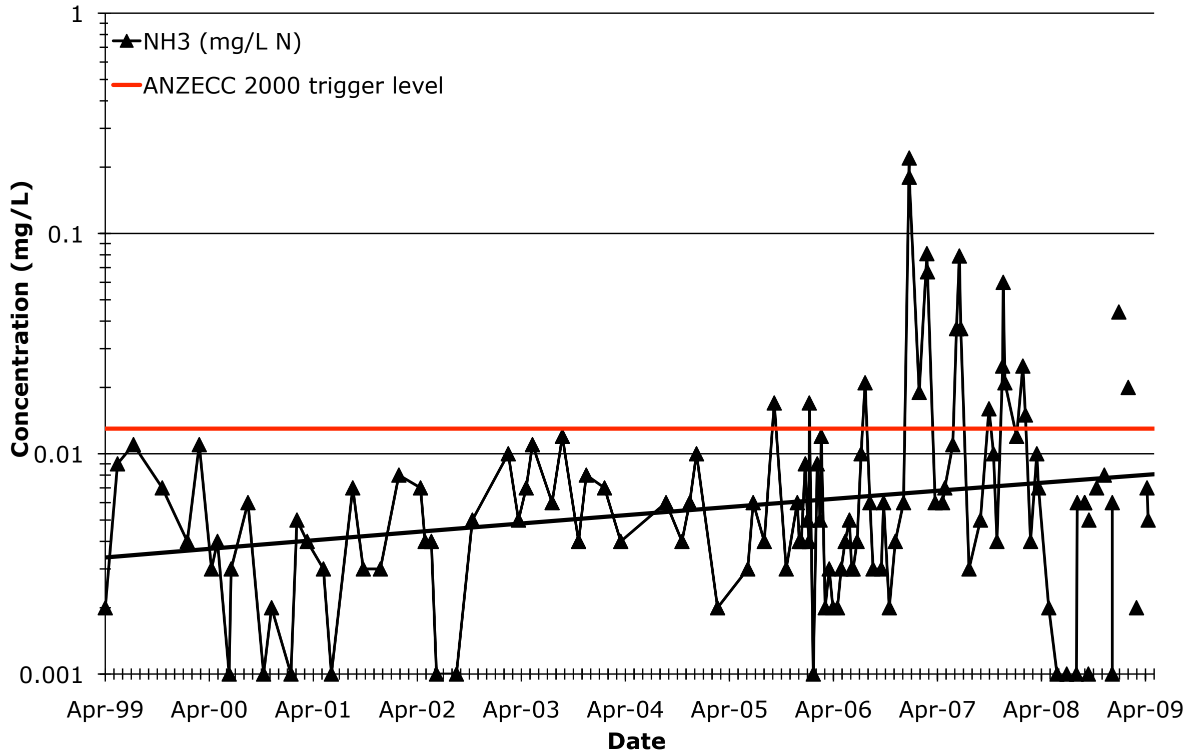

Figure 8-9. Ten-year time series, trendline and ANZECC trigger value (13 µg/L) for ammonia data at sampling site MUR213 Murrumbidgee River source.

