Port Waterways

Water Quality Improvement Plan

Appendices

APPENDIX A

STATUTORY CAPACITY TO IMPLEMENT THE PORT WATERWAYS WATER QUALITY IMPROVEMENT PLAN

Background

The Port Waterways Water Quality Improvement Plan (WQIP) has taken the aspirations of the South Australian community for the Port waterways and used that information to develop targets for their water quality. Using monitoring and modelling, targets for discharge of nutrients to the waterway have been derived and a strategy has been developed for water quality managers to reduce or maintain their nutrient loads to levels consistent with these targets. There are two major sources of nutrient loads to the Port waterways [Penrice Soda Products and SA Water's Bolivar Wastewater Treatment Plant (WWTP)]. Reductions in these loads are required if the waterways are to improve. There are also other sources of discharge to the waterway, which do not significantly contribute to the overall water quality of the waterways, but which are very significant at a local level. The WQIP assumes that although these are not targeted to increase, local effects may result in a reduction in these loads.

The development of this WQIP has been achieved through consensus and consultation, as stakeholders have responded to the information about the way that the excess nutrients affect the Port waterways. In the long term, achieving these goals will be through an open and consultative approach. Dischargers however, operate within a legislative framework, and the way that legislation will be applied to support this process needs to be clearly understood.

The following describes some of the relevant legislation and how this can be applied to support the WQIP.

It is important to recognise however, that the community of the Port waterways are of fundamental importance to the implementation of the WQIP. An active, involved local community will challenge the status quo and encourage improvement, while giving important feedback on the progress of the WQIP. This is particularly important where improvement will come from a substantial increase in the re-use of wastewater—where there is no statutory capacity to implement.

Relevant legislation

Legislation covers many aspects of businesses and individuals that interact with the Port waterways. It is not proposed that an exhaustive list of these be provided. All South Australian legislation can be accessed online at: <www.legislation.sa.gov.au/index.aspx>.

The following legislation has aims that are consistent with the outcomes sought for the Port waterways:

- *Environment Protection Act 1993*
- *Development Act 1993*
- *Natural Resources Management Act 2004*
- *Adelaide Dolphin Sanctuary Act 2005*
- *Local Government Act 1999*

These are listed with their full titles and objects and a summary of their statutory capacities with respect to the Port Waterways WQIP.

Environment Protection Act 1993

An Act to provide for the protection of the environment; to establish the Environment Protection Authority and define its functions and powers; and for other purposes.

Objects

(1) The objects of this Act are—

(a) to promote the following principles ***(principles of ecologically sustainable development):***

(i) that the use, development and protection of the environment should be managed in a way, and at a rate, that will enable people and communities to provide for their economic, social and physical well-being and for their health and safety while—

(A) sustaining the potential of natural and physical resources to meet the reasonably foreseeable needs of future generations; and
(B) safeguarding the life-supporting capacity of air, water, land and ecosystems; and
(C) avoiding, remedying or mitigating any adverse effects of activities on the environment;

(ii) that proper weight should be given to both long and short term economic, environmental, social and equity considerations in deciding all matters relating to environmental protection, restoration and enhancement; and

(b) to ensure that all reasonable and practicable measures are taken to protect, restore and enhance the quality of the environment having regard to the principles of ecologically sustainable development, and—

(i) to prevent, reduce, minimise and, where practicable, eliminate harm to the environment—

(A) by programmes to encourage and assist action by industry, public authorities and the community aimed at pollution prevention, clean production and technologies, reduction, re-use and recycling of material and natural resources, and waste minimisation; and
(B) by regulating, in an integrated, systematic and cost-effective manner—
  - *activities, products, substances and services that, through pollution or production of waste, cause environmental harm; and*
  - *the generation, storage, transportation, treatment and disposal of waste; and*

(ii) to co-ordinate activities, policies and programmes necessary to prevent, reduce, minimise or eliminate environmental harm and ensure effective environmental protection, restoration and enhancement; and

(iii) to facilitate the adoption and implementation of environment protection measures agreed on by the State under intergovernmental arrangements for greater uniformity and effectiveness in environment protection; and

(iv) to apply a precautionary approach to the assessment of risk of environmental harm and ensure that all aspects of environmental quality affected by pollution and waste (including ecosystem sustainability and valued environmental attributes) are considered in decisions relating to the environment; and

(v) to require persons engaged in polluting activities to progressively make environmental improvements (including reduction of pollution and waste at source) as such improvements become practicable through technological and economic developments; and

(vi) to allocate the costs of environment protection and restoration equitably and in a manner that encourages responsible use of, and reduced harm to, the environment with polluters bearing an appropriate share of the costs that arise from their activities, products, substances and services; and

(vii) *to provide for monitoring and reporting on environmental quality on a regular basis to ensure compliance with statutory requirements and the maintenance of a record of trends in environmental quality; and*

(viii) *to provide for reporting on the state of the environment on a periodic basis; and*

(ix) *to promote—*

  (A) *industry and community education and involvement in decisions about the protection, restoration and enhancement of the environment; and*

  (B) *disclosure of, and public access to, information about significant environmental incidents and hazards.*

The Minister, the Authority and all other administering agencies and persons involved in the administration of this Act must have regard to, and seek to further, the objects of this Act.

This Act is most relevant to the management of the two major dischargers of nutrients to the waterways. These dischargers are subject to environmental authorisations under the Environment *Protection Act 1993*, (EP Act) which allows the Environment Protection Authority (the Authority) to direct aspects of their day-to-day activities, consistent with the objects of the EP Act. Provisions of the EP Act have also been used to:

- Develop and enforce environment improvement programmes with SA Water which have seen the closing down of the Port Adelaide wastewater treatment plant, the upgrade of the Bolivar wastewater treatment plant and the resulting nutrient reduction of over 1,000 tonnes per year from these sources.
- Develop and enforce an environment improvement programme by Penrice Soda Products to remove the solids from their discharge in 2002 and more recently, to enforce their agreed nutrient discharge reduction from 820 tonnes to 575 tonnes by 2010.

The EP Act allows the Authority to exert considerable control over the activities of the holder of an environmental authorisation. However, the objects of the EP Act need to be considered here as they require the Authority:

"(b) *to ensure that all reasonable and practicable measures are taken to protect, restore and enhance the quality of the environment having regard to the principles of ecologically sustainable development,"* and

(i) *to prevent, reduce, minimise and, where practicable, eliminate harm to the environment—*

  (A) *by programmes to encourage and assist action by industry, public authorities and the community aimed at pollution prevention, clean production and technologies, reduction, re-use and recycling of material and natural resources, and waste minimisation; and*

  (B) *by regulating, in an integrated, systematic and cost-effective manner—activities, products, substances and services that, through pollution or production of waste, cause environmental harm; and the generation, storage, transportation, treatment and disposal of waste.*

Directions that the Authority gives, and agreements that it enters into, must be 'reasonable and practicable'. The Port Waterways WQIP will provide advice to the Authority on the nutrient discharge goal for SA Water and Penrice, so that the Authority can ensure that the authorisations issued to these organisations set conditions that keep them reducing their discharges to meet these targets as soon as possible.

An example of this is the approach of the Authority to Penrice Soda Products. Negotiations with Penrice suggest that it is reasonable and practicable for the nitrogen in their discharge to be reduced to 575 tonnes per year by 2010. While Penrice will make efforts to further reduce their discharge to 250 tonnes per year by 2015, the Authority has no reason to be confident that this is practically achievable. This information will be continually re-assessed and, prior to 2010, a further environment improvement programme will be negotiated with Penrice Soda Products to further reduce their nitrogen discharge. This process will continue until Penrice's nitrogen discharge load is reduced to the level required to achieve the goal of the WQIP.

In this way the EP Act allows the Authority to continually 'lock in' interim goals for improvement under the guidance of over-arching strategies such as the WQIP.

General environmental duty

Section 25 of the EP Act:

> *(1) A person must not undertake an activity that pollutes, or might pollute, the environment unless the person takes all reasonable and practicable measures to prevent or minimise any resulting environmental harm.*

It places an obligation on all people not to pollute. Enforcement of this obligation is through Environment Protection Orders. In addition to authorised officers employed by the Authority, other government officers and an increasing number of local council officers are becoming authorized officers under the EP Act, enabling them to initiate action to prevent pollution.

Development Act 1993

An Act to provide for planning and to regulate development in the State; to regulate the use and management of land and buildings, and the design and construction of buildings; to make provision for the maintenance and conservation of land and buildings where appropriate; and for other purposes.

Objects

The object of this Act is to provide for proper, orderly and efficient planning and development in the State and, for that purpose—

- *(a) to establish objectives and principles of planning and development; and*
- *(b) to establish a system of strategic planning governing development; and*
- *(c) to provide for the creation of Development Plans—*
    - *(i) to enhance the proper conservation, use, development and management of land and buildings; and*
    - *(ii) to facilitate sustainable development and the protection of the environment; and*
    - *(iia) to encourage the management of the natural and constructed environment in an ecologically sustainable manner; and*
    - *(iii) to advance the social and economic interests and goals of the community; and*
- *(d) to establish and enforce cost-effective technical requirements, compatible with the public interest, to which building development must conform; and*

(e) *to provide for appropriate public participation in the planning process and the assessment of development proposals; and*

(f) *to enhance the amenity of buildings and provide for the safety and health of people who use buildings; and*

(g) *to facilitate—*

(i) *the adoption and efficient application of national uniform building standards; and*

  (ii) *national uniform accreditation of buildings products, construction methods, building designs, building components and building systems.*

This Act allows the regulation of new development and provides for consultation on proposed developments by affected stakeholders, including other statutory authorities. The Development Assessment Commission oversees the administration of the Development Act. Activities that have the potential to cause environmental harm are specified in both the Development Act and the EP Act. The EPA has the power under specific circumstances to direct the Development Assessment Commission to refuse consent for a proposed development or to add conditions to ensure that the likelihood of a proposal causing harm to the environment is minimised.

The referral arrangement between the Development Act and the EP Act operates in an effective manner to reduce potential pollution in the catchment for the Port waterways. This ensures that the potential for activities to pollute stormwater, or generate a wastewater discharge to the waterway is minimised both during development and during its operation.

Natural Resources Management Act 2004

An Act to promote sustainable and integrated management of the State's natural resources; to make provision for the protection of the State's natural resources; to repeal the *Animal and Plant Control (Agricultural Protection and Other Purposes) Act 1986*, the *Soil Conservation and Land Care Act 1989* and the *Water Resources Act 1997*; and for other purposes.

Objects

(1) *The objects of this Act include to assist in the achievement of ecologically sustainable development in the State by establishing an integrated scheme to promote the use and management of natural resources in a manner that—*

  (a) *recognises and protects the intrinsic values of natural resources; and*

  (b) *seeks to protect biological diversity and, insofar as is reasonably practicable, to support and encourage the restoration or rehabilitation of ecological systems and processes that have been lost or degraded; and*

  (c) *provides for the protection and management of catchments and the sustainable use of land and water resources and, insofar as is reasonably practicable, seeks to enhance and restore or rehabilitate land and water resources that have been degraded; and*

  (d) *seeks to support sustainable primary and other economic production systems with particular reference to the value of agriculture and mining activities to the economy of the State; and*

  (e) *provides for the prevention or control of impacts caused by pest species of animals and plants that may have an adverse effect on the environment, primary production or the community; and* *(f) promotes educational initiatives and provides support mechanisms to increase the capacity of people to be involved in the management of natural resources.*

(2) For the purposes of subsection (1), ecologically sustainable development comprises the use, conservation, development and enhancement of natural resources in a way, and at a rate, that will enable people and communities to provide for their economic, social and physical well-being while—

(a) sustaining the potential of natural resources to meet the reasonably foreseeable needs of future generations; and

(b) safeguarding the life-supporting capacities of natural resources; and

(c) avoiding, remedying or mitigating any adverse effects of activities on natural resources.

(3) The following principles should be taken into account in connection with achieving ecologically sustainable development for the purposes of this Act:

(a) decision-making processes should effectively integrate both long term and short term economic, environmental, social and equity considerations;

(b) if there are threats of serious or irreversible damage to natural resources, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation;

(c) decision-making processes should be guided by the need to evaluate carefully the risks of any situation or proposal that may adversely affect the environment and to avoid, wherever practicable, causing any serious or irreversible damage to the environment;

(d) the present generation should ensure that the health, diversity and productivity of the natural environment is maintained or enhanced for the benefit of future generations;

(e) a consideration should be the conservation of biological diversity and ecological integrity;

(f) environmental factors should be taken into account when valuing or assessing assets or services, costs associated with protecting or restoring the natural environment should be allocated or shared equitably and in a manner that encourages the responsible use of natural resources, and people who obtain benefits from the natural environment, or who adversely affect or consume natural resources, should bear an appropriate share of the costs that flow from their activities;

(g) if the management of natural resources requires the taking of remedial action, the first step should, insofar as is reasonably practicable and appropriate, be to encourage those responsible to take such action before resorting to more formal processes and procedures;

(h) consideration should be given to Aboriginal heritage, and to the interests of the traditional owners of any land or other natural resources;

(i) consideration should be given to other heritage issues, and to the interests of the community in relation to conserving heritage items and places;

(j) the involvement of the public in providing information and contributing to processes that improve decision-making should be encouraged;

> (k) *the responsibility to achieve ecologically sustainable development should be seen as a shared responsibility between the public sector, the private sector, and the community more generally;*

> *the local government sector is to be recognised as a key participant in natural resource management, especially on account of its close connections to the community and its role in regional and local planning.*

The Natural Resources Management Act (NRM Act) provides for the integration of South Australia's natural resources—including water resources. This enables the control of flows from the Port waterways catchment, but also the ability to specify outcomes for water quality from the catchment.

The NRM Act provides for the protection and management of catchments and the sustainable use of land and water resources and, insofar as is reasonably practicable, seeks to enhance and restore or rehabilitate land and water resources that have been degraded. This includes responsibility for the effect that water discharged from the Port waterways catchments has on its water quality.

The local government sector is recognised under the NRM Act as a key participant in natural resource management, especially on account of its close connections to the community and its role in regional and local planning.

While working with local government and other government and non-government authorities, the NRM Act enables the local NRM Board, the Adelaide and Mount Lofty Ranges Natural Resource Management Board to plan for positive outcomes for the Port waterways.

Adelaide Dolphin Sanctuary Act 2005

An Act to establish a sanctuary to protect the dolphin population of the Port Adelaide River estuary and Barker Inlet and its natural habitat; to provide for the protection and enhancement of the Port Adelaide River estuary and Barker Inlet; to amend the *Aquaculture Act 2001*, the *Coast Protection Act 1972*, the *Development Act 1993*, the *Environment Protection Act 1993*, the *Fisheries Act 1982*, the *Harbors and Navigation Act 1993*, the *Historic Shipwrecks Act 1981*, the *Mining Act 1971*, the *National Parks and Wildlife Act 1972*, the *Native Vegetation Act 1991* and the *Petroleum Act 2000*; and for other purposes.

Objects

The objects of this Act are—

> (a) *to protect the dolphin population of the Port Adelaide River estuary and Barker Inlet; and*

> (b) *to protect the natural habitat of that population.*

An Act to promote sustainable and integrated management of the State's natural resources; to make provision for the protection of the State's natural resources; to repeal the Animal and Plant Control (Agricultural Protection and Other Purposes) Act 1986, the Soil Conservation and Land Care Act 1989 and the Water Resources Act 1997; and for other purposes.

The Adelaide Dolphin Sanctuary Act (ADS Act) establishes a sanctuary to protect the dolphin population of the Port Adelaide River estuary and Barker Inlet and its natural habitat; to provide for the protection and enhancement of the Port Adelaide River estuary and Barker Inlet.

The ADS Act allows the Department of Environment and Heritage (DEH) to directly intervene to protect dolphins from harm, but also requires that the objects of other Acts that enable management of the Port waterways include the objects of the ADS Act.

These acts are:

- *Aquaculture Act 2001*
- *Coast Protection Act 1972*
- *Development Act 1993*
- *Environment Protection Act 1993*
- *Fisheries Act 1982*
- *Harbors and Navigation Act 1993*
- *Historic Shipwrecks Act 1981*
- *Mining Act 1971*
- *National Parks and Wildlife Act 1972*
- *Native Vegetation Act 1991*
- *Petroleum Act 2000.*

The development of the Port Waterways WQIP has been undertaken with considerable input from the Adelaide Dolphin Sanctuary, which in turn takes much of the management of the water quality of the Sanctuary from the Port Waterways WQIP.

Local Government Act 1999

An Act to provide for local government; and for other purposes.

Objects

The objects of this Act are—

(a) to promote the continuance of a system of local government in South Australia under which elected local government bodies are constituted for the better governance of the State in a manner that is consistent with the provisions of Part 2A of the Constitution Act 1934; and

(b) to encourage the participation of local communities in the affairs of local government and to provide local communities, through their councils, with sufficient autonomy to manage the local affairs of their area; and

(c) to provide a legislative framework for an effective, efficient and accountable system of local government in South Australia; and

(d) to ensure the accountability of councils to the community; and

(e) to improve the capacity of the local government system to plan for, develop and manage local areas and to enhance the capacity of councils to act within their local areas as participants in the Australian system of representative government; and

(f) to encourage local government to provide appropriate services and facilities to meet the present and future needs of local communities; and

(g) to encourage local government to manage the natural and built environment in an ecologically sustainable manner; and

(h) to define the powers of local government and the roles of council members and officials.

The Local Government Act provides for local government authorities and includes the object of encouraging local government to manage the natural and built environment in an ecologically sustainable manner.

Local councils have the statutory ability to ensure that small business and individuals plan their activities and manage them in a manner that minimises harm to the Port waterways.

Their officers are active in their local area and many are also authorised under the EP Act and act to enforce it for their local area. Local councils also run education programs to ensure that the skills needed to minimise discharges to the Port waterways are available to businesses and individuals in their area.

Aspects of the WQIP where statutory power does not exist

With SA Water's recent completion of a major upgrade to the Bolivar wastewater treatment plant, further capital expenditure is unlikely to be reasonable or practicable in the first few of the WQIP cycles. The WQIP looks to the increase in the development of the re-use of wastewater to provide load reductions from Bolivar. However, no legislation exists to force the re-use of wastewater.

In this case, the re-use of wastewater needs to be supported by stakeholder interest, and the need for additional supplies of water for metropolitan and near-metropolitan Adelaide.

A cooperative approach between stakeholders is needed to ensure that a viable strategy for wastewater is developed which includes extensive re-use of the Bolivar discharge.

Summary

The main statutory capacity to ensure the implementation of the WQIP rests with the EPA. The Authority is well placed and resourced to enable the implementation to proceed –subject to the availability of cost—effective solutions.

The cooperative arrangements that exist legislatively between the Development Act, the Adelaide Dolphin Sanctuary Act and the Environment Protection Act enables the consideration of individual developments in the Port waterways catchment from planning through to operation. This is with a with a view to the ability of the Port waterways to function as a viable habitat for dolphins. Prevention of further deterioration of the waterway is well within the capacity of these Acts.

With the ability of the Adelaide and Mount Lofty Ranges Natural Resource Management Board to invest with local councils and other groups to protect and enhance the quality of water from the Port waterways catchment, including urban areas, the capacity exists for the Port Waterways WQIP to be implemented with respect to local discharges derived from the stormwater system.

A major part of the WQIP: reductions from the Bolivar wastewater treatment plant through extra re-use cannot currently be managed via statutory means. Continued stakeholder support for an integrated re-use strategy for the Adelaide region is required to allow this increase in wastewater re-use to be achieved.

APPENDIX B

PROGRAMS AND FUNDING FOR THE IMPLEMENTATION OF THE PORT WATERWAYS WATER QUALITY IMPROVEMENT PLAN

Introduction

The WQIP has used community agreed environmental values to develop water quality targets for the Port waterways. Modelling has enabled us to relate point source nutrient loads to the waterways to these water quality targets and to identify that two major remaining discharges now determine the overall water quality of the area. Discharge targets for these point sources have been derived by the modelling.

In turn, these dischargers—Penrice Soda Products (Penrice) and the SA Water managed Bolivar wastewater treatment plants (WWTP) and other stakeholders such as local councils have responded by looking for ways to reduce the nutrient load in their discharges.

The success of the WQIP also relies on other more minor nutrient discharge loads to the Port waterways remaining steady, or improving over time against a background of continual urban and industrial development of northern metropolitan Adelaide.

The following information provides further information about the programs in place to implement the WQIP.

A number of factors including the information derived by the development of the WQIP are driving work to conserve water resources, re-use wastewater and limit the discharge of wastewater to the Port waterways. The following information therefore represents a snapshot of work actively being pursued at the time of the publishing of the Port Waterways WQIP, rather than a complete list of projects under consideration for the improvement of the Port waterways.

This information also excludes work that is primarily aimed at dealing with other issues and has only a marginal effect on the loads of nutrients to the Port waterways.

Programs and funding

For consistency, the information follows the form of Table 2.5 in Section 2 of the WQIP.

Catchments

The Adelaide and Mount Lofty Ranges Natural Resources Management (A&MLR NRM) Board exercises control over the planning for catchment works in the area. The Board has currently developed its management plan for the region.

Other programs

The management of stormwater loads is likely to require a carefully considered series of projects over an extended period, integrated with other initiatives such as implementation of water sensitive urban design elements in new and in-fill development and innovative solutions such as market based instruments and subsidies. The following projects, under active consideration by the A&MLR NRM Board, are included to indicate how these kinds of projects are being considered. These projects include:

- Port Road wetlands and ASR. Primarily an initiative of City of Charles Sturt this system discharges into northern end of West Lakes.

- Cheltenham Racecourse wetland and re-use that would harvest from the Torrens Road drain which otherwise discharges through wetlands into the North Arm.
- Riverside Golf Club management of the disused SA Water Port Adelaide WWTP, a stormwater sourced wetland.

Torrens, Hindmarsh, Enfield and Prospect catchments

No specific program

Northern Adelaide Barossa Catchment

Waterproofing Northern Adelaide

Waterproofing Northern Adelaide (WNA) will complete the integrated water cycle management for the urban areas of Tea Tree Gully, Salisbury and Playford to the east of Port Wakefield Road. The project will provide flood mitigation, environmental enhancement of the main waterways and a sustainable recycled water supply of 12 GL/year with a net groundwater recharge of 5 GL/year.

WNA will:

- create 29 new or expanded wetland ASR's and over 100 km of distribution mains
- reduce the discharge from the Bolivar low salinity wastewater treatment plant by 20 GL/year and this should produce a reduction in nutrient outflow of about 40 t/year.

Construction is to be complete by mid–2010 and the scheme fully operational by the winter of 2011.

The construction cost of the project is $104 m, which includes the expenditure needed for users to make use of the recycled water.

Local stormwater

No specific programs.

Regional groundwater

No specific programs.

West Lakes

No specific programs.

Bolivar

Low-salinity wastewater treatment plant.

While no capital works are proposed to change either of the Bolivar plants at this time, a number of projects are being undertaken to re-use wastewater from the low salinity plant.

Virginia pipeline scheme extension

A Virginia pipeline scheme extension into Angle Vale will enable an additional 3 GL/year Class A reclaimed water from the Bolivar WWTP to be used for irrigation. To date irrigators have signed up to take 2.8 GL/year.

SA Water is responsible for the implementation of the project, which will be privately owned and operated by WRSV, as is the existing Virginia scheme.

The estimated completion date for construction is June 2008; with the current cost estimate for the project is $4.7 million. Funding sources include both state and federal government (pending).

Waterproofing the North

See above—Catchments.

High salinity wastewater treatment plant

No specific program.

Penrice Soda Products

Penrice Soda Products have committed to a reduction in their discharge of nitrogen (in the form of Ammonia) from 820 tonnes per year in 2005 to 575 tonnes per year by 2010 (see note below). Their commitment to this is reflected in the Environment Improvement Programme (EIP) that has been agreed with the EPA. Adherence with the EIP carries penalties under the Environment Protection Act.

Penrice also aspires to further reductions in the discharge of nitrogen to 250 tonnes by 2015. As the cost effective technology to achieve this has not yet been developed, Penrice are unable to legally commit to this target prior to 2010, and perhaps beyond. Penrice will however, reduce their discharge of nitrogen to limit that technology will allow and continue to reflect new reduction targets through EIPs or similar legislatively based agreements until they reach a discharge load that will allow the water quality objectives for the Port waterways to be achieved.

Note:
The Port waterways uses nitrogen to measure loads to ensure that all discharges are assessed on a mass equivalent basis and to account for transformations that occur in the various forms of nitrogen discharge after discharge. 700 tonnes of Ammonia has the equivalent mass of 575 tonnes of Nitrogen.

Penrice's Environment Improvement Program

Substantial parts of the EIP agreed between the EPA and Penrice are provided below. Monitoring in 2006 showed that Penrice are achieving the required compliance actions.

General description

Brief

Penrice Soda Products is licensed under the EP Act, to operate a chemical production plant. The plant manufactures soda ash and sodium bicarbonate using the Solvay process (referred to in Appendix 1).

Licence compliance

Penrice Soda Products is required to develop an EIP to address the following:

Non-compliance of discharge to marine or inland waters with the mandatory provisions of the Environment Protection Water Quality Policy 2003, namely clauses 13a and 13b.

Condition 310–50, Ammonia Reduction EIP, of the license 0787 states that Penrice Soda Products must:

1 Implement and maintain the approved Penrice Soda Products Osborne Manufacturing Facility 'Ammonia Reduction Environmental Improvement Plan' Document number ENV–4A.1, dated September 2005; and

2 Ensure that the approved EIP referred to in paragraph 1, is reviewed by the Licensee before 31 December in each year and, if there is a significant change regarding environmental matters or agreed timeframes, or both, submit an updated EIP to the Authority.

The EIP must be implemented over a five–year period and must include the following objectives:

- reducing ammonia (as Total Nitrogen) concentration and net loads in the waste water stream discharged to the Port River
- reducing nutrient net loads to the Port River

- reviewing BATEA, for better environmental management, cleaner production/waste minimisation and new treatment processes
- conducting a feasibility study to investigate possible options available to reduce ammonia levels beyond/or to meet annual EIP targets.

Referenced documentation

In developing this EIP, Penrice Soda Products has considered these other relevant documents:

- Correspondence from the EPA to Penrice Soda Products, EPA 05/10264 pt2, dated 10 August 2005.
- Penrice Soda Products Holdings Ltd, Osborne Manufacturing Facility, Ammonia Reduction, Environment Improvement Plan, December 2002–December 2006, document number ENV-3A revision 3.
- EPA documentation 'Draft communication plan Port Waterways Project', version 1.0, June 2005.
- Environment Protection Act 1993 (amended volume 1.7.2005)
- Environment Protection Water Quality (WQ) Policy 2003.

Intent

Penrice Soda Products Holdings Limited will aim to comply with the WQ Policy by committing to reduce the discharge of ammonia to the local marine environment via the plant's waste water stream.

The EIP will act as a regulatory tool under the Act (amended V1.7.2005) to provide for scheduled improvements at Penrice Soda Products to meet Section 25 of the EP Act, general environmental duty and the WQ Policy.

This EIP will focus on reducing ammonia discharge to the Port River. This EIP will be attached to Penrice Soda Products EPA operating license 0787 and exemption to the WQ Policy.

The EIP strategy for ammonia reduction which inturn is expected to reduce nutrient loading and toxicity levels to the Port River will be completed by committing to annual reduced target loadings of ammonia discharged via Penrice's waste water stream.

The goal will to be to reduce the ammonia loss to the Port River to 700 tonnes per annum, achievable by the end of the term of the EIP on 31 December 2010. Progress on achieving this target will be monitored and reviewed on an annual basis.

The ammonia reduction will be as follows:

Year	Total Ammonia (tonnes)	Total Nitrogen (tonnes)
2006	900 tonnes/year	740 tonnes/year
2007	850 tonnes/year	699 tonnes/year
2008	800 tonnes/year	658 tonnes/year
2009	750 tonnes/year	617 tonnes/year
2010	700 tonnes/year	576 tonnes/year

Note: The step-by-step reductions are captured under the compliance actions of the EIP.

In addition to achieving these reduction targets Penrice Soda Products will commit to an aspirational target beyond these targets by continuing to review BATEA and performing a feasibility study reviewing this. This will also incorporate any in-plant trials to determine the effectiveness of any proposed equipment installation.

Any future planning at Osborne that includes the expansion of the soda ash production plant that would normally involve a proportional increase in ammonia loss to the Port River, will see Penrice commit to ammonia loss reduction technology to ensure the targets set out in the EIP are achieved.

Table B3 Ammonia Reduction Environmental Improvement Strategic Plan, 2006-10

ID		TASK	2006	2007	2008	2009	2010
1		**Monitoring, measuring and loss allocation**					
1.1		Continue ammonia loss matrix	***	***	***	***	***
1.2		Update full site ammonia loss survey	***				
1.3		Better improve shift information system for ammonia consumption	***				
1.4		Evaluate suitability of ammonia monitoring equipment available	***				
1.5		Develop online ammonia loss technology for cooling water streams	***	***	***		
	1.5.1	Revise/research available technology	***				
	1.5.2	Construct prototype	***	***			
	1.5.3	Implement prototype		***	***		
2		**Distiller steam, lime & pH control systems**					
2.1		Clean distillers to schedule	***	***	***	***	***
2.2		Upgrading of MOL Secondary Circuit	***				
2.3		Prelimer Blow Down project	***	***			
	2.3.1	Investigate options available	***				
	2.3.2	Implement project		***			
2.4		Preheater condensate ammonia recover	***				
2.5		Upgrade feeder liquor flow measurement to electromagnetic flow meters	***	***			
2.6		Review flash technology for ammonia reduction of DBO streams	***	***			
2.7		Advanced control upgrade of DCS		***	***		
3		**Equipment integrity**					
3.1		Maintain Carbonating Tower tube replacement program using titanium	***	***	***	***	***
3.2		Replace cooling tubes/plates as programmed	***	***	***	***	***
3.3		Upgrade Carbonating Tower Circulating mains to FRP	***	***	***		
3.4		Continue to investigate use of alternative materials to improve life	***	***	***	***	***
3.5		Replace distiller heater/PCD column		***	***		
3.6		Investigate option to upgrade to 3 distillers	***	***			
3.7		Replacing of feeder liquor stock tank	***				
3.8		Pipe work integrity survey	***				
3.9		Vessel integrity survey	***				
3.10		Replace strong gas and kiln gas coolers and pipe sections	***	***			

4		Ammonia Soda	2006	2007	2008	2009	2010
4.1		Absorbed Hold up prevention early detection via DCS upgrade	***	***	***		
4.2		Identify & bund key risk areas of ammonia loss of plant	***	***	***		
4.3		Upgrade DCS system for easier operator viewing and ammonia loss focus	***	***	***		
4.4		Procedure review and upgrade	***				
4.5		Develop an environment equipment register to aid in plant improvement to ammonia loss	***				
4.6		Plant ammonia efficiency improvement initiatives	***	***	***	***	***

EIP compliance actions

Penrice Soda Holdings Limited is committed to reducing ammonia, which includes nutrients and toxicants. Penrice will undertake all actions outlined in the 'ammonia reduction strategy plan' in order to meet annual reduction targets addressed in the EIP.

Compliance action 1
By **31 December 2006**, Penrice Soda Holdings Ltd will demostrate a reduction of **102 t/yr** of ammonia discharged to the Port River from **1002 t/yr to 900 t/yr** or as Total Nitrogen from **824 t/yr to 740 t/yr**.

Compliance action 2
By **31 December 2006**, Penrice Soda Holdings Ltd will engage a consultant to complete a desk top review of methods available including a feasibilty study on ammonia reduction in waste water streams.

Compliance action 3
By **31 December 2007**, Penrice Soda Holdings Ltd will demonstrate a reduction of **50 t/yr** of ammonia discharged to the Port River from **900 t/yr to 850 t/yr**, or as Total Nitrogen **740 t/yr to 699 t/yr**.

Compliance action 4
By **31 December 2008**, Penrice Soda Holdings Ltd will demonstrate a reduction of 50 t/yr of ammonia discharged to the Port River from **850 t/yr to 800 t/yr**, or as Total Nitrogen **699 t/yr to 658 t/yr**.

Compliance action 5
By **31 December 2009**, Penrice Soda Holdings Ltd will demonstrate a reduction of **50 t/yr** of ammonia discharged to the Port River from **800 t/yr to 750 t/yr**, or as Total Nitrogen **658 t/yr to 617 t/yr**.

Compliance action 6
By **31 December 2010**, Penrice Soda Holdings Ltd will demostrate a reduction of **50 t/yr** of ammonia discharged to the Port River from **750 t/yr to 700 t/yr**, or as Total Nitrogen **617 t/yr to 576 t/yr**.

Compliance action 7
All above compliance actions will be achieved by undertaking the proposed **'ammonia reduction strategy plan'** addressed in **attachement 1**.

Compliance action 8
Penrice Soda Holdings Ltd will commit to an aspirational ammonia discharge target of **250 t/yr** based on BATEA by the **2015**.

Additional programs

Further projects are underway at Penrice aimed at achieving their aspirational target of 250 tonnes of nitrogen by 2015. These works are in initial stages and are not yet developed to the point that implementation at Osborne can be planned, or timetables developed for implementation. In addition, Penrice in agreement with the EPA recently modified their operating license to include a research and development commitment on an annual basis.

These further projects include:

- Distiller Blow Off Recovery in which the distiller effluent is separated and piped to large holding basins where the ammonia is allowed to naturally strip to atmosphere. The capital expenditure for this project is expected to be close to $1 m.
- Research and development project with South Australian Research and Development Institute in which the use of an algal bio-filter is being investigated to remove a proportion of the Nitrogen in from the waste water stream. The costs of the initial stage are $40,000.

Bulk Handling

Implementation of Code of Practice for Materials Handling on Wharves
This code of practice applies to all people, organisations and agencies that own, operate and use wharf facilities and vessels for the purpose of materials handling within the marine and inland waters environment of the state of South Australia.

The EPA will undertake a program of making relevant individuals and organisations aware of the code and its implications for their activities and will monitor acceptance and compliance with the code.

The cost of this work will be provided by the EPA.

Fertiliser Industry

No specific programs.