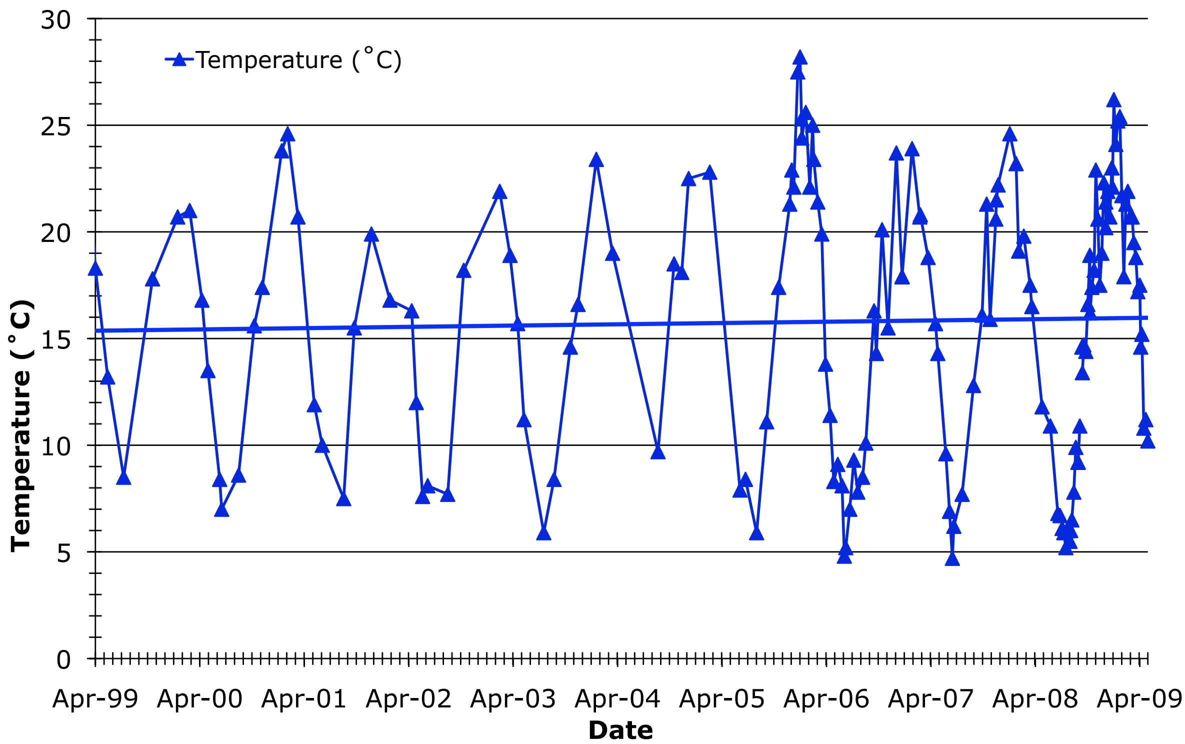

Figure 8-10. Ten-year time series and trendline for temperature data at sampling site MUR213 Murrumbidgee River source.

9. Water quality time series – receiving environment

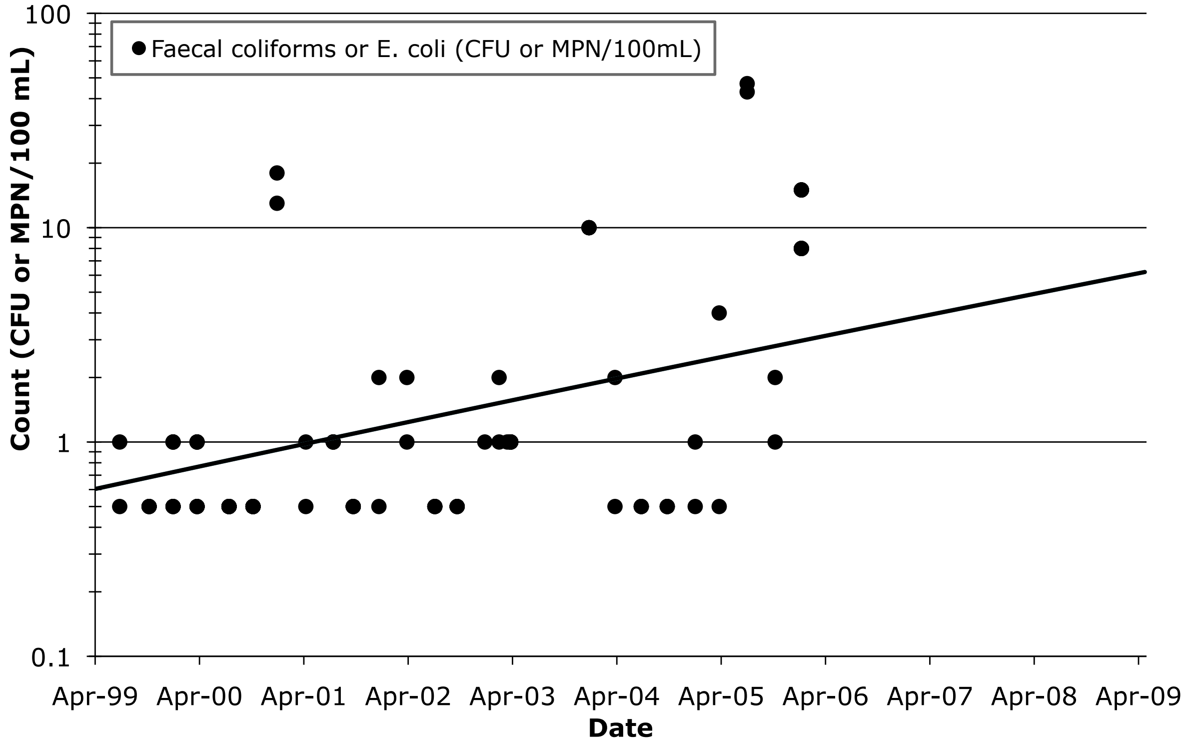

Figure 9-1. Ten-year time series and trendline for microbial count data at sampling site GOO724 Googong Reservoir receiving environment. Values at 0.5 were at the detection limit of < 1.