Recreation

Implementation of Code of Practice for Vessel and Facility Management: Marine and Inland Waters
This code of practice applies to people, organisations and agencies that own, operate and use vessels, vessel construction and maintenance facilities (including slipways and launch facilities), and vessel storage facilities (including dry dock boat yards, marinas, moorings, boat and yacht clubs) within or adjacent to the state waters of South Australia, including the Port waterways.

The EPA will undertake a program of making relevant individuals and organisations aware of the code and its implications for their activities and will monitor acceptance and compliance with the code.

The cost of this work will be provided by the EPA.

Wingfield Waste Management Centre

No specific programs.

Garden Island landfill

No specific programs.

Internal sources

No specific programs.

Atmospheric sources

No specific programs.

APPENDIX C

REASONABLE ASSURANCE STATEMENT FOR THE PORT WATERWAYS WATER QUALITY IMPROVEMENT PLAN

Aim

This Reasonable Assurance Statement (RAS) seeks to provide stakeholders with a high degree of confidence that if the Port Waterways WQIP is implemented, the WQIP load target it is aiming for will be achieved.

Scope

The RAS considers how certain we are about:

(a) our knowledge of the response of the system to pollutant loads, and where there is scientific uncertainty a suitable Margin of Safety has been applied

(b) the effectiveness of proposed interventions to achieve load reductions

(c) the adoption of proposed interventions, in terms of timing and extent. To account for uncertainty—in the spirit of the precautionary principle— this may require high levels of adoption of key interventions.

Response of the system to pollutant loads

Ecosystems such as the Port waterways show response to changes in nutrient loads in different ways. These responses depend on whether the load is increasing or decreasing, and to what extent the system has been previously impacted.

If we consider the Port waterways prior to European settlement, we understand that the nutrient levels were low and land-sourced inputs were irregular. As the nutrient loads increased and became more regular, changes in seagrass cover would have lagged behind changes in populations of shorter-lived organisms such as *Ulva* spp. and other more seasonal users of nutrients.

As nutrient levels continued to rise, the seagrass showed the response that is now understood to be fairly typical of like systems—it gradually disappeared. The Adelaide Coastal Waters Study has shown that the loss of seagrass from the Adelaide Metropolitan coast occurred as human populations rose, but lagged behind this by eight years or so (Wilkinson et al 2005).

In the same way, the Port waterways are likely to respond to the reductions in nutrients in a complex manner, with some time lags.

Margin of Safety

The nutrient targets in the WQIP are derived from modelling and as such are subject to some uncertainty. In developing these targets, assumptions have been made to ensure that estimates err on the side of caution, rather than aim for loads that could turn out to be too high to achieve the environmental benefits nominated by the community.

Aspects of the modelling that have provided this margin of safety include:

- basing the model on winter conditions when discharge loads from Bolivar are at their highest
- deriving targets from 90th percentile values rather than median values.

For this reason, it is important to continually re-assess the target values as we monitor the water quality of the waterways, and use this information to upgrade the nutrient model. It is expected that as we understand more, we may understand that the nutrient levels able to be sustained by the waterways are a little higher than the targets provided by the present model.

Major discharges

With SA Water having decreased the amount of nitrogen discharged from wastewater treatment plants (WWTP) by over 1,000 tonnes, anecdotal information suggests that the presence of *Ulva* spp is diminished somewhat in the waterways. Comparison of aerial photos suggests that there may be some recovery of seagrass in parts of Barker Inlet.

Microalgal blooms still occur in the Port River on a regular basis and the ban on shell fish consumption still applies.

The Port Waterways WQIP targets a nutrient load reduction of 245 tonnes per year, with unspecified load reductions from Bolivar wastewater treatment works through additional re-use of wastewater. This additional re-use of wastewater is likely to occur progressively as opportunities to use the wastewater from Bolivar are realised over an unspecified period of time.

In this situation, it is expected that there may be a minimal response of the water quality of the waterways to early decreases in wastewater discharge. Any increase in seagrass cover during the time of the WQIP may be small and that increase may well be related to the nutrient reductions previously achieved by SA Water as a result of the upgrades of the Bolivar plant undertaken up to 2004.

It is expected that until the nutrient levels in the area fall below a certain threshold, there will be a minimal response to those reductions. The current information to hand does not indicate at what discharge level this threshold may be. This understanding is important for stakeholders and their investment strategies as failure to continue with nutrient load reductions until target levels are achieved may result in substantial costs without the desired environmental outcomes. Additionally, if a lag occurs between nutrient load increases and the loss of long-lived organisms such as seagrasses; a similar lag may follow nutrient load reductions.

In the meantime, nuisance algae can be expected to generally diminish throughout the waterways and water clarity should continue to improve.

Minor discharges

The WQIP provides for no increase in nutrient loads from other sources. While these discharges can have little effect on the waterways as a whole, their localised effect should not be discounted.

As the water quality of the whole of the waterway improves, the water will become less turbid and nuisance algal blooms will decrease in size and extent. With a general improvement in the background, the localised effect of the more minor discharge loads will become more apparent. Further, as many of these discharges such as stormwater are close to areas of easy public access, the localised effect of them in the form of turbidity and the growth of nuisance algae will likely attract community attention and become increasingly important.

Targets set for the WQIP

The targets set for the WQIP (detailed in Section 2.7) are as follows:

Source	Target
Penrice Soda Products	Nitrogen load from 820 tonnes per year to 575 tonnes per year
SA Water	Nitrogen load to reduce by an unspecified amount.
Other EPA licensed (eg bulk loading, marinas)	No increase in nitrogen load
Catchment	No increase
West Lakes	No increase
Local stormwater	No increase
Atmospheric	No increase
Regional groundwater	No increase
Recreation sourced	No increase

Background

With the bulk of the nitrogen in the waterway coming from two sources, the success of the plan is largely dependant on these sources achieving substantial reductions in their nitrogen discharges.

Other discharges to the waterway are so low in comparison that even their complete elimination would have no discernible effect on the whole of the waterway. However, many of these smaller discharges have a local effect. As the water quality of the Port waterway begins to improve, the effect of these local sources will become more apparent.

It is also important to understand how the community uses the Port waterways. The greatest portion of the community interacts with a very small part of the waterway on a regular basis, and will form their perceptions about its health from these small parts. Therefore, the relevance of these smaller, more localised discharges must not be ignored.

Penrice Soda Products *Nitrogen load from 820 tonnes per year to 575 tonnes per year*
For the Port waterways to achieve a water quality that is consistent with stakeholder expectations, Penrice needs to achieve a nitrogen discharge load of 200 tonnes per year. The target of 575 tonnes represents a load reduction that Penrice are committed to achieve by 2010, within the WQIP period. Penrice believe that a discharge load of 250 tonnes of Nitrogen per year may be achievable in the longer term, but are unable to provide a firm commitment to achieve this without further research and development of options.

The Environment Protection Act provides for a number of ways of managing point source discharges like Penrice. An EIP is a document where a licensee is able to set out a works program aimed at resolving an area of their activities that is causing harm to the environment. On the basis of the work undertaken to develop the WQIP, the EPA has negotiated an EIP with Penrice Soda Products to achieve the interim discharge load.

The EIP is legally binding on Penrice and company officers have a clearly defined liability and reporting requirements, with regular assessment and review of progress. The EIP is a publicly available document.

There is, therefore, a high level of assurance that Penrice Soda Products will achieve its target for the WQIP.

SA Water *Nitrogen load to reduce by an unspecified amount*

For the Port waterways to achieve a water quality that is consistent with stakeholder expectations, SA Water needs to achieve a nitrogen discharge load of 100 tonnes per year from the Bolivar WWTP. This compares with the present level of discharge of 477 tonnes per year. Similarly, phosphorus levels need to drop from the present 232 tonnes to 40 tonnes per year.

SA Water have undertaken a major capital development of their wastewater treatment in the last ten years, having spent over $200 m to remove the discharge from the Port Adelaide WWTP and redirect the sewage to an upgraded Bolivar facility that comprises a low salinity plant that emits a water quality suitable for irrigation and a high salinity plant. The effect of this work has been to reduce nitrogen discharges by 1,034 tonnes per year between 1998 and 2003. This occurred immediately prior to the development of the WQIP.

Given the above and the need for further work to other WWTPs as a result of findings of the Adelaide Coastal Waters Study, further major capital works at the Bolivar WWTP is not proposed within the WQIP period.

Increasing the amount of re-use of the Bolivar wastewater is a likely area of load reduction from the Bolivar WWTP. SA Water are constantly seeking to expand the amount of re-use effluent taken up and with the current shortage of water available to South Australia, further uptake of this water is likely. A separate initiative, Waterproofing Adelaide, has set some targets for wastewater re-use.

An impediment to further re-use is the disparate nature of wastewater re-use proposals, where individual proposals are each considered on their own merits. This makes it difficult to provide for the infrastructure costs to be met for any single proposal. There is an opportunity for a market-focussed strategy to be developed for the re-use of wastewater across Adelaide. However, until this is achieved, the utilisation of the Bolivar wastewater will not be at optimal levels.

As re-use demand is outside of SA Water sphere of control, they are unable to offer a numerical target for nutrient load reduction at this time.

With no target aimed for, the WQIP can only conclude no further reduction from Bolivar over the period of the WQIP. Error associated with this estimation is likely to be a positive outcome for the WQIP.

Other EPA licensed *No increase in nitrogen load*

The nitrogen load from the other EPA licensed discharges is low, and generally incidental to their other activities. For example, bulk loading activities discharge small amounts of nutrients through spillage during loading and where clean-up is not undertaken appropriately.

There has been considerable development of codes of practice including Materials Handling on Wharves, and Vessel and Facility Management: Marine and Inland Waters, and other regulatory tools to deal with these issues. In addition, the EPA is continually ensuring that new developments and further development of existing facilities is undertaken to best practice.

There is a high likelihood that there will be no further increase in the nitrogen load from these sources, and reduction is much more likely.

While these discharges can have little effect on the waterways as a whole, their localised effect should not be discounted.

As the water quality of the whole of the waterway improves, the water will become less turbid and nuisance algal blooms will decrease in size and extent. With a general improvement in the background, the localised effect of the more minor discharge loads will become more apparent.

Catchment *No increase in nitrogen load*
With the formulation of the A&MLR NRM Board, existing functions of the former catchment water management boards were integrated.

Existing programs to minimise the load of pollutants from the catchment have largely been retained, and the A&MLR NRM Board is developing further programs with this aim.

While these programs are likely to be effective within the WQIP period, there is also likely to be considerable further development of the urbanised parts of the catchment over this period. This has the potential to result in further increases in stormwater flows and their resultant nitrogen loads to the Port waterways.

A project to identify and require appropriate targets for the implementation of Water Sensitive Urban Design in new developments in Metropolitan Adelaide has been funded by the Australian Government. This is likely to result in reductions of nutrients and other pollutants such as suspended solids in coming years.

The catchment monitoring undertaken as part of the development of the WQIP has not been continued by the A&MLR NRM Board and experience elsewhere has shown that without effective monitoring, performance is often lower than expected.

Therefore there is some uncertainty about whether or not this target will be achieved for the WQIP. Additionally, assessment of whether the target is being met is not ongoing.

West Lakes *No increase in nitrogen load*
The West Lakes nitrogen load is mainly derived from nutrients in coastal waters, rather than from the catchment. Modelling from the Adelaide Coastal Waters Study shows that the sources of these nutrients are Penrice Soda Products and the Glenelg WWTP. With the drop in discharge from Penrice over the period of the WQIP, this load should decrease. No similar drop in the nutrients from the Glenelg WWTP is scheduled in the period of the WQIP, but this may also occur through some increase in wastewater re-use.

Therefore it is highly likely that this target will be achieved, and there is a likelihood that some reduction will occur.

Local Stormwater *No increase in nitrogen load*
The contribution from local stormwater, although low, is highly visible to the community. With the recent move to the increased use of rainwater for domestic purposes, flow, and hence nutrients, are likely to reduce.

It is likely that there will be significant variations from different locations as stormwater is retained and treated to different extents. For example, the proposed inner Port development will result in a large potential increase in run-off from the area. It is not clear if there will be any significant collection or treatment of this run-off. In contrast, the City of Port Adelaide–Enfield has been very active in promoting better stormwater management throughout small businesses in the community. This work will result in a lower volume of runoff with fewer pollutants, some of which are nutrients.

The target is likely to be achieved overall, but with a patchy response.

Atmospheric *No increase in nitrogen load*
Atmospheric sourced nutrients are derived mainly from automobiles. With improvements in engine technology and the increasing cost of petroleum products, the nutrient load from this source is highly likely to reduce. However, with the further development of the LeFevre Peninsula as a heavy manufacturing and transportation hub, local vehicle movements will increase.

The target is likely to be achieved.

Regional Groundwater *No increase in nitrogen load*
The flow of regional groundwater and the materials contained in it only change over long timeframes.

Change during the period of the WQIP is unlikely.

Recreation sourced *No increase in nitrogen load*
While recreational use of the Port waterways is set to increase, the development and implementation of the Code of Practice for Vessel and Facility Management will reduce the likelihood of discharges from recreational vessels.

A neutral or improved outlook is likely.

REFERENCES

Wilkinson J, White N, Smythe L, Hutson J, Bestland E, Simmons C, Lamontagne S and Fallowfield H 2005, *Volumes of inputs, their concentrations and loads received by Adelaide metropolitan coastal waters*, ACWS Technical Report No. 18, prepared for the Adelaide Coastal Waters Study Steering Committee, September 2005, Flinders Centre for Coastal and Catchment Environments, Flinders University of SA.

APPENDIX D

WQIP FOR PORT ADELAIDE'S WATERWAY

Project summary

The Water Quality Monitoring Program (WQMP) aims to provide water quality and flow monitoring to characterise the inputs of nutrients to the Port waterways.

While the existing Ambient Water Quality Monitoring Program undertaken by the EPA is aimed at providing information about the water quality of the Port waterways, it is unable to provide information about catchment flows to the waterways, or the likely contribution of nutrients from sedimentary sources within the waterways.

The WQMP has provided this information through:

- development of a project to gain an understanding of the contribution of sediments in the waterways to the nutrient loads
- water quality and flow data from the catchments that discharge to the waterway.

An additional outcome of the project will be the provision of infrastructure to enable flow-weighted sampling of nutrients by Adelaide and Mount Lofty Ranges Natural Resource Management (A&MLR NRM) Board on an ongoing basis.

The work to measure the contribution of sediments to the waterway's nutrient levels has previously been reported on and published by the EPA.

This work is also required as an input to the water quality model of the waterways, which will be used as a decision support system to aid the development of management options for the waterway.

The current report includes information on the status of monitoring of the water quality and flow from the catchments. The Port Waterways area, the extent of the catchments and the locations of the monitoring stations are shown in Figure 1.1 of the WQIP.

The EPA intends to undertake a review of the program in conjunction with the newly established A&MLR NRM. The aim of this review will be to inform the provision of appropriate monitoring to assist the continuing implementation of the Port Waterways WQIP.

A similar partnership will be formed with the Department for Environment and Heritage, Adelaide Dolphin Sanctuary, to ensure that monitoring supports the achievement of the objects and objectives of the *Adelaide Dolphin Sanctuary Act 2005*.

Status of monitoring stations

All the following sites are operational as at March 2006.

a) Barker Wetland 1 (A5041009)
The Barker Wetland receives stormwater flows from the North Arm East drain, the Hindmarsh Enfield Prospect drain, the South Road drain and the Dunstan Road drain. The catchment includes the northern Adelaide suburbs of Enfield, Prospect, Hindmarsh, Cavan, Wingfield, Regency Park and Dry Creek; and consists mostly of residential and industrial land.

The configuration of the Barker wetland was altered during 2004. The construction of the Port Adelaide Expressway resulted in stormwater from the Dunstan Road and South Road drains becoming hydraulically isolated from the eastern section of the Barker wetland. Consequently, a second gauging and monitoring station was required for the western section of the wetland. This new monitoring station is discussed below and is referred to as Barker Wetland 2.

The Barker Wetland 1 monitoring location became operational in early May 2004. Existing overflow culverts allowed the contractor to install water level sensors and gauge flows relatively quickly. The automatic composite sampling equipment was installed in an existing instrument shelter on the site.

This monitoring location has been providing reliable data for determining the nutrient loads entering the Barker Inlet from the eastern section of wetland. The flows that now enter the Barker Inlet from the western section of the wetland via a new culvert added due to the construction of the Port Adelaide Expressway are not captured by this monitoring location.

The summary statistics for the main water quality parameters from the weekly composite sampling (ie discharge volumes, TP, NOx, TKN and TN loads) are shown in Table D1. In addition to displaying the total flows and loads of nutrients recorded over this period, this table also provides the mean and median values for the discharge volumes and nutrient loads. Statistical measures showing the variability in the data (standard deviation and inter-quartile range) as well as the extremes (maximum and minimum) are also given.

Table D1 Statistical summary of weekly nutrient loads determined by flow proportional composite sampling at Barker Wetland 1 (A5041009) for the period 1 May 2004 to 4 August 2005

Weekly statistic	Discharge volume (ML)	Total P load (kg)	TKN load (kg)	NOx load (kg)	Total N load (kg)
Mean	77.0	13.1	84.4	14.2	98.7
Median	20.1	3.6	23.0	0.3	23.0
StDev	173.3	24.4	152.4	38.7	186.8
Max	1058.7	151.4	869.7	218.2	1092.2
Min	0.0	0.0	0.0	0.0	0.0
IQR	66.5	14.5	77.1	5.7	90.5
95% CI mean	55.9–98.0	10.1–16.1	65.9–102.9	9.5-18.9	76.0–121.4
Total	5002.7	851.9	5485.6	925.2	6415.6
Number of weeks composite sampler operating for the period is 65.					

b) Barker Wetland 2 (A5041017)

Transport SA had agreed to fund the construction of a new monitoring location for the western section of Barker wetland to capture the flows from the South Road and Dunstan Road drains. The construction of this station has been completed and has been operational since 3 October 2004.

Flow was gauged at Barker Wetland 2 during the period 8 October 2004 to 4 August 2005. The summary statistics for the main water quality parameters from the weekly composite sampling (ie discharge volumes, TP, NOx, TKN and TN loads) are shown in Table D2. During the 43 weeks of operation of the monitoring site over 580 ML of stormwater flowed over the culvert into Barker Inlet, with total phosphorus (P) and nitrogen (N) loads of around 0.08 t and 0.74 t respectively.

Table D2 Statistical summary of weekly nutrient loads determined by flow proportional composite sampling at Barker Wetland 2 (A5041017) for the period 8 October 2004 to 4 August 2005

Weekly statistic	Discharge volume (ML)	Total P load (kg)	TKN load (kg)	NOx load (kg)	Total N load (kg)
Mean	13.6	2.0	13.9	3.4	17.3
Median	0.0	0.0	0.0	0.0	0.0
StDev	47.8	7.3	44.2	14.0	58.1
Max	294.6	36.0	248.4	81.9	331.1
Min	0.0	0.0	0.0	0.0	0.0
IQR	2.1	0.2	2.5	0.1	2.6
95% CI mean	6.5–20.7	0.9–3.1	7.3–20.5	1.3–5.5	8.6–26.0
Total	584.8	85.8	599.0	144.2	744.1
Number of weeks composite sampler operating for the period is 43.					

c) West Lakes (A5041008)

The West Lakes waterway is essentially a marine water body with a localised stormwater catchment that is largely residential in nature. Nutrient inputs into the West Lakes waterway are derived from intermittent stormwater flows following rainfall events as well as nutrients imported from Gulf St Vincent through the inlet pipe. Seawater flows into West Lakes during most tidal cycles, with the exception of some neap tidal periods. The volumes of seawater flowing into West Lakes each day are quite large and consequently Gulf St Vincent is a relatively large contributor to the nutrient loads of the West Lakes system.

The West Lakes flow monitoring and composite sampling equipment is situated at the Bower Road outlet gates where water flows from West Lakes into the upper reaches of the Port River. Water level sensors have been installed upstream of the outlet structure and downstream on the Port River side of the outlet. In addition, flow velocities were measured along the outlet channel so that the instrumentation could be calibrated to low flows. Flows are calculated from the difference in water level between the upstream and downstream sensors using an empirically derived equation.

The previous bio-fouling in the stilling wells and on the floats that threatened to compromise flow measurements has been rectified by frequent visits to the site by the contractor to clean the wells and to take calibrating measurements.

The summary statistics for the main water quality parameters from the weekly composite sampling (ie discharge volumes, TP, NOx, TKN and TN loads) are shown in Table D3. During the 59 weeks of operation of the monitoring site around 79 GL of water discharged into the Port River from West Lakes, with total P and N loads of about 6.6 t and 44.6 t respectively.

Table D3 **Statistical summary of weekly nutrient loads determined by flow proportional composite sampling at the West Lakes outlet (A5041008) for the period 12 May 2004 to 7 July 2005**

Weekly statistic	Discharge volume (ML)	Total P load (kg)	TKN load (kg)	NOx load (kg)	Total N load (kg)
Mean	1338.1	112.5	680.7	74.0	755.6
Median	1185.8	96.8	527.6	55.8	603.9
StDev	817.2	80.7	539.5	65.9	557.1
Max	5069.2	361.3	2684.8	296.8	2754.7
Min	106.2	3.8	54.3	2.6	54.4
IQR	1052.9	94.4	602.3	79.9	689.6
95% CI mean	1234-1442	102.2–122.8	611.8–749.5	65.6-82.4	684.5–826.6
Total	78945.0	6636.3	40158.9	4365.7	44578.4
Number of weeks composite sampler operating for the period is 59.					

d) Dry Creek (A5041005)

This monitoring station is situated between the Salisbury Highway bridge and the railway bridge. Due to the difficulties with this site and a lack of viable alternative locations, the consultant (WDS) has developed and installed a unique solution to deliver good quality nutrient load information. The station was completed in the first quarter of 2005 and water level data has been acquired since then to create flow information. The data from the temporary sampling station that was present throughout 2004 has been updated to provide 51 weeks of nutrient load data.

A targeted desktop study needs to be undertaken by WDS to validate the flow equations that have been used for this sampling location. This is due to be performed early in 2006. Until then the nutrient load data is provided in this report with the proviso that the calculated flow volumes may be altered once the validation work has occurred. Certainly, there appear to be periods of consistent flow in the dataset where little or no flows were expected. As such, the information provided in this report is likely to overestimate the flows and hence the loads entering the Port River from the Dry Creek catchment.

The summary statistics for the main water quality parameters from the weekly composite sampling (ie discharge volumes, TP, NOx, TKN and TN loads) are shown in Table D4. During the 51 weeks of operation of the monitoring site around 13.5 GL of water discharged into the Barker Inlet with total P and N loads of about 1.3 t and 12 t respectively.

Table D4 Statistical summary of weekly nutrient loads determined by flow proportional composite sampling at Dry Creek (A5041005) for the period 20 August 2004 to 11 August 2005.

Weekly statistic	Discharge volume (ML)	Total P load (kg)	TKN load (kg)	NOx load (kg)	Total N load (kg)
Mean	264.8	24.8	193.4	41.2	234.7
Median	51.7	3.8	43.7	4.8	48.6
StDev	503.5	61.5	362.8	93.9	446.3
Max	2241.1	311.3	1937.4	442.7	2264.7
Min	0.0	0.0	0.0	0.0	0.0
IQR	146.2	8.6	113.1	22.8	123.1
95% CI mean	195.8–333.9	16.4–33.2	143.6-243.2	28.4-54.1	173.5–295.9
Total	13507.1	1264.7	9863.2	2103.5	11969.4
Number of weeks composite sampler operating for the period is 51.					

Note: This data may vary after the flow rating equations have been further validated by WDS.

e) Little Para River (A5041006)

In conjunction with the Northern Adelaide and Barossa Catchment Water Management Board an improved flow structure was designed and constructed for the Little Para River monitoring location. Delays in the construction of the flow structure at this location meant that nutrient load monitoring did not commence until 3 October 2004.

Between 3 October 2004 and 5 August 2005 flow and water quality data were collected. The summary statistics for the main water quality parameters from the weekly composite sampling (ie discharge volumes, TP, NOx, TKN and TN loads) are shown in Table D5. During the 44 weeks of operation of the monitoring site around 400 ML of water discharged into the Barker Inlet, with total P and N loads of about 0.03 t and 0.36 t respectively.

There was some uncertainty concerning the low flow measurements at this site as it is thought that the flow control structure was leaking. Evidence of this is seen in the data from 32 of the 44 weeks of operation at this site recording no flows. The EPA along with Salisbury Council rectified this problem with some minor earthworks in mid-2005, and WDS have monitored this station to ensure that accurate flow recordings have since been obtained. Another factor that could contribute to the reduced flows over this sampling site is the detention wetland upstream of the flow structure that delays stormwater from reaching the flow structure. This could increase the amount of water infiltrating the soil to recharge the local groundwater systems.

Table D5 Statistical summary of weekly nutrient loads determined by flow proportional composite sampling at Little Para River (A5041006) for the period 2 October 2004 to 5 August 2005

Weekly statistic	Discharge volume (ML)	Total P load (kg)	TKN load (kg)	NOx load (kg)	Total N load (kg)
Mean	9.1	0.7	7.9	0.2	8.1
Median	0.0	0.0	0.0	0.0	0.0
StDev	30.6	2.2	25.0	0.4	25.3
Max	148.9	11.9	139.4	2.4	139.9
Min	0.0	0.0	0.0	0.0	0.0
IQR	0.2	0.0	0.1	0.0	0.1
95% CI mean	4.6–13.6	0.4–1.1	4.2–11.6	0.1–0.2	4.3–11.8
Total	401.4	31.8	347.5	7.4	355.1
Number of weeks composite sampler operating for the period is 44.					

f) Helps Road drain (A5041007)

An old railway bridge was originally to be used for the flow structure at this location. However, further inspection found that it was unsuitable and led to a new v-notch weir being designed and constructed. Construction of this flow structure was completed in February 2005. The flow monitoring and sampling equipment were installed and operational soon afterwards and the station has been recording flows from late March 2005 to the present. The data provided in this report covers the period between 18 March 2005 and 4 August 2005.

The summary statistics for the main water quality parameters from the weekly composite sampling (ie discharge volumes, TP, NOx, TKN and TN loads) are shown in Table D6. During the 20 weeks of operation of the monitoring site around 920 ML of water discharged into the Barker Inlet, with total P and N loads of about 0.21 t and 0.92 t respectively.

Table D6 **Statistical summary of weekly nutrient loads determined by flow proportional composite sampling at Helps Road drain (A5041007) for the period 18 March 2005 to 4 August 2005**

Weekly statistic	Discharge volume (ML)	Total P load (kg)	TKN load (kg)	NOx load (kg)	Total N load (kg)
Mean	46.3	10.7	40.9	5.1	46.0
Median	0.0	0.0	0.0	0.0	0.0
StDev	144.2	37.6	142.0	14.5	156.4
Max	635.4	168.0	634.7	63.2	698.0
Min	0.0	0.0	0.0	0.0	0.0
IQR	8.2	1.7	6.2	2.1	8.4
95% CI mean	14.7-77.9	2.5–19.0	9.8-72.0	1.9-8.2	11.8–80.3
Total	925.6	214.8	818.3	101.2	920.5
Number of weeks composite sampler operating for the period is 20.					

Summary of monitoring infrastructure

All elements of the monitoring infrastructure have been installed. Four locations have had new flow structures installed (Little Para River, Barker Wetland 2, Helps Road drain and Dry Creek). At West Lakes and Barker Wetland 1 there were existing structures that were adopted for flow measurement, and only the instrumentation needed to be installed. All six sites have composite samplers installed and operational. The Dry Creek location needed an innovative solution to accurately determine flows through the complex wide channel. Work has to be done by WDS to validate the initial gauging equation used for this site.

Discussion of annual flows and nutrient loads

Due to delays in the initial implementation of the WQMP described in previous progress reports, the total number of weeks that nutrient load monitoring operated is not as comprehensive as originally planned. The maximum period a monitoring site has been operating is 65 weeks for Barker Wetland 1 and the minimum is 20 weeks for Helps Road drain. This range is not ideal for predicting annual values, with between two and five years of data being preferred. The annual load values given below and the subsequent discussion should be viewed with this in mind.

The overall data (as seen in Table D7) indicates that over 90 GL/year flows into the Port River system from the surrounding catchment areas, which overall deliver around 60 t/year N and 8.5 t/year P. These values are considerably lower than the current point source loads from the two major polluting industries (Penrice Soda Products and Bolivar WWTP) that together contribute around 1600 t/year N and 180 t/year P (WQIP Stage 1 Report).

Table D7 Calculation of annual flows and nutrient loads into the Port River and Barker Inlet system from the surrounding catchment areas

	Discharge volume (GL) (95%CI)	Total N (tonnes) (95%CI)	Total P (tonnes) (95% CI)
Dry Creek	13.77 (10.2–17.4)	12.20 (9.0–15.4)	1.29 (0.85–1.7)
Little Para River	0.47 (0.24-0.71)	0.42 (0.22-0.61)	0.04 (0.02–0.06)
Helps Road drain	2.41 (0.76-4.1)	2.39 (0.61–4.2)	0.56 (0.13-0.99)
West Lakes	69.58 (64.2–75.0)	39.29 (35.6-43.0)	5.85 (5.3-6.4)
Barker Wetland	4.71 (3.24-6.2)	6.03 (4.4–7.7)	0.78 (0.58–1.0)
Total annual loads to Port River	90.94 (78.6-103.3)	60.34 (49.9-70.8)	8.52 (6.9-10.2)

Note: Values in brackets indicate the data variability through the 95% confidence level.

The majority of the 90 GL annual flows (approx 77%) are due to inputs from West Lakes. As the flows are a key contributor to the load calculations it is not surprising to see that the relative contribution of West Lakes to the N and P loads is high (65% and 69% respectively).

The next highest contributions of flows and loads to the Port River system are from the Dry Creek and Barker wetlands catchments. The Dry Creek contribution is driven mostly by the high flows generated from the large catchment area. The contribution from Barker Wetland is significant as the catchment area supplying the wetland is considerably smaller than the Dry Creek catchment. This could be due to the resuspension of sediments within the wetland while being transported to the Barker Inlet during significant flow events, rather than to the runoff quality in the catchment. This is difficult to validate as suspended sediment data was not acquired throughout the project or gathered to compare inflow and outflow concentrations of N and P from the wetland.

The overall trends discussed above are apparent in Table D8, which displays catchment yields of total flows and nutrients for the Dry Creek, Barker Wetland and Helps Road drain catchments. The catchment yields for Barker Wetland appear to be significantly higher than for Dry Creek and Helps Road drain. The low catchment yield for flows in the Helps Road drain is due to the majority of stormwater flows in the northern part of the catchment being captured by a stormwater retention lagoon at Munno Para, and a high proportion of other flows being intercepted through soil infiltration (Wilkinson et al 2005).

It is difficult to discuss in depth the annual flows and loads from both the Little Para River and Helps Road drain locations. As mentioned previously, the Little Para River monitoring location had a problem with a leaky flow structure that prevented low flows from being recorded, hence diminishing the more significant flows to some extent. The Helps Road drain location has generated good quality flow and water quality data but has only been operation for 20 weeks, with flows recorded for only eight weeks of this period.

Table D8 Calculation of catchment yields from three key catchments in the WQMP. West Lakes was excluded as the majority of the water is sourced from the gulf

	Effective catchment area (km^2)	Parameter	Catchment yield (ML/km^2)	Catchment yield (kg/km^2)
Dry Creek	141.9	Flow Nitrogen Phosphorus	97.0 - -	- 86.0 9.1
Helps Road drain	124	Flow Nitrogen Phosphorus	19.4 - -	- 19.3 4.5
Barker Wetland	45	Flow Nitrogen Phosphorus	104.7 - -	- 134.0 17.3

Note: Little Para River was excluded due to uncertainty in the flows due to the leaky flow structure.

Revision of the water quality monitoring program (Stage 2) to address additional water quality and flow monitoring objectives and requirements identified in the WQIP

The WQIP has been developed to establish the proportion of nutrient loads into the Port waterways that are attributed to runoff from rainfall on defined catchments. The loading per unit area can be derived from varying land use proportions and different catchment management initiatives. The established WQMP meets the goal of determining the catchment loads of nutrients flowing into the Port waterways. It is recommended that the program should continue in its current form until approximately two years' worth of load data has been obtained. At that time a more thorough review of the data can be performed to identify the stations that provide the best outcomes in terms of quantifying diffuse nutrient loads to the Port waterways.

At this point in the monitoring program it is anticipated that the EPA will continue to operate it until the funds have been exhausted. Responsibility for the continuation of the programme and funding will be discussed with the A&MLR NRM Board.

A revised monitoring program would have aims that are slightly different from those that guided the development of the WQMP for the following reasons:

- The nutrient input from catchment sources to the Port waterways is confirmed as being low relative to the loads from point sources. This means that the initial focus of the WQIP will be to reduce the point sources while ensuring that catchment sources remain small.
- The A&MLR NRM Board are likely to be interested in a larger range of pollutants in the catchment discharge than just nutrients, and may require information about discharges further up into their catchments.

Both of the above reasons will need to be taken into account by the A&MLR NRM Board and the EPA in future planning for the monitoring plan.

Responsibility for the development and maintenance of the catchment monitoring program rests with the A&MLR NRM Board, who will review the findings of the current program along with other needs.

In addition, the requirements of the Adelaide Dolphin Sanctuary will need to be taken into account to ensure that future monitoring programs support achievement of the objectives of the Adelaide Dolphin Sanctuary Act.

The review should also provide information about the value of the monitoring system used for the Dry Creek station. While this may offer a cost-effective and practical solution for the creeks on the Adelaide (and other Australian) floodplains with a highly variable bed, the accuracy of the data derived from it needs to be well understood prior to other catchment managers being able to assess its value for other applications.

APPENDIX E

WATER FLOWS

Introduction

As discussed in the Stage 1 report (EPA 2005a), the Port waterways, being an estuarine-marine system, are dominated by tidal flows. Prior to European settlement freshwater inflows from the south were intercepted by extensive freshwater/brackish wetlands, which dampened the effect of major storm flows. These wetlands no longer exist and the area is now urbanised. The major stream formerly discharging into the Port waterways, the Torrens River, was diverted directly into Gulf St Vincent via a channel cut through the dune system at West Beach.