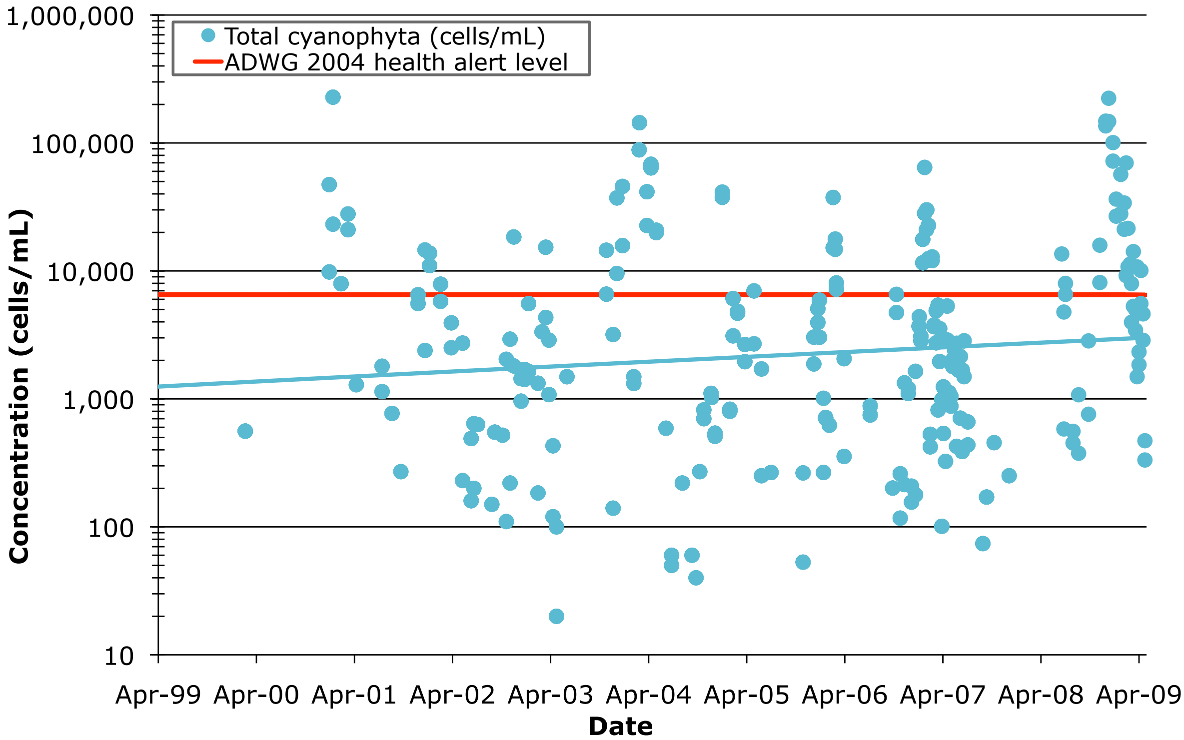

Figure 9-2. Ten-year time series, trendline and cyanobacterial health alert level (6,500 cells/ml) for cyanobacteria count data at sampling site GOO724 Googong Reservoir receiving environment.

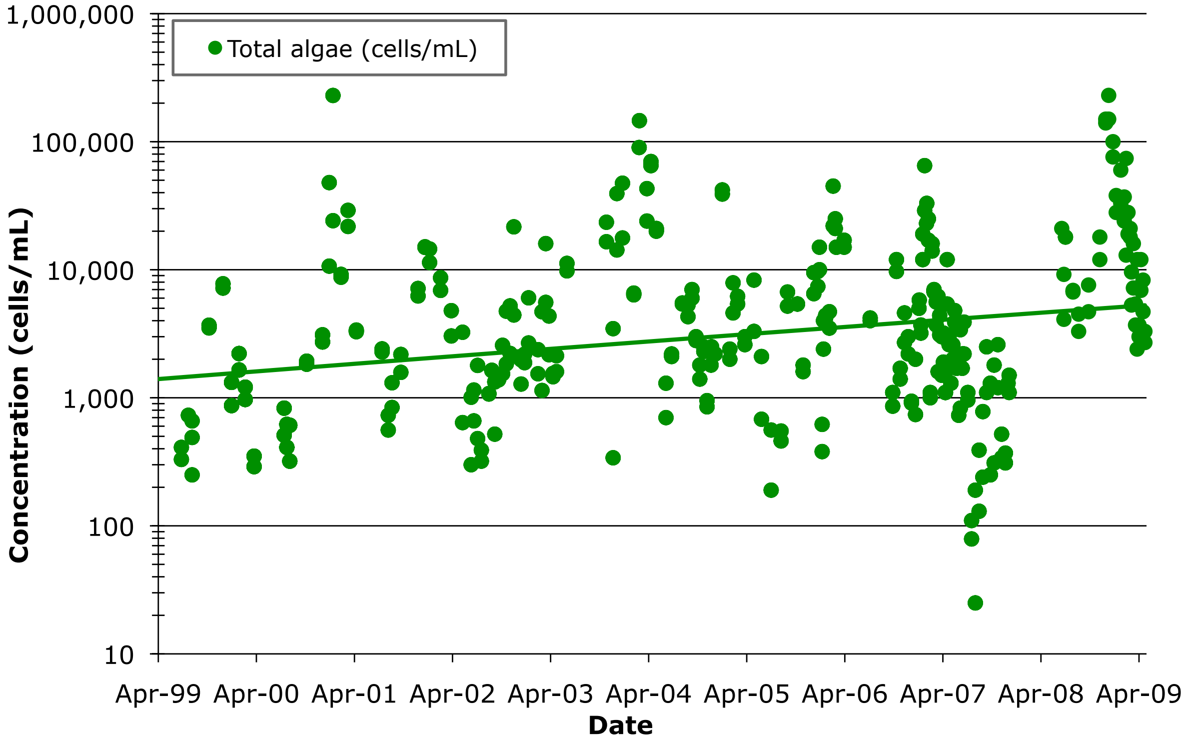

Figure 9-3. Ten-year time series and trendline for algal count data at sampling site GOO724 Googong Reservoir receiving environment.

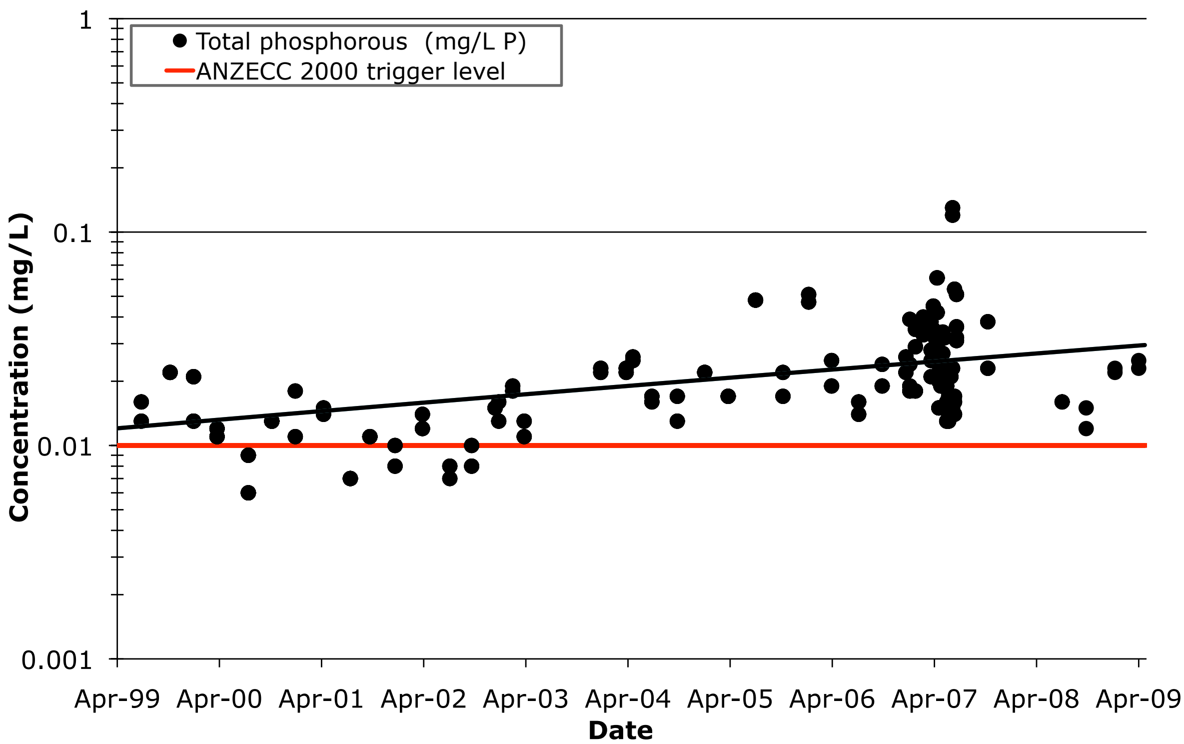

Figure 9-4. Ten-year time series, trendline and ANZECC trigger value (10 µg/L) for total phosphorus data at sampling site GOO724 Googong Reservoir receiving environment.