To the north, on the eastern side, are Dry Creek, Little Para River and Smith Creek. These were formerly ephemeral in nature, largely flowing to the coast only during major flood events, and for Smith Creek and Dry Creek in particular spreading out into the former extensive salt marsh areas. The lower part of Dry Creek is now an artificial drain, allowing the rapid passage of floodwaters from its urbanised catchment.

The emphasis of this study is on nutrient reduction in the estuary system, rather than on environmental flows. However, in order that strategies adopted to minimise pollution do not inadvertently impact on flow regimes, the estuarine nature of the waterways and the characteristics of catchment drainage to the waterways are considered below in relation to:

- flows in the Dry Creek, Little Para and Smith Creek catchments
- interruptions to or improvements in tidal flows and the effects of sea level variations due to climate change
- the development of constructed freshwater wetlands and fish passage opportunities.

Catchment stormwater and environmental flows

Existing stormwater programs addressing environmental flow requirements

The management of stormwater flows entering the Port waterways is now receiving considerable attention from stakeholders, with legislation now requiring councils to prepare Stormwater Management Plans, which must include water quality and harvesting objectives.

It is widely recognised that the flows entering the waterways are highly altered from pre-European flows. While the programs listed below are mainly concerned with improving water quality they often also address the increased flows entering the waterways.

The need to address stormwater issues associated with the Port waterways has long been recognised. As a result many programs have been initiated by various stakeholders, including (but not limited to):

- Former Northern Adelaide and Barossa Catchment Water Management Board
- Former Torrens Catchment Water Management Board
- Barker Inlet Port Estuary Committee
- City of Port Adelaide-Enfield
- City of Salisbury
- City of Charles Sturt
- City of Prospect
- Playford City Council
- Tea Tree Gully City Council.

Some of the programs aimed at addressing water quality impacts from stormwater include:

- development of stormwater management plans
- development of catchment and water management plans
- water quality monitoring of creeks and rivers
- construction of wetlands
- construction of pollutant removal systems
- development of stormwater reuse
- river and creek restoration and management plans
- 'WaterCare' programs working with local communities and industry.

This is intended as a general list of projects due to the large number already completed and currently underway. For more information on individual projects advice should be sought from the relevant stakeholders listed in this section.

There are several programs aimed at reducing stormwater flows entering the waterways and regaining environmental flow requirements, specifically:

(a) Salisbury Integrated Water Management Plan
The Salisbury Integrated Water Management Plan is an initiative of the City of Salisbury and includes the Playford City Council, Tea Tree Gully City Council and Adelaide and Mount Lofty Ranges Natural Resource Management (A&MLR NRM) Board.

The plan, completed in June 2005, seeks to address long-term sustainable and innovative water management options for the Salisbury area, and encompasses all aspects of water use. The development of the plan has included investigating the differences between pre-European and current stormwater flows discharging from the catchments, and tries to establish the environmental flows required to return the systems to a natural regime while protecting public and private infrastructure.

Because many of the catchments identified for management over 20 years in this plan are associated with the Port waterways, the plan will be an important process for addressing environmental flow requirements.

(b) Urban stormwater master plans
The City of Port Adelaide–Enfield, with assistance from the Cities of Charles Sturt and Prospect and the A&MLR NRM Board, has initiated the preparation of an Urban Stormwater Management Plan (USMP) aimed at minimising the impact of stormwater on the Port waterways.

The USMP integrates urban planning, engineering and environmental issues, and opportunities into a holistic framework to guide long-term planning of stormwater catchments in the area.

(c) Local government development plan reviews
There are direct impacts on stormwater generation rates from development. In order to minimise the impact of new development, seven local governments in association with A&MLR NRM Board are reviewing the Council Planning Scheme (Development Plan) and making recommendations for individual councils to improve the health of catchments and the flow of water.

Methodology for setting interim river flow objectives

(a) Estimation of pre-European flows from the northern Adelaide Plains to the Barker Inlet
Surface runoff into the Barker Inlet (the inlet) has been estimated from all catchment areas discharging towards it in an arc between the Port River and the Gawler River (refer Figure 1.1 in the main report).

The main structural elements of the area are the coastal plains to the west and the elevated hilly areas to the east of the Para Fault escarpment. The plains area widens from about 5 km in the south to 25 km in the north. The catchments making up this area are described in greater detail below.

The annual rainfall isohyets follow the mapped height contours closely. Rainfall at the coast is 400–450 mm/year. At the foot of the escarpment it is about 500 mm/year, rising to about 600 mm/year along the top of the immediate escarpment (which forms the boundary of the area to the north). The Little Para River and Dry Creek have broken through the Para Fault escarpment and, particularly for the Little Para River, drain more elevated land to the east. Rainfall rises to 850 mm/year over the headwaters of the Little Para River in the Millbrook area.

The area has undergone extensive change since European settlement due to urbanisation and agriculture. The effects of these changes are felt via reduced interception and evapotranspiration losses resulting from the clearance of pre-existing deeper rooted vegetation, reduced infiltration losses resulting from surface sealing in urban areas and soil compaction in rural areas, and removal of surface ponding via engineered drainage paths. All these effects give rise to increased runoff from rainfall. However, in some agricultural areas the effects of farm dams, contour banking and seasonal ploughing may have had a counterbalancing effect.

Descriptions and maps of the geology, drainage and vegetation of the area, particularly in the earliest days of settlement, have been useful in forming hypotheses on flow levels.

(b) Method of investigation

Urbanisation is recognised as having had by far the greatest impact on flows since European settlement. The main direction of investigation has therefore focused on the collation of flow data and information from rural catchment areas within the Adelaide region, free from the effects of urbanisation. The majority of these catchments lie in the Mount Lofty Ranges and Willunga basin, and have mixed land uses and topography. Investigation has focused on flow records from catchments which are deemed to have had their runoff characteristics changed least during the period following European settlement. The flow records only extend back about 25 years and therefore reflect runoff from land subject to recent farming methods.

Previous analysis of the measured flows has shown that they exhibit a very marked general similarity in the relation between runoff and rainfall. Annual runoff in any catchment is virtually negligible when annual rainfall is less than 400–500 mm/year, but rises relatively consistently to about 20% of rainfall at 800–1,000 mm/year. Other than rainfall, investigations have not credibly quantified the individual impacts of the many other factors known to affect runoff. Despite the inability of the data to show these differences on a catchment scale, it is generally accepted that the clearance and replacement of native vegetation with pasture or other shallow-rooted crops has had the effect of increasing runoff, while the replacement of pasture by forestry has had the effect of reducing runoff. However, with the general recognition that greater runoff has led to increased erosion and soil loss, methods for reducing and slowing runoff have been gradually implemented in most agricultural areas.

The only locations where runoff is measured from areas with a near complete coverage of native vegetation are First Creek in the national park at Waterfall Gully (which receives a very high rainfall) and Rocky River in the Flinders Chase on Kangaroo Island. However, as described above, the annual rainfall-to-runoff plots for these two sites show no significant departure from those of other catchments (Table E1). Data in this table shows the runoff depth read from the fitted plots for a selection of catchments, interpolated for annual rainfalls of 500, 600 and 800 mm/year.

Table E1 'Best fit' mean runoff depth (mm/year) for three annual rainfall readings

	Runoff depth (mm/year)		
Catchment	**500**	**600**	**800**
Angas River	5	12	70
Mt Barker Creek	12	35	115
Scott Creek	-	45	100
Baker Gully	10	20	75
Dashwood Gully	*2*	*7*	*75*
Echunga Creek	8	30	85
Lenswood Creek	-	50	150
Burnt Out Creek	*7*	*12*	*70*
Little Para River	15	45	125
North Para River	20	60	150
First Creek	-	-	105
Rocky River	8	32	120

Note that both Dashwood Gully and Burnt Out Creek (in italics) have pine forest coverage and show among the lowest runoff readings. It is probable that the very dense canopy of pine forests may reduce runoff to a greater extent than the more open woodland canopy of native vegetation found in this region. The conclusion is that runoff under pre-European conditions may not have been greatly less than under present mixed farming conditions where farm dams and flow/erosion control methods are employed.

Other specific differences in runoff response to rainfall are provided from a network of seven gauging stations in the Pedler Creek catchment in the Willunga basin. The data, which shows that runoff is lost by infiltration as it travels across the outwash plains at the foot of the escarpment, has been used to assess losses in this study.

No continuous records of flow are available for non-urbanised catchments on the Adelaide Plains or other low gradient plains areas in South Australia. These are areas where no incised drainage paths are mapped (or are visible by casual ground inspection). Flow is very infrequent and the lack of incised flow channels means that flow cannot be measured using conventional methods. However, flow records are increasingly available for plains sites downstream of urbanised areas. Where these also receive runoff from upstream undeveloped hills face areas, analysis of the records confirms that the contribution from the non-urbanised surfaces is likely to be small and generally below the level of error of measurement.

Despite this, experience indicates that runoff from plains areas does occur under occasional conditions of combined high intensity and sufficient duration of rain.

General evidence on the paucity of flows on low rainfall plains areas is provided where watercourses are mapped for a short distance across the outwash area at the foot of the escarpment, but then stop. This is a common feature in all locations of low rainfall, where occasional runoff generated from hilly areas is lost due to infiltration and evaporation on the surrounding plains. In general the distance across the plain that any watercourse is mapped is proportional to the size of the upstream catchment at the point that it discharges onto the plain.

Examination of early maps of the study area confirms that the only stream path that is mapped all the way to the inlet is that of the Little Para River. Even the path of Dry Creek, which has a 48-km^2 catchment within the hills behind the Para Fault escarpment, is shown as ceasing before it reaches the inlet. The losses taking place from the Little Para River along its path over the plains have been investigated and found to be of the order of 0.4 ML/day/km. The continuous mapped path of the Little Para River to the sea therefore indicates that the flow discharged onto the plain has always been sufficiently large and frequent to overcome the channel losses and maintain the channel. Information on losses is used in the estimation of flows herein.

(c) Present day flows

Present day flows have been estimated in previous studies (Table E2).

Table E2 Estimation of present day flows in previous studies

Catchment/ Outlet	Estimated annual flow (ML/year)
North Arm east	2,650
HEP (drain)	1,700
Dunstan Road	350
North Arm west	950
Dry Creek	10,500
Little Para River	3,000
Helps Road	2,500[a]
Smiths Creek	500[a]

Note: Estimates given in the report assumed future urban development. Figures given here are for present-day development levels.

In all cases except for the Little Para River these flows have been greatly increased over the pre-European situation by subsequent urbanisation. The Little Para River only receives runoff from a small urban area as it crosses the plains and most of its catchment flows are now diverted to water supply. The pre-European flows may therefore have been greater than the present flows (see below).

(d) Hypotheses tested

The following hypotheses have been adopted in establishing a daily rainfall runoff model to estimate the pre-European flows into the Barker Inlet from this area.

Area to the north of the Little Para River

Runoff takes place from a series of subparallel creeks draining off the low escarpment which forms the eastern boundary of the catchment. Despite the low rainfall (about 550 mm/year) and relatively mild slopes, pre-European runoff events were sufficient to create incised channels which early surveyors/mappers were able to trace for a short distance onto the plain. It is hypothesised that the sediments carried by the flows were deposited as an outwash fan and created a situation in which the majority of flows, being small, were lost via infiltration into the fan deposits. Deeper drainage from the fan may also be lost via the fault line which follows the front of the escarpment, thus recharging the deep aquifers beneath the plains. Any runoff in excess of the losses taking place across the outwash area would be confined in front of the escarpment by the slightly raised natural levee areas associated with the Gawler River to the north and the Little Para River to the south, and the slightly elevated land in the Virginia area.

Because of the low and infrequent flows reaching the plain and the very low lateral and longitudinal slopes along the southwest flow path towards the inlet, no incised and continuous flow paths were formed across the plain. Most flow generally coalesced into shallow pools where it infiltrated and evaporated. The high salinity of the upper aquifers in this area supports this hypothesis, as does the implied need for subsequent expenditure on artificial drains. Only in larger events did the water overflow the pools and gradually move to the southwest along the lines of the present day Helps Road drain towards an outlet in the present area of the Bolivar WWTP. Such infrequent events may have merged with water overflowing from the Little Para River caused by the same event. The low frequency and velocity of such flows, together with the mangrove-building processes at the coast, would explain the absence of any evidence of flow paths.

The excavation of the Virginia drain from the Smithfield area towards the west–northwest did not follow the natural drainage path, but was instituted to relieve pressure on the Helps Road drain.

Little Para River

Monthly inflow records from the upstream non-urbanised catchment into the dam have been collated. The present day flows average about 8,000 ML/year. The catchment upstream of the plains is hilly and is mainly cleared for grazing and country living, but there are many small areas of uncleared scrub. The size of the present days flows, plus the mapping of the river's flow path across the plains and into the inlet, suggest that it was the major contributor of flows to the inlet from the study area. Because the river is perched as it crosses the plains, there is insignificant additional contributing catchment once it leaves the escarpment, except for possible merging with flows from the Cobbler Creek catchment draining a small area of land behind the escarpment to its immediate south. Losses taking place as it crosses the plains have been previously investigated and found to be of the order of 2,200 ML/year.

Dry Creek

Dry Creek is the only other creek to emerge through the escarpment and have a significant area of hills catchment. However, the rainfall is still relatively low and the eastern margin of the central part of the catchment is mapped as having sandy soils. Despite its larger, hilly catchment and slightly higher rainfall, its path as mapped across the plains ceases about halfway across the short distance to the inlet. This observation supports the hypothesis that before urbanisation its flow was small and infrequent, as implied by its name. Analysis of present day (post-urbanisation) flow records at Bridge Road near its exit from the escarpment suggests that losses are occurring in this reach.

Plains area to the south of the Little Para River

In the northern plains area drainage lines from the escarpment, as mapped, cease very shortly after emerging onto the plain. Drainage on the plains between Cobbler and Dry creeks is likely to have been towards the southwest to join with flows from both the Little Para–Cobbler Creek system and Dry Creek in the area of their present day outlets.

Flows from the escarpment in the Enfield area had the shortest distance to cross the plain to the sea. There is evidence of coastal swamps in this area and it is likely that outflow to the inlet was via overflows from these swamps at several locations along the southern edge of the inlet.

Models and decision support systems for determining flow requirements

(a) The Watercress model

The 'Watercress' daily rainfall to runoff model has been used to explore the effects of different assumptions and make an estimate of pre-European flows. The model was chosen since it has become the 'de facto' standard for runoff estimation in South Australia and provides an array of methods for examining the effects of swamps and losses from river reaches.

A daily time step was chosen for the rainfall to runoff modelling as this provides the best compromise between rainfall data availability, ease of data handling and accuracy of modelling.

The Watercress model simulates flows via natural and engineered water systems, and estimates runoff from rainfall within its catchment component. The estimation method is similar to that used in most other runoff models in that it attempts to simulate the broadscale processes affecting rainfall after it reaches the land surface via a series of interlinked mathematical expressions. These expressions attempt to re-create the most significant processes taking place at the surface of the catchment and within the underlying unsaturated and saturated vertical and lateral drainage paths.

The various processes are modelled by selection of different coefficients included in the mathematical expressions. Changes to vegetation and related land and water developments and infrastructures are therefore simulated within the model by changing specific coefficients to represent the processes of surface interception, infiltration and evapotranspiration. Continued evaporation and infiltration losses from downstream channels and pools may also be included.

Areas of catchment which receive the same rainfall and are deemed to be hydrologically similar are identified as subcatchments, and their runoff is estimated from a single record of rainfall by a single set of coefficients within the model. The total catchment runoff is then the sum of the runoff generated from the identified subcatchments. Because quantifiable differences in hydrological processes are uncertain, it is usual to identify subcatchments more on the basis of the availability of rain gauges than on land use and land type.

(b) Model structure
The model layout is shown in Figure E1.

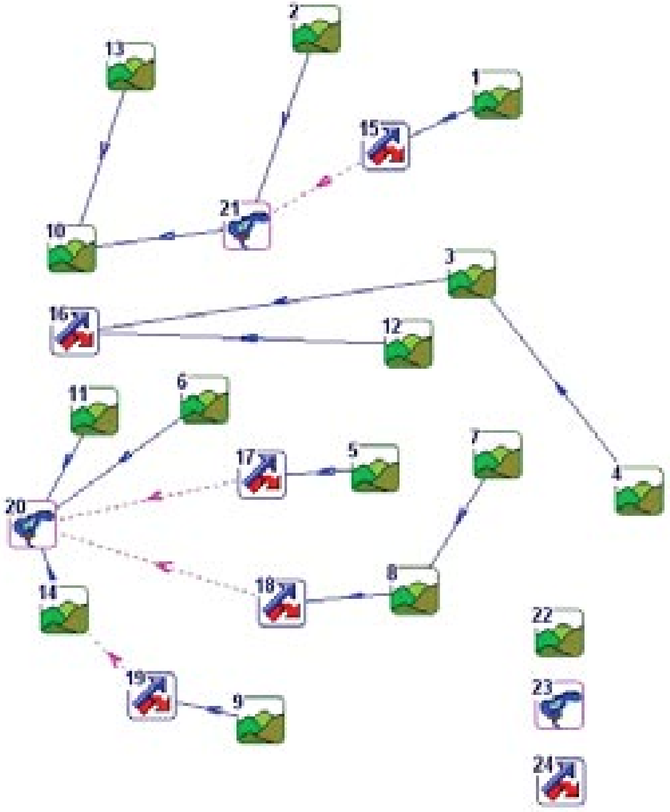


Figure E1 Watercress model layout

Three types of processes were modelled:

Catchment nodes: Nodes 1, 2, 3 etc predict daily runoff from an input record of rainfall. The catchment area and coefficients used to define the operation of the model are the major inputs to the node databases.