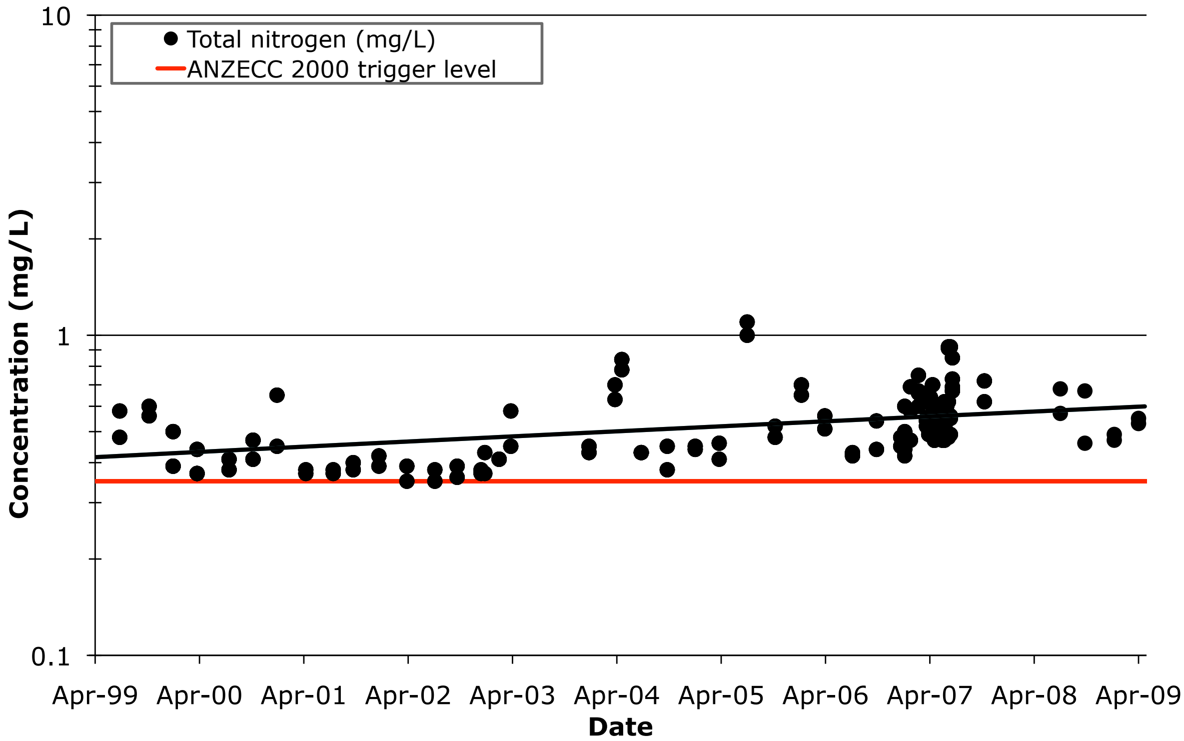

Figure 9-5. Ten-year time series, trendline and ANZECC trigger value (350 µg/L) for total nitrogen data at sampling site GOO724 Googong Reservoir receiving environment.