Loss nodes: Nodes 15 to 19 divert a proportion of the predicted daily flow to infiltration loss. The amount diverted is calculated as:

Diversion = B + K * (daily flow) for all daily flow > B, or = daily flow for all daily flow < B.

The values of B (base level) are calculated as I*N*L where I is the infiltration and evapotranspiration loss in ML/day/km of reach length, N is the number of creek lines discharging from the escarpment (from the upstream catchment) and L is the reach length per creek in which losses take place as they travel across the outwash fan. K is the proportion of flow lost above the base level B and in all cases has been assumed to be 5%. The assumed values of I, N and L are shown in Table E3.

Table E3 Assumed values of I, N, L, B in loss node calculations

Node	I	N	L	B = I*N*L
15	0.2	8	2	3.2
16	0.4	1	20	8
17	0.2	6	2	2.4
18	0.2	1	10	5
19	0.2	3	2	1.2

Detention/evaporation nodes: Nodes 20 and 21 are storages provided with very shallow depth and high surface area to simulate the ponding of flow on the plains. Their maximum surface areas when full to 100 ML were assumed to be 2 km^2 and 1 km^2 respectively. Inflow was subject to loss at the pan evaporation rate applied to the calculated surface area. Outflow only occurred when the storage exceeded 100 ML.

Four different catchment types were identified as likely to have different responses of runoff to rainfall:

- the steeper and/or more elevated catchments within the Little Para River and Cobbler Creek catchments and the escarpment along the eastern boundary of Dry Creek (nodes 3, 4, 7, 12)
- the less steep escarpment catchments bordering the eastern side of the plains areas to the north and south of the Little Para River and south of Dry Creek (nodes 1, 5, 9)
- the central part of Dry Creek with its sand soils (node 8)
- the low gradient plains catchments between the escarpment and the inlet (nodes 2, 6, 10, 11, 13, 14).

(c) Rainfall records

In seeking locations where daily rainfall has been measured continually over a common period of time, a compromise has to be made between the length of the common period used and the availability of recording sites with enough continuous daily records to provide an adequate spatial coverage of locations. Rainfall data coverage in this area is generally good, with the exception of the central eastern part of the catchment where data from the gauge at Williamstown had to be used. Seven gauges were used (Table E4).

Table E4 Rain gauges

Name Met.	Bureau No.
Virginia	23030
Smithfield PO	23025
Millbrook/Houghton	23731/23715
Williamstown PO	23752
Salisbury	23023
Pooraka PO	23026
Tea Tree Gully Council	23027

(d) Model calibration results

Present day non-urbanised flows: The model was first run and calibrated to produce runoff under present day conditions, but without urbanisation (Figure E2). The only hard calibration data that was available were the measured flows into the Little Para dam (1968–92).

The model parameters for the less steep escarpment areas and central Dry Creek catchment were set at values previously used in calibrations of the model for these areas, with particular reference to a previous model for Smith Creek. This creek emerges from the escarpment to the north of Little Para River. Although now urbanised on its plains section, it includes a relatively large non-urbanised subcatchment for which model values had been chosen previously.

The model parameters were chosen for the plains catchments subjectively, but within the range of values previously used for lower runoff catchments, to produce only occasional runoff.

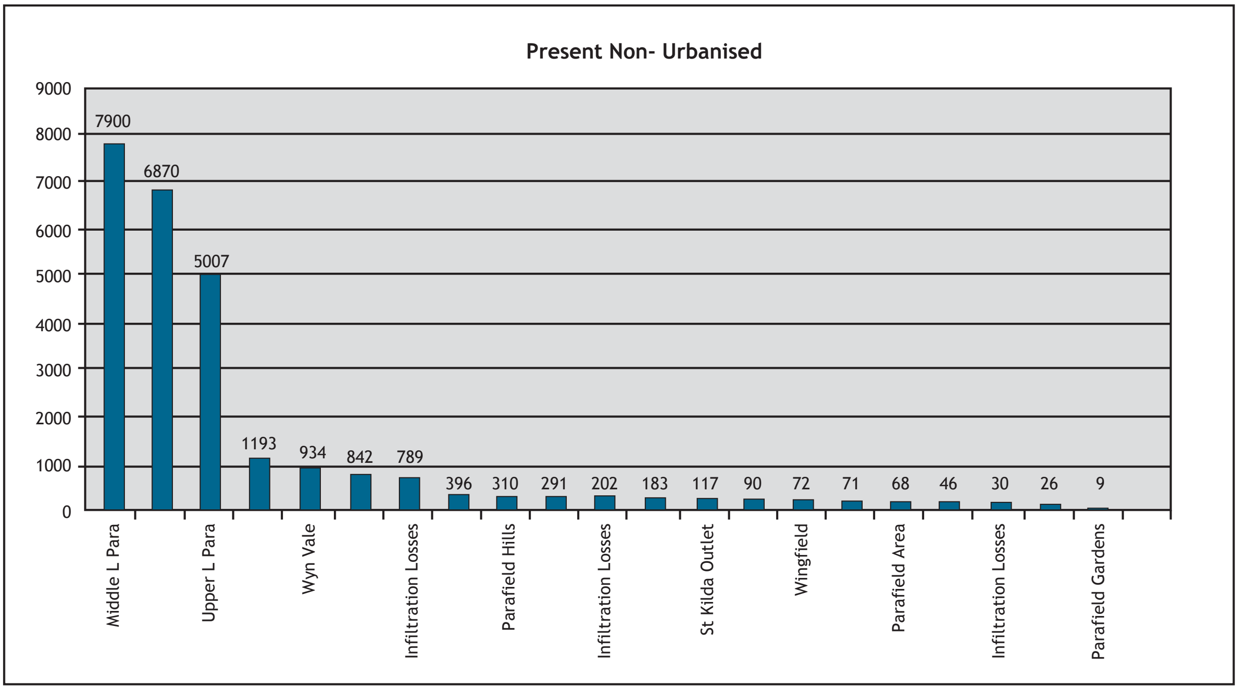


Figure E2 Present day non-urbanised flows (ML/year)

Pre-European flows: The greatest differences between present day flows and pre-European flows are incorporated in the model above. The only changes made to reflect the pre-European condition are allowances for the additional effects of increased vegetation and reduced losses in farm dams. This is accomplished in the model (Figure E3) by increasing:

- evapotranspiration coefficient from 0.65 to 0.75
- interception loss by 10%
- maximum soil moisture capacity by 5 mm.

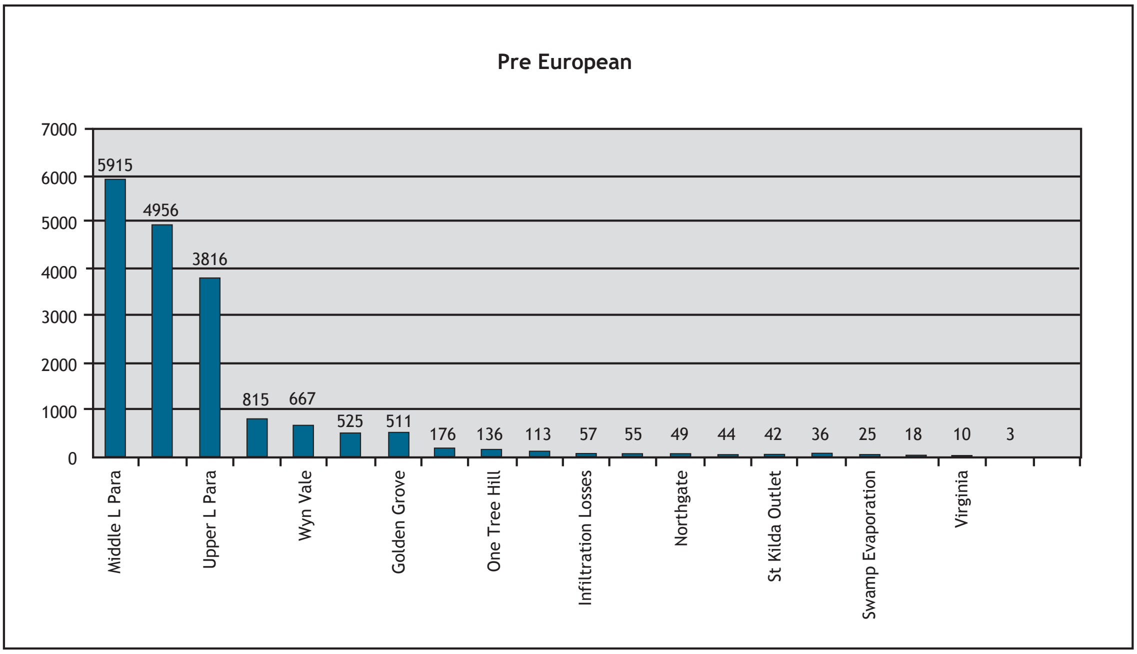


Figure E3 Pre-European flows (ML/year)

The annual flows predicted by the model, as would have occurred under the rainfall experienced from 1902 to 2002 if conditions had remained the same as in pre-European times, are given in Figures E4 and E5.

A comparison between flows to the Barker Inlet now and in pre-European times is provided in Table E5.

Table E5 Comparison of flows to the Barker Inlet

Catchment/outlet	Present flow (ML/year)	Pre-European flow (ML/year)
South of Dry Creek	3,260	<100
South of Little Para River inc. Dry Creek	10,500	<300
Little Para River	3,000	5,000
South of Gawler River	3,000	<50

Conclusions

The total of flows into the Barker Inlet from the area between the Port River and the Gawler River would have been greatly reduced in pre-European times below present levels. The main causes of flow increase are urbanisation and improved drainage. These have caused very large increases in runoff from the plains areas, which previously would have only experienced very low and sporadic levels of runoff. Vegetation clearance is believed to be only a secondary cause of increased present day flows.

Despite this general increase, present day levels in the Little Para River are predicted to be less than they were in pre-European times due to the damming of the river in 1974 and the subsequent removal of the majority of its flows to water supply. Compensatory flows released from the dam infiltrate into the river bed, and only a relatively small area of urban development exists within the catchment below the dam to provide additional stormwater to the river to partly replace the diverted flows.

The low levels of predicted pre-European flows from the areas to the north and south of the Little Para River are based on mapped evidence of the lack of any formal drainage paths in these areas and the observed and/or implied (but not measured) effects of:

- losses taking place from flows as they traverse the outwash fan areas at the foot of the escarpments
- storage and depletion of runoff by infiltration, and evaporation of any flows sufficient to traverse the outwash fans and arrive on the plains areas.

Interruptions in tidal flows

Tidal flows have been interrupted by:

- urban and industrial development, resulting in the loss of salt marsh and preventing inland tidal excursions
- the construction of levee banks, further alienating areas that had been tidally inundated
- the construction of easements without culverts across shallow tidal channels (eg the transmission line easement across to Torrens Island Power Station)
- the modification of flow patterns in Angas Inlet as a result of cooling water needs for the power station.

Significant actions that have improved flows or had some compensatory benefits, together with further opportunities, include:

- construction of a culvert in the tidal channel, resulting in mangrove recolonisation (the transmission line easement across southern Barker Inlet formerly interrupted flows, causing the loss of large mangrove areas)
- removal of the seawall by ICI (Penrice) in 1954, when the salt fields were constructed, resulting in the large-scale re-establishment of mangroves
- construction of the 170–ha Barker Inlet wetland, which includes an intertidal area of approximately 50 ha for mangrove colonisation
- preparation of a management plan for the Mutton Cove Conservation Park, which aims to improve tidal exchange within the cove by modifying the inlet structure—these modifications to flow are intended to benefit the biological communities of the cove
- removal of the tide gates at the mouth of Dry Creek, which could have some benefits for fish passage.

Because of the extent of urban development, further opportunities are limited in the foreseeable future. However, the following points need to be recognised:

- The Land Management Corporation (LMC) is currently considering development opportunities for the Gillman area, which includes some wetland sites. Opportunities to develop intertidal mangrove/samphire accession areas similar to the Barker Inlet wetland are also being considered. Part of the Gillman area is used for flood storage when large storm events (up to 1-in-100-year ARI) coincide with high tides. Currently, water is retained behind a levee and is released to the Port River through a flap gate during low tides. Consideration is now being given to including gates in the levee to allow free tidal exchange, thus allowing the area to be rejuvenated. Like the gates currently on the Barker Inlet wetland, these could be closed during periods of flooding, maintaining the area's important flood protection role.

- The need for salt marsh accession areas should be seen as a general planning issue for the region. If land became available behind the levee banks on the eastern side (ie the salt fields and Bolivar WWTP lagoon area), the environmental needs of the area should be recognised rather than seeing this as land only for new development. Predicted sea level rises are likely to have little effect on the mangroves, depending on the rate of change, because they trap sediments and will adjust to the changes. At risk, however, are the remaining salt marsh areas.

Constructed wetlands and fish passage opportunities

Within the vicinity of the Port waterways a number of large freshwater wetland systems have been developed, including:

- Greenfields wetlands, Stages I, II and III
- Barker Inlet wetland
- Magazine Creek wetland
- Range wetland.

The Greenfields wetlands were developed by the City of Salisbury, which was also responsible for the design and construction of the Barker Inlet wetland. Collectively, these represent a substantial area and partly replace some of what has been lost. The wetlands were developed with the following broad objectives:

- to improve stormwater quality and protect downstream ecosystems in the Port waterways
- to improve landscape amenity and provide passive recreational opportunities
- to provide improved habitat for fauna and flora
- to provide opportunities for the harvesting and reuse of stormwater and, in some instances, flood control.

A small detention basin was also developed on the Lefevre Peninsula at Snowdens Beach but was never completed to the stage where it had the attributes of a functioning wetland system.

It is also important to recognise that:

- The City of Salisbury has developed stormwater wetlands throughout its council area in the Little Para and Dry Creek catchments.
- Stormwater management plans are being developed by the TCWMB and the City of Port Adelaide–Enfield for drainage leading to the Barker Inlet, Magazine Creek and Range wetlands, as well as to West Lakes, which will result in reduced pollutant load export from the catchment. The plan for one combined drain, the Hindmarsh–Enfield–Prospect (HEP) drain, has been completed. Wetland detention basins are proposed and will likely be developed with similar multiple objectives as indicated above.
- As a means of reducing pollution potential, stormwater wetlands are proposed as part of the new development on Lefevre Peninsula. Consistent with this, a wetland to intercept and treat runoff from the new expressway has been constructed.

The Greenfields, Barker Inlet, Magazine Creek and Range wetlands have achieved their objectives, and the Barker Inlet and Greenfields wetlands are now part of the Metropolitan Open Space System (MOSS).

Although only developed in the early 1990s, the Barker Inlet wetland has developed significant conservation value and has been listed as a wetland of national importance.

Because of the proximity of these wetlands to the Port waterways, there is a significant opportunity for fish movement from the estuary into the wetlands. The previous TCWMB undertook a study of native fish and their requirements in the Torrens catchment, which included examining opportunities to install fish ladders to assist passage.

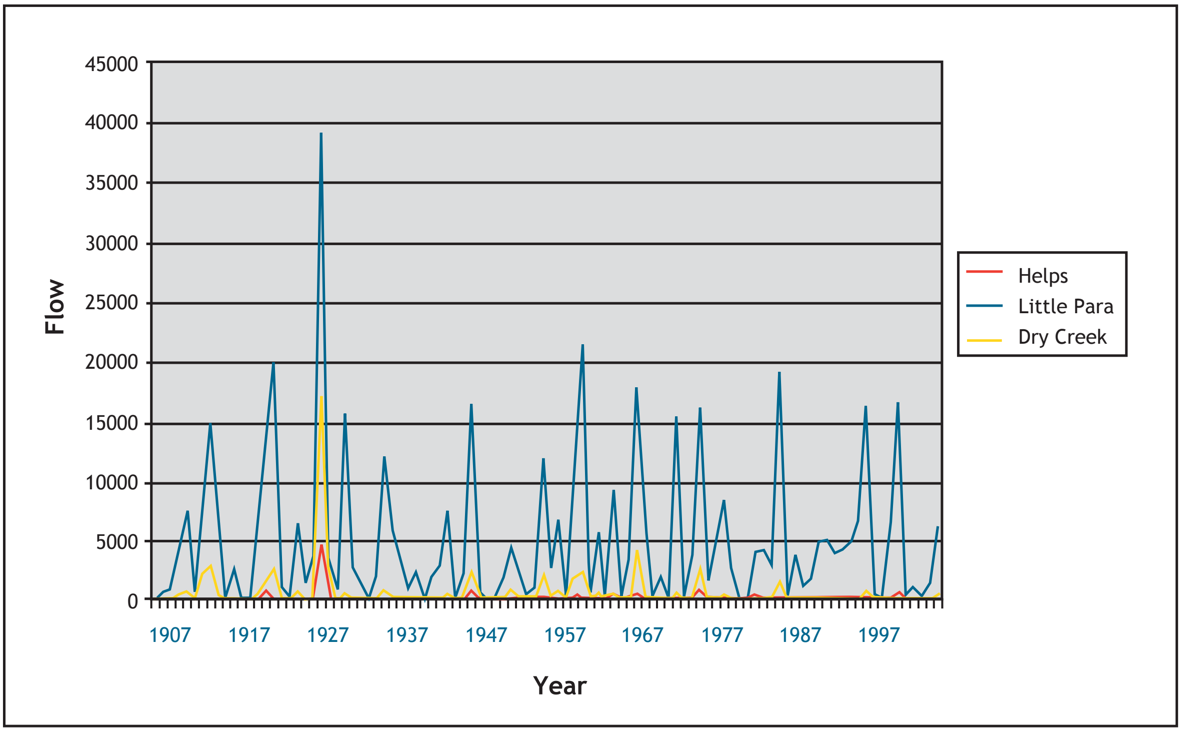


Figure E4 **Estimated pre-European annual flows to Barker Inlet**

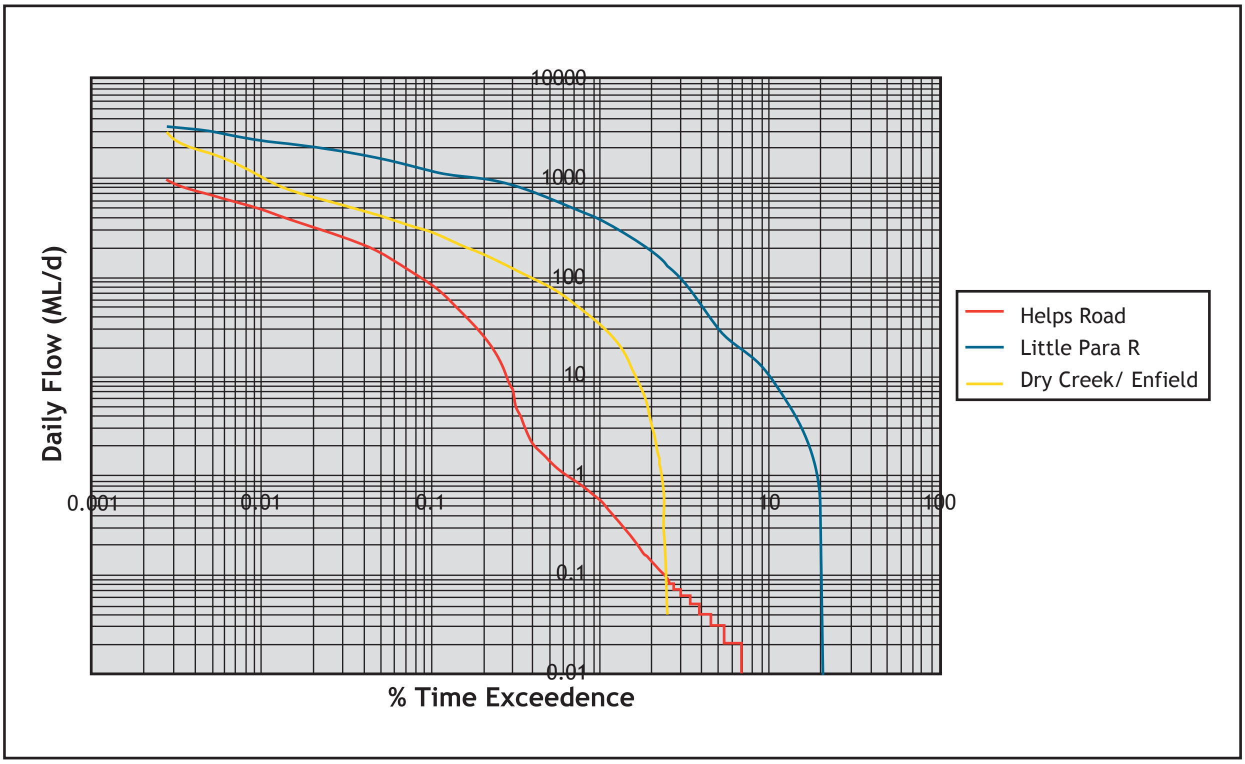


Figure E5 Percent time exceedence for estimated pre-European daily flows to Barker Inlet

APPENDIX F

MODEL OUTPUT OF NUTRIENT LOAD REDUCTIONS FOR THE PORT WATERWAYS (INCLUDING PROCEEDINGS OF STAKEHOLDER WORKSHOP ON THE MODEL)

Introduction

The nutrient load targets used for the draft Port Waterways Water Quality Improvement Plan (WQIP) are derived from the use of a water quality model of the waterways area. Details of the model used and its calibration are contained within another two reports for the Port waterways: *Port Waterways—Nutrient Load Reductions Study, Nutrient Modelling Coupled to a 3D Hydrodynamic Model* (EPA 2006) and *Port Waterways—Cardno Lawson Model Calibration* (EPA 2005). However, some information further to section 2 of the draft WQIP is contained within this appendix to enable users of the draft WQIP to manage discharges to the waterways.

This document includes information about:

- nutrient loads to the Port waterways
- future load reduction required to achieve the objectives
- further detail in the form of graphic output from the model
- proceedings of a workshop where aspects of the water quality model were subjected to independent comment by water quality and modelling specialists.

Nutrient loads to the Port waterways

Nutrient load monitoring at reference sites in the Port waterways between 1998 and 2004 indicates the following changes:

In the Port River segment:

- There is virtually no phosphorus (P) in the Penrice discharge. The impact on P concentrations of removing the Port Adelaide WWTP discharge is clearly apparent at the reference sites, as shown on Figure F1. At Pelican Point (PTR8) the reduction is less as a result of greater tidal exchange with open gulf waters.
- There is also a major difference in total nitrogen (N) and ammonia, as shown for the reference sites in Figure F2. However, concentrations of ammonia, although significantly reduced, remain above the water quality objective (WQO) value of 10 µg/L. Summary water quality data (mean, median, minimum, maximum, percentiles (10, 80 and 90)) for all reference sites is included in Tables F1 to F14. Using the EPA classification, these have been colour-coded as green (good), brown (moderate) or red (poor). The data for the Port River segment sites is given in Tables F5 to F7 and indicates that:
  - Birkenhead (PTR3) and Snowden Beach (PTR5) sites remain classified as poor for nutrients, except for total P. Soluble P only marginally exceeds the WQO value of 10 µg/L.
  - The influence of greater tidal exchange at the Pelican Point reference site (PTR8) shows lower concentrations of ammonia and soluble P, which are now classified as moderate.

In the Central Barker Inlet segment:

- Nutrient concentrations have reduced between 1998 and 2004, as indicated by the graphs for the reference sites at North Arm (NAR2), Swan Alley (BKR4) and St Kilda (BKR2) for total N, ammonia and total P in Figures F3, F4 and F5 respectively.
- As in the Port River segment, although concentrations have reduced, they are still above the WQO value. The classified summary data for the reference sites, included in Tables F4, F5 and F6, indicates that:

  - In the southern part of the segment at North Arm (NAR2) and Swan Alley (BKR4) concentrations of total N and ammonia are still relatively high and are classified as poor. Total P concentrations are now below the WQO value of 25 µg/L, but soluble P concentrations are marginally above the WQO value of 10 µg/L. As discussed below in more detail, in this area of the segment the previous Port Adelaide WWTP and Penrice would have been the principle sources of nutrients. Further north in the segment at St Kilda, there is a greater contribution to the nutrient levels from the Bolivar WWTP.
  - At the St Kilda reference site (BKR2), as a result of the reduction in ammonia discharges between 1998 and 2004, concentrations of ammonia have declined but are still classified as poor. Total N also remains relatively high and is classified as poor (Table TF4). P concentrations are higher than at Swan Alley or the North Arm, reflecting the contribution of the Bolivar discharge.

In the Northern segment:

- There is virtually no change in the loads of total P discharged between 1998 and 2004, as reflected in the concentrations at reference sites BOL1, BOL2 and BKR1 and shown on Figure F6.
- The load reduction in N from Bolivar is apparent but variable between locations, as indicated in Figure F7 for total N and Figure F8 for ammonia. The variability is due to:
  - the specific location and its proximity to the discharge point, and variations due to tide and wind-driven currents
  - the pattern of change as illustrated on maps for P, showing concentration gradients in a spring high tide in Figure F9, a spring low tide in Figure F10, a neap tide in Figure F11 and a north-wind-driven current in Figure F12. This also illustrates a practical difficulty with time series ambient water quality monitoring data, which invariably demonstrates considerable variation. In the Port waterways, in addition to variations in source (stormwater, etc) and seasonal effects (eg rates of removal, microbial decay), the figures illustrate that large variations over short time intervals also occur due to the physical variables of tide, wind direction and strength. This is also noted on Figure F8, where the distinct tidal signals between daily high and low tides, and between spring high, spring low and neap tides, can be seen. The effects of wind direction are also noted.
- As shown in Table TF1 for BOL1, Table TF2 for BOL2 and Table TF4 for BKR1:
  - Ammonia levels are above the WQO values not below the wg objectives for NH4 (10 µg). At BOL1, the reference site in closest proximity, concentrations were higher in 1998 (0.41 mg/L 90th percentile) but lower in 2004 (0.106 mg/L 90th percentile). This is also due to changes in effluent quality and concentrations, with lower ammonia levels but higher concentrations of nitrate.
  - Higher concentrations of nitrate now occur at BOL1 and BOL2 (Table TF2) but there is little difference at BKR1 (Table TF4).

While the reference sites provide specific information on concentration change and variability, they do not adequately define the areal extent of effluent dispersion. This is another practical difficulty with ambient water quality monitoring programs, which usually have a limited number of sampling sites. The DSS model has generated maps of the distribution of nutrients for 1998 and 2004 data (Figures F13 and F14 respectively for total N; Figures F15 and F16 respectively for ammonia; Figures F17 and F11 respectively for total P). Neap tide conditions have been selected for comparison between years and to indicate the general pattern of dispersion because of the long residence time in Barker Inlet and its significance to nutrient uptake in algal growth. However, as noted earlier and shown on the Figures, considerable variation can occur due to tide and wind, particularly in the Northern segment. Reviewing these maps, the following are to be noted:

- The difference in concentration in total N between the two periods is apparent (Figures F13 and F14), with a significant overall reduction in 2004, but concentrations throughout most of the study are still exceed the WQO value of 230 µg/L. In 1998 the Port River and Central Barker Inlet segments had very high concentrations of N. These areas still have the highest concentrations in 2004. The effect of the Bolivar discharge can also be clearly seen.
- In 1998 the whole study area had elevated concentrations of ammonia (Figure F15), above the WQO value of 10 µg/L. Even with the diversion of the Port Adelaide WWTP effluent to Bolivar and the reductions in ammonia discharged from Penrice in 2004, concentrations in the Port River and most of the Central Barker Inlet segments still exceeded the WQO value. This is discussed further below in relation to additional load reductions discharged from Penrice.
- The removal of the P load discharged to the Port River (105 t/year in 1998) has had a marked effect (Figure F11) on concentrations throughout the Port River and Central Barker Inlet segments, with concentrations of total P generally below the WQO value of 25 µg/L.

Chlorophyll *a* was used as an indicator of ecosystem response to nutrient enrichment of the waterways. Light alteration in the water was modelled using measured secchi disc depths. Maps showing its concentrations in 1998 and 2004 are given as Figures F18 and F19 respectively. Points to note are:

- The general range in concentration and pattern is very similar during both periods. The concentration data for chlorophyll *a* in Tables F1 to F9 also indicates very little change.
- The highest concentrations occur in the North Arm–Central Barker Inlet segment, while the Port River-segment levels are similar to those of the Northern segment. The relatively low concentrations in the Northern segment are due to the level of exchange with gulf waters. Although phytoplankton blooms do occasionally occur in the waters of the Northern segment offshore of the Bolivar discharge, the regular high volume exchange usually continuously replaces the phytoplankton, reducing the potential for population growth. On the maps for N (Figure F14) and P (Figure F11) there is an apparent rapid dispersion of the nutrients northwards and westwards towards the open gulf. This is also as a result of the level of exchange with gulf waters compared with those of the Central Barker Inlet segment. The pattern of dispersion shown in Figures F9 to F12 demonstrates that effluent from Bolivar that is carried into the inlet has a long residence time, allowing for its effect on algal growth. In the Northern segment the model does not account for epiphytic growth or other macroalgae, which, being fixed, would demonstrate a response to elevated levels of nutrients.
- Even with substantial reduction in nutrient loads during 1998–2004, the minimal change in chlorophyl *a* concentrations indicates that there are still sufficient nutrients in the system to produce excessive algal growth, and further reductions are necessary.
- The exception may be the Port River segment. Toxic algal blooms occur occasionally, facilitated by the available nutrient supply. Following removal of the P load discharged from the now diverted Port Adelaide WWTP, this situation is likely to improve even though there is still an abundance of bioavailable nitrogen. There should be a reduction in the frequency, extent and duration of algal blooms.
- The introduced algal species *Caulerpa taxifolia* and *C. racemosa* represent a major threat to the aquatic ecosystem. Even with the reduction in loads, the quantity of nutrients available still favour a rapid spread of these species in the waterways.

Future load reduction required to achieve the water quality objectives

Ammonia in the Penrice discharge

As indicated above and shown on Figure F16, even with the improvements made to date, the current Penrice discharge of 820 t/year (2004) produces concentrations above the WQO value of 50 µg/L in the Port River segment and the majority of the more ecologically sensitive Central Barker Inlet segment.

Changes in the concentration of ammonia at reference sites Birkenhead (PTR3), Snowdens Beach (PTR5), North Arm (NAR2) and Swan Alley (BKR4) as a result of further reductions in the annual loads of ammonia discharged are shown on Figures F20 to F24 respectively. These clearly indicate that achieving concentrations below the WQO value will require a substantial reduction from the current (2004) level of 820 t/year to an annual load of the order of 200 t/year. At this loading areas of the Port River and Angas Inlet still have concentrations above the WQO value, as shown on Figure F25. The following points are also to be noted:

- Although areas of the Port River and Angas Inlet have concentrations above the WQO value, the majority of the waterways including most of Barker Inlet are below this value.
- Within the Port River, although there is no salinity gradient as is typically found in estuaries, stratification occurs due to the differential mixing of West Lakes inflows and tidal excursion from the gulf with the effluent discharge. Within Barker Inlet, the waters and ammonia are relatively well mixed, while in the Port River concentrations will be variable.
- The ammonia load from Penrice is approximately uniform throughout the year. It is known from 10 years of monitoring of ambient water quality in the Port River that total N and ammonia concentrations are lower in summer than in winter, even though the discharges of nitrogen during this period from the Port Adelaide WWTP and Penrice did not differ significantly with season. The reduction in ambient N concentrations in summer was probably due to higher biological activity such as a more rapid uptake by macroalgae, phytoplankton and other marine plants, and higher rates of denitrification. Calculation of a total maximum discharge load of ammonia from Penrice during winter is likely to be conservative.
- Toxicants can have additive or synergistic effects which can also be exacerbated by thermal increases. Consequently, in order to ensure that the toxic component is low, a WQO value of 910 µg/L may not be considered too conservative.

Nutrients in the Bolivar discharge

Even with the relocation of the Port Adelaide WWTP, the load reductions from Bolivar and the reduction of Penrice's load from 820 t/year at present to 200 t/year, chlorophyll levels remain high, as shown in Figure F26. The distribution of total N and P are shown on Figures F27 and F28 respectively.

The water quality modelling, by means of which the total maximum N and P loads were derived, was based on a period covering May and June 2004—the winter period. In the spring-summer period, because algal growth is greater with the available nutrients, chlorophyll *a* concentrations should be higher. However, this could be offset by reductions in the loads discharged during this period, particularly P. The N and P loads from the Bolivar treated effluent discharge are higher in winter than in summer because more than half of the low salinity treated effluent is diverted for horticultural irrigation in summer compared to almost none in the winter period from May to August. Monthly loads discharged for 2004 are shown on Figure F29 below to illustrate the seasonal load distribution.