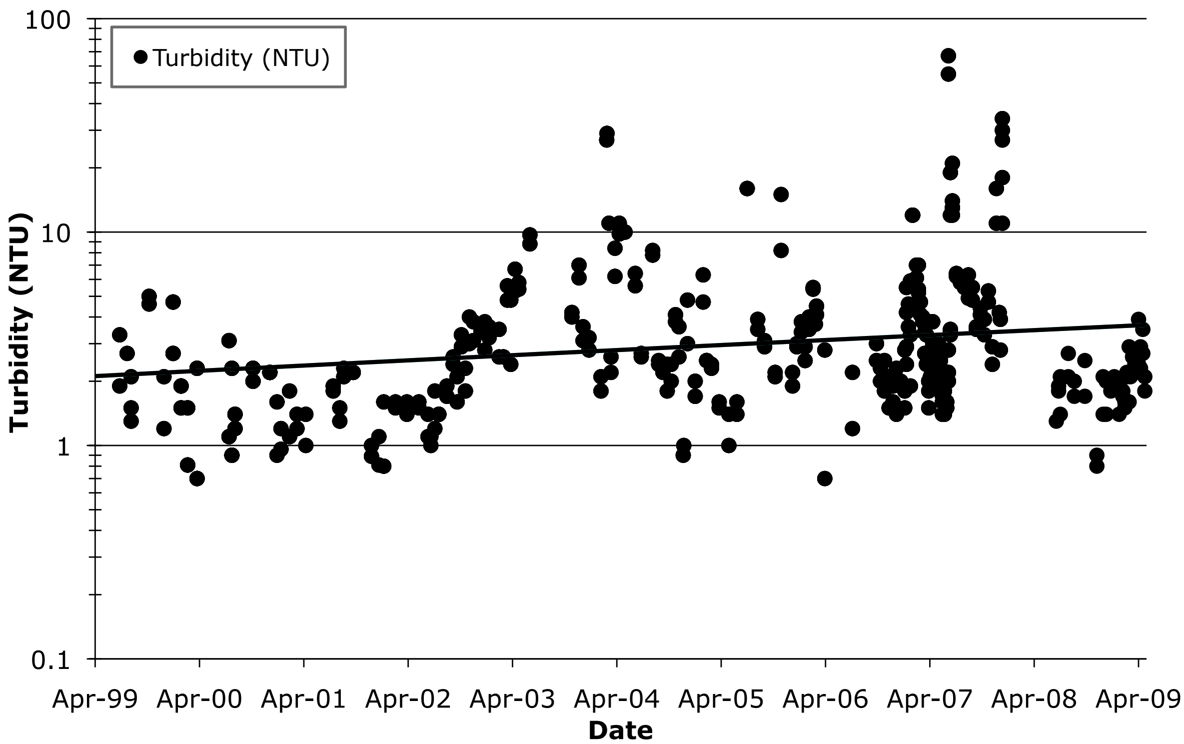

Figure 9-6. Ten-year time series and trendline for turbidity data at GOO724 Googong Reservoir receiving environment.

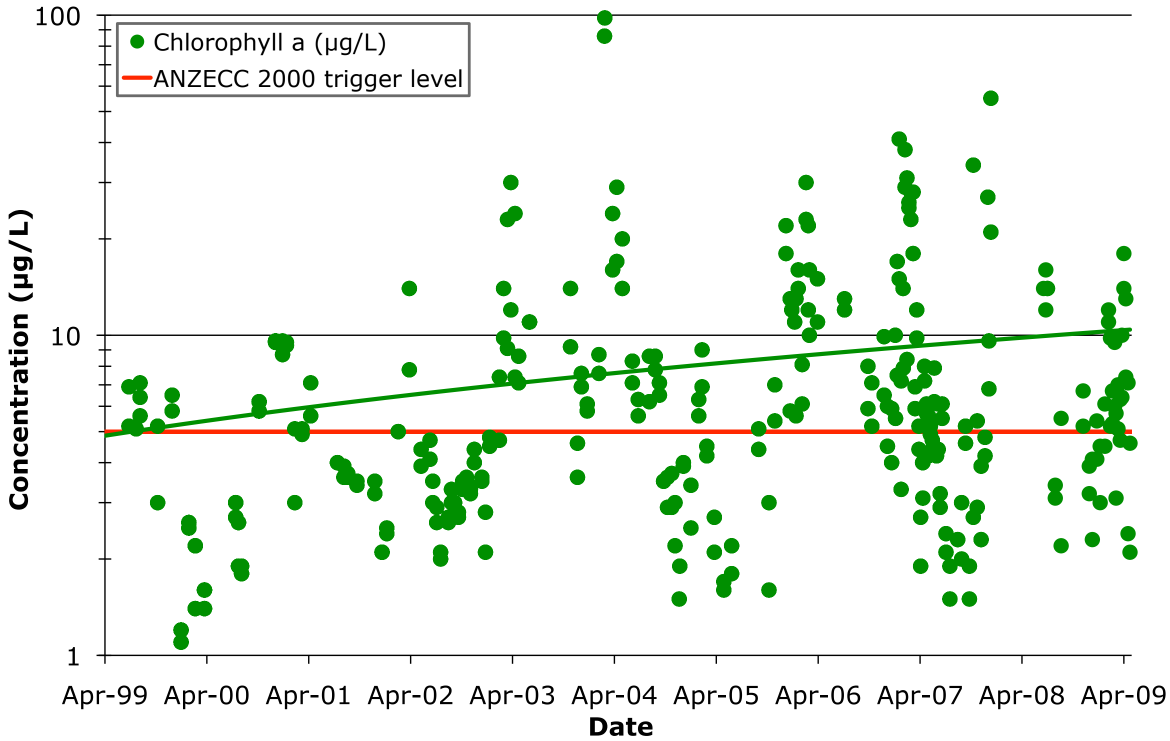

Figure 9-7. Ten-year time series, trendline and ANZECC trigger value (5 µg/L) for chlorophyll *a* data at sampling site GOO724 Googong Reservoir receiving environment.

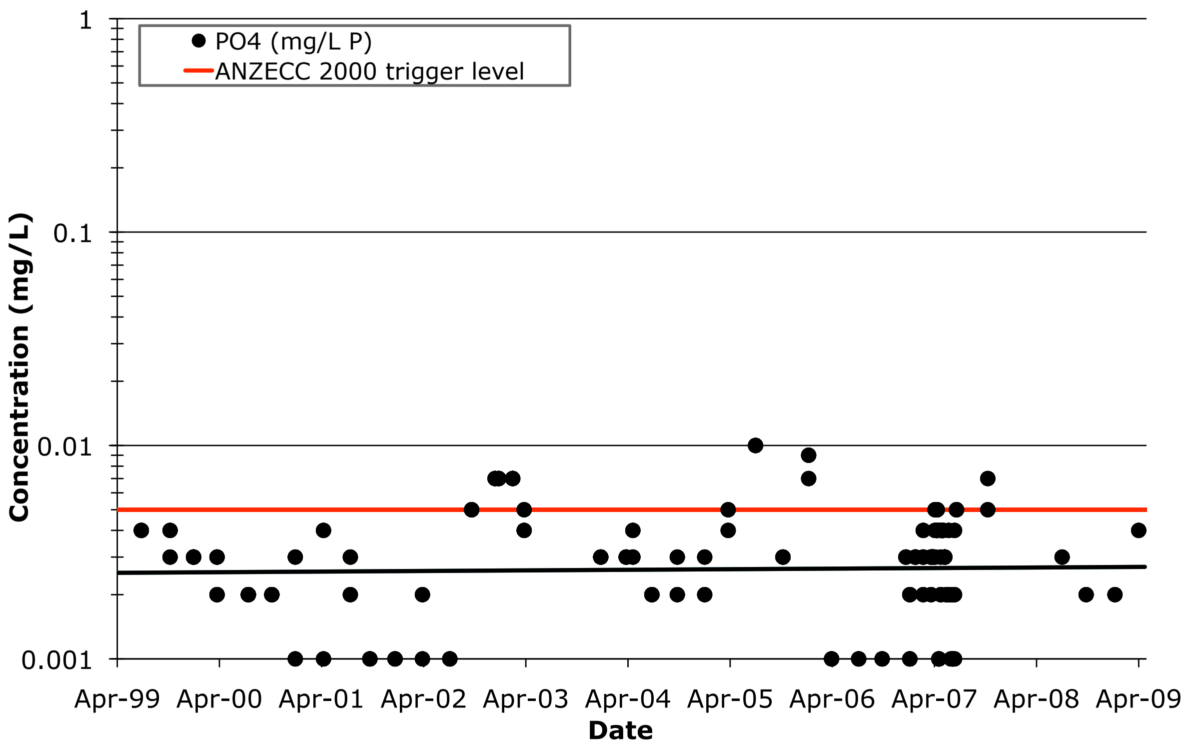

Figure 9-8. Ten-year time series, trendline and ANZECC trigger value (15 µg/L) of reactive phosphorus data at sampling site GOO724 Googong Reservoir receiving environment.

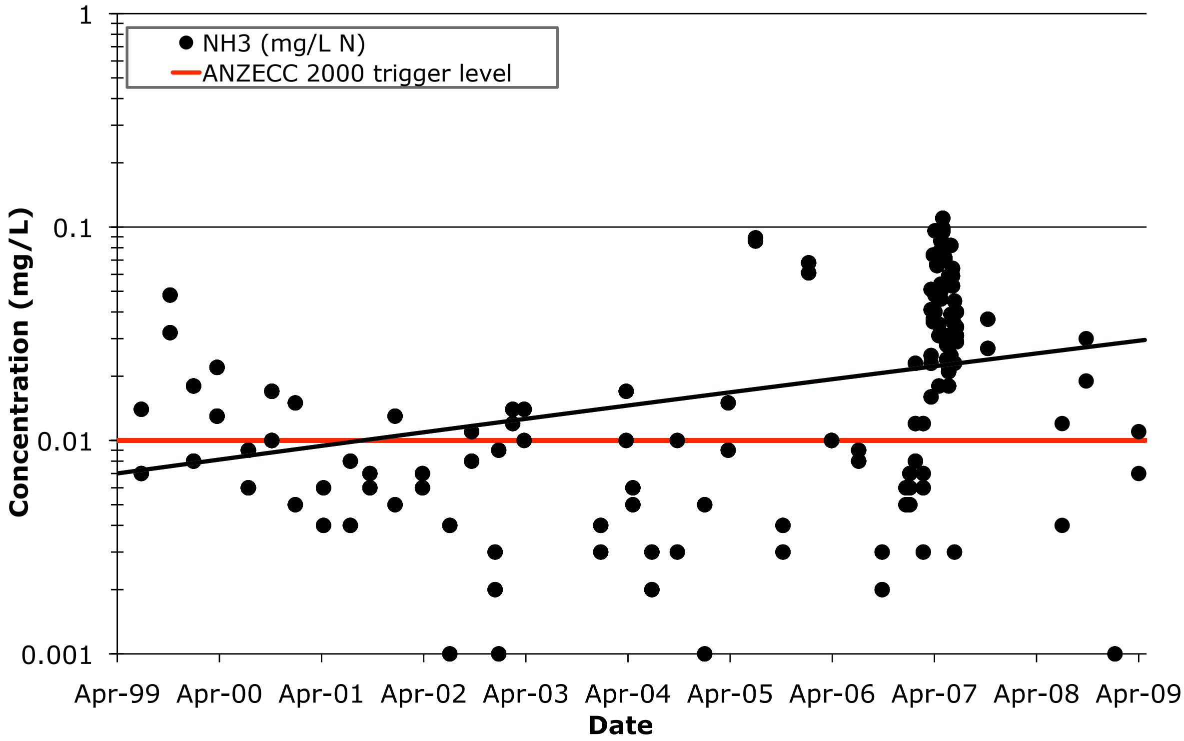

Figure 9-9. Ten-year time series, trendline and ANZECC trigger value (10 µg/L) for ammonia data at sampling site GOO724 Googong Reservoir receiving environment.

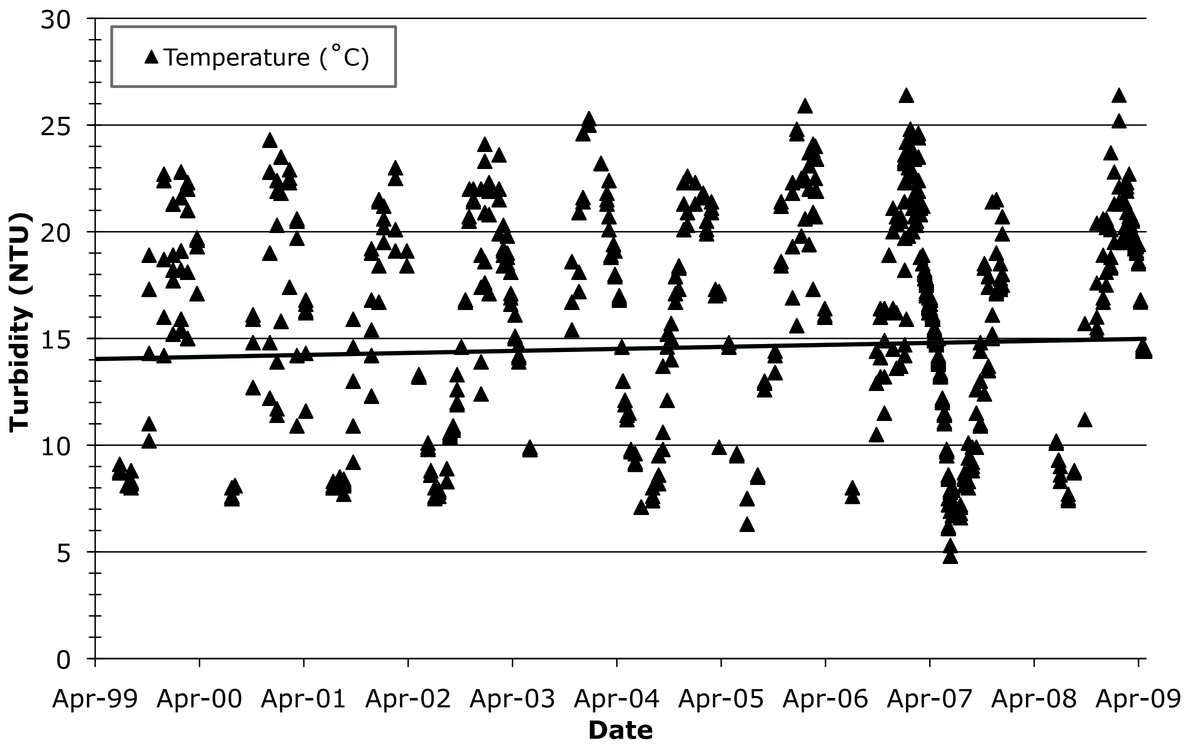

Figure 9-10. Ten-year time series and trendline for temperature data at sampling site GOO724 Googong Reservoir receiving environment.