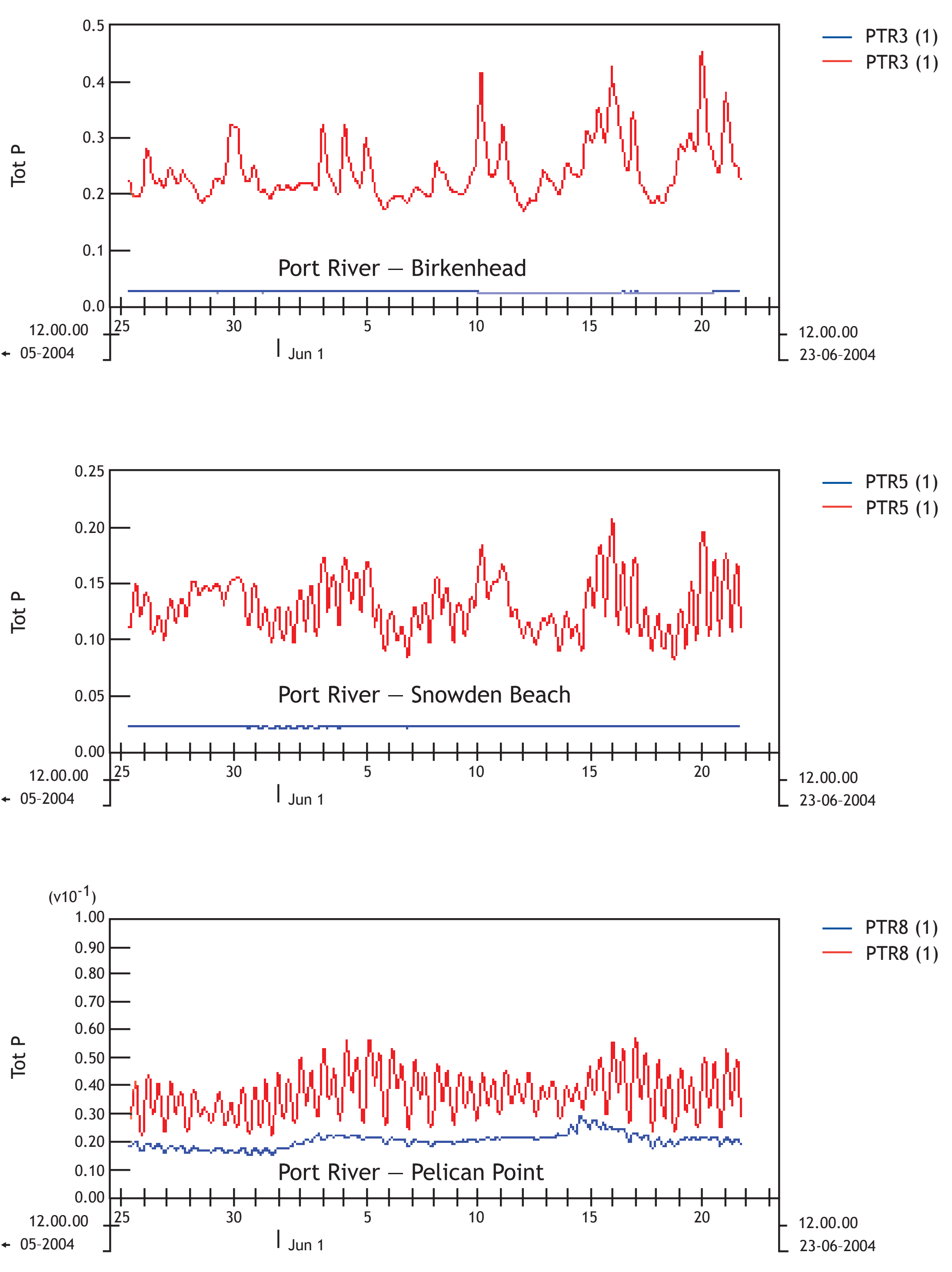
The maximum P load from the Bolivar effluent channel was calculated by determining the interaction of this nutrient with N in various segments of the Port waterways. The main focus was on the reduction of chlorophyll production in the southern region of the Barker Inlet and in the areas around Eastern Passage and North Arm Creek. Chlorophyll production was predicted to be greater in these areas because they have also experienced significant ecological disturbance from nutrient enrichment including seagrass loss and excessive *Ulva* growth. An analysis of modelling scenarios with different N discharges from Penrice showed that the only factor affecting chlorophyll concentrations was the variation in P loads from Bolivar. These areas of the Port waterways are P limited because of the significant nitrogen discharges from Penrice and seasonal variations in ambient ammonia and nitrate concentrations result in only insignificant changes to the Redfield (N:P) ratio.

The effect on chlorophyll *a* concentrations of progressively reducing nutrient (P) levels in the Bolivar discharge are shown on Figure F30 for the Central Barker Inlet segment (Swan Alley) and Figure F31 (North

Arm). It is apparent that to achieve a chlorophyll *a* level of 1 µg/L, loads have to be reduced to approximately 100 t/year N and 40 t/year P for both the high salinity and low salinity plants. There is a much smaller benefit expected in the Port River (Figure F32) (Birkenhead PTR3), except at Pelican Point (PTR8) (Figure F33). For the two Bolivar scenarios the distribution of chlorophyll *a* is shown on figures F34 and F35, where it can be seen (particularly on Figure F35) that there is a considerable reduction in chlorophyll concentrations, with the majority of the waterways now below the WQO value of 1 µg/L. The maximum load allocation from Bolivar of 40 t/year P is less than the minimum load achievable at the Bolivar facility allowing for total reuse of treated effluent from the low salinity WWTP. Therefore, the current seasonal variation in P loads from Bolivar will be unlikely to lead to sustained periods of low chlorophyll production in summer.

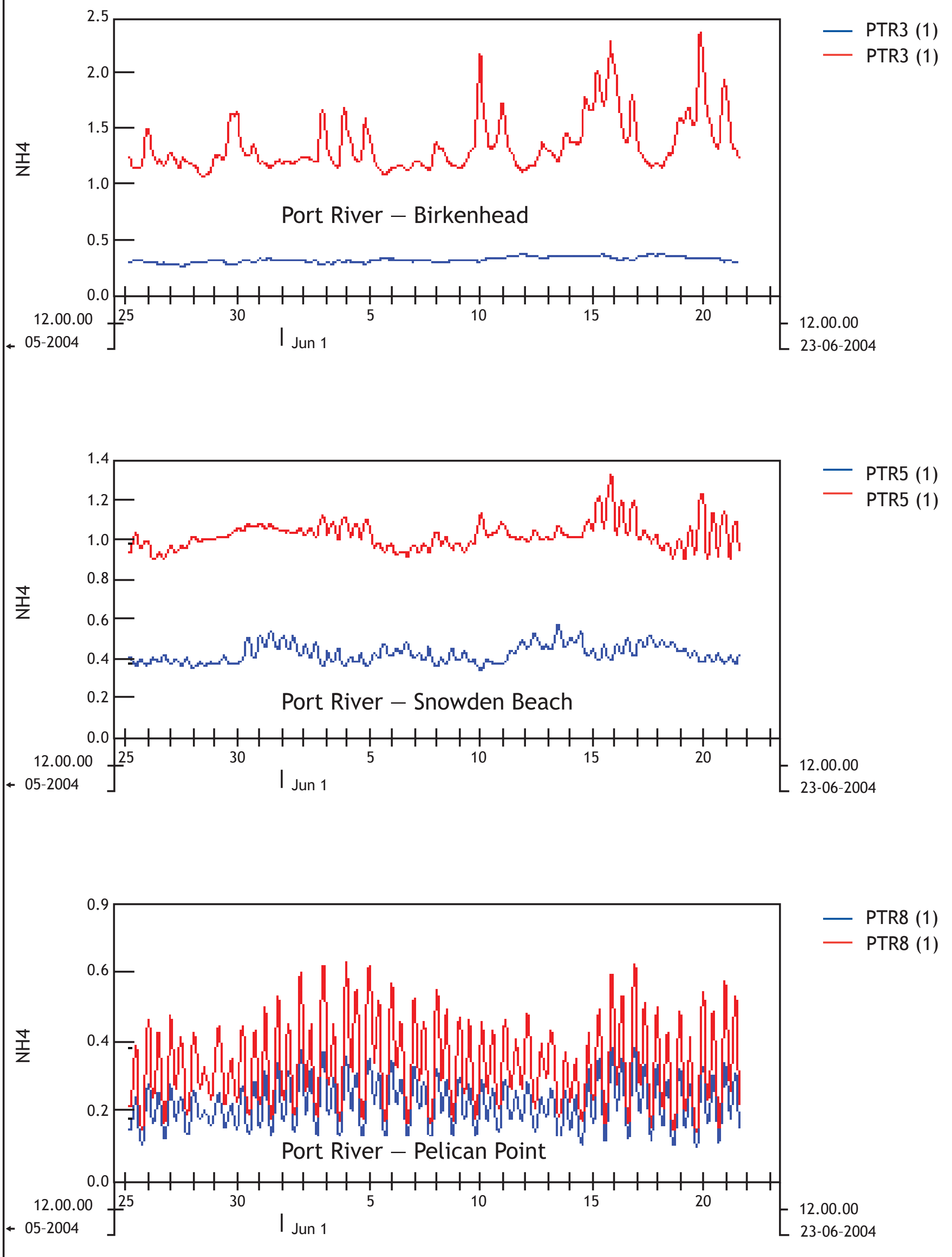
Nitrate levels generally remain above the low WQO value of 5 µg/L at all reference sites. This is a reflection of the discharge concentrations in the Bolivar effluent, oxidation of ammonia and some contributions from other minor sources such as groundwater inflows. Importantly, however, the overall effect of the nutrient load reduction is lower chlorophyll *a* levels.

Because the water quality modelling scenarios were based on the higher winter loads of N and P from Bolivar, it is likely that a seasonal signature in discharges will remain as reuse of the Bolivar effluent increases but with a lower overall volume discharged. It is not possible to be certain whether the ecosystem response to nutrient loads under summer conditions of increased light and higher temperature will lead to significant changes in the estimate of maximum P load allocation for the Port waterways. However, reconfiguring the water quality model to run summertime scenarios was not feasible within the agreed timeframes.



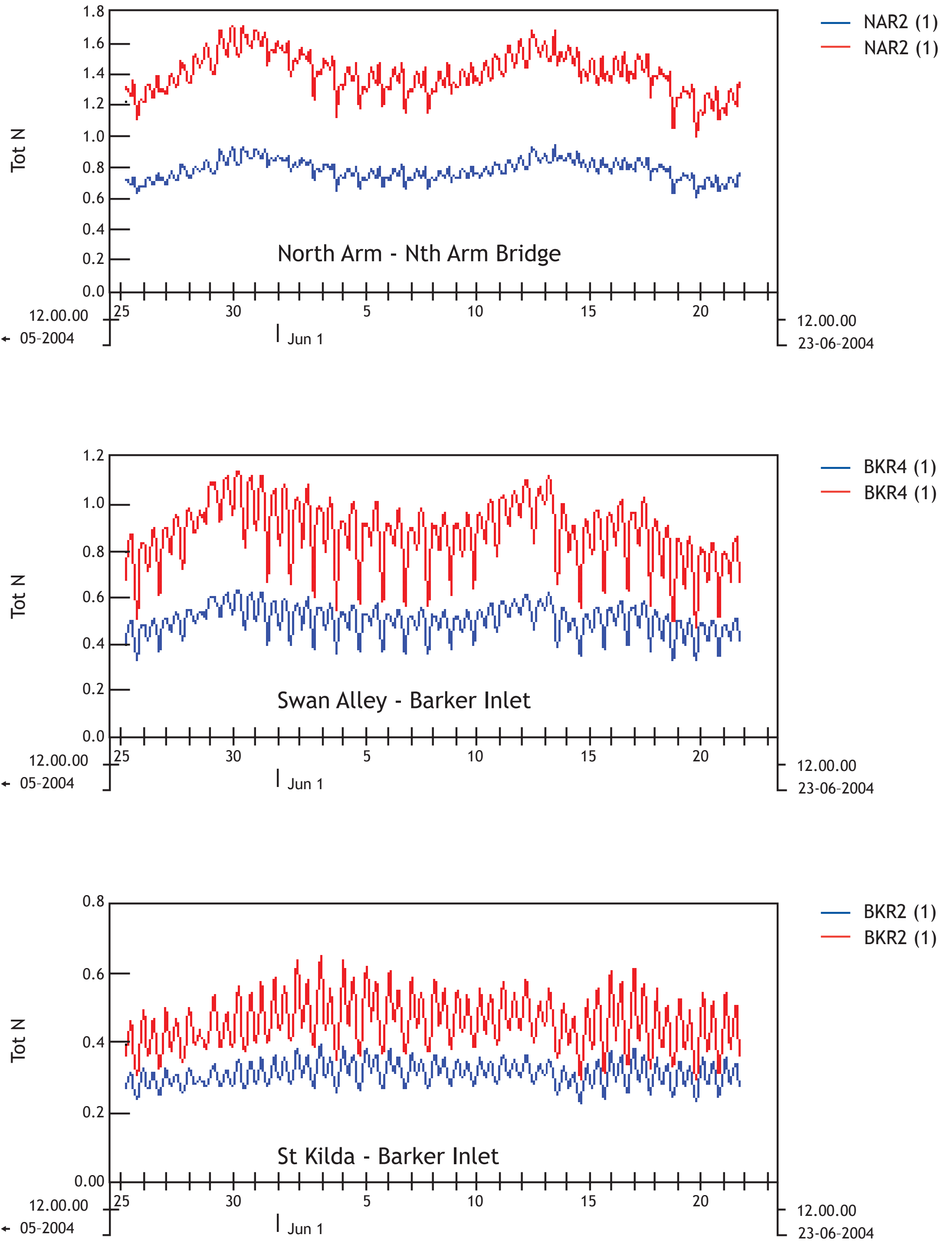
Total Phosphorus as P (mg/L) Comparison of 1998 & 2004 nutrient loads Port Adelaide WWTP loads moved to Bolivar for 2004 data	Red 1998	Blue 2004
	3D hydrodynamics	
Environment Protection Authority of South Australia	Winter	2004

Figure F1 Differences in modelled total phosphorus at three sites along the Port River following reductions in nutrient discharges between 1998 and 2004



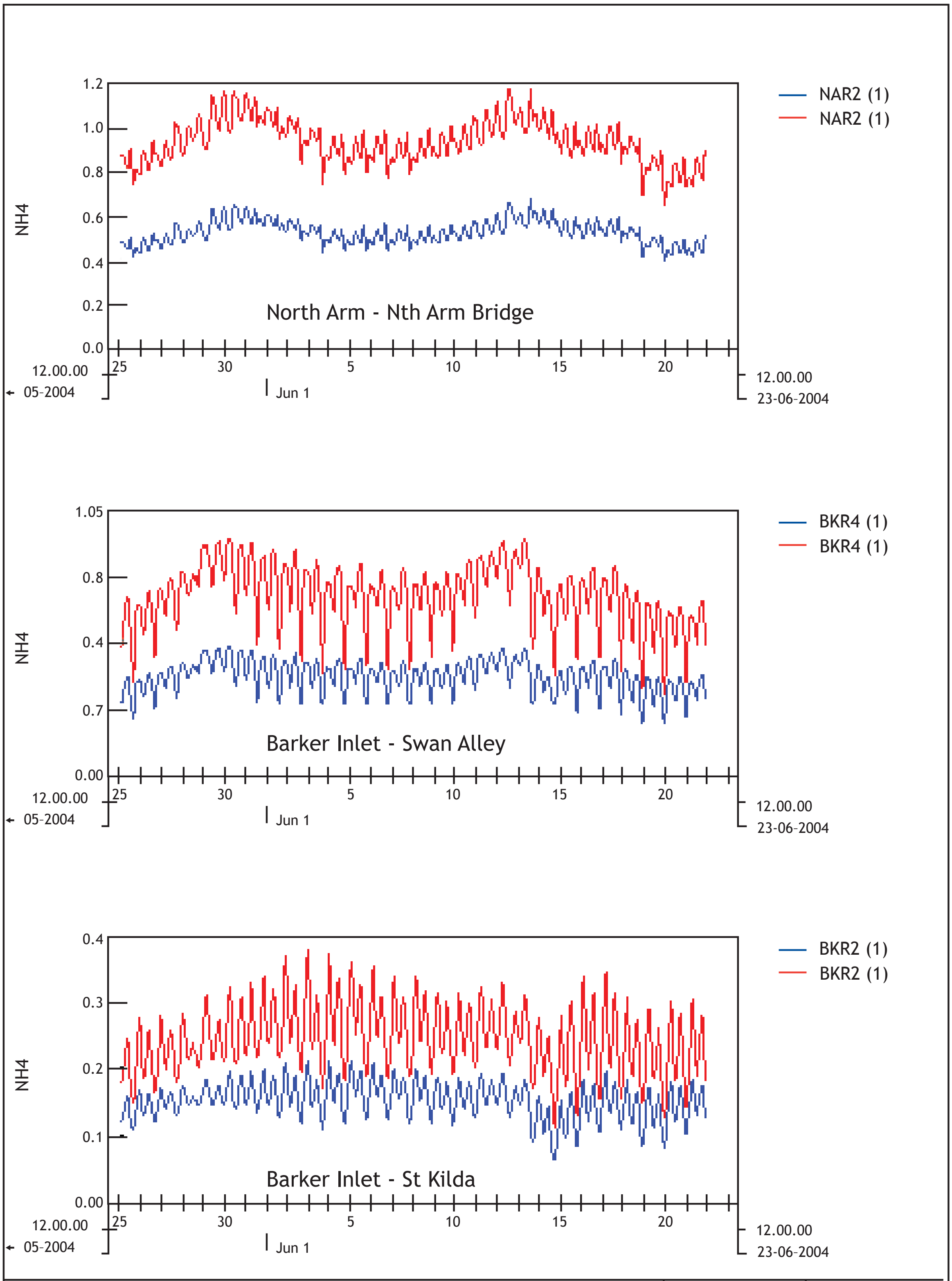
Ammonia as N (mg/L) Comparison of 1998 & 2004 nutrient loads Port Adelaide WWTP loads moved to Bolivar for 2004 data	Red 1998	Blue 2004
	3D hydrodynamics	
Environment Protection Authority of South Australia	Winter	2004

Figure F2 **Differences in modelled total ammonium at three sites along the Port River following reductions in nutrient discharges between 1998 and 2004**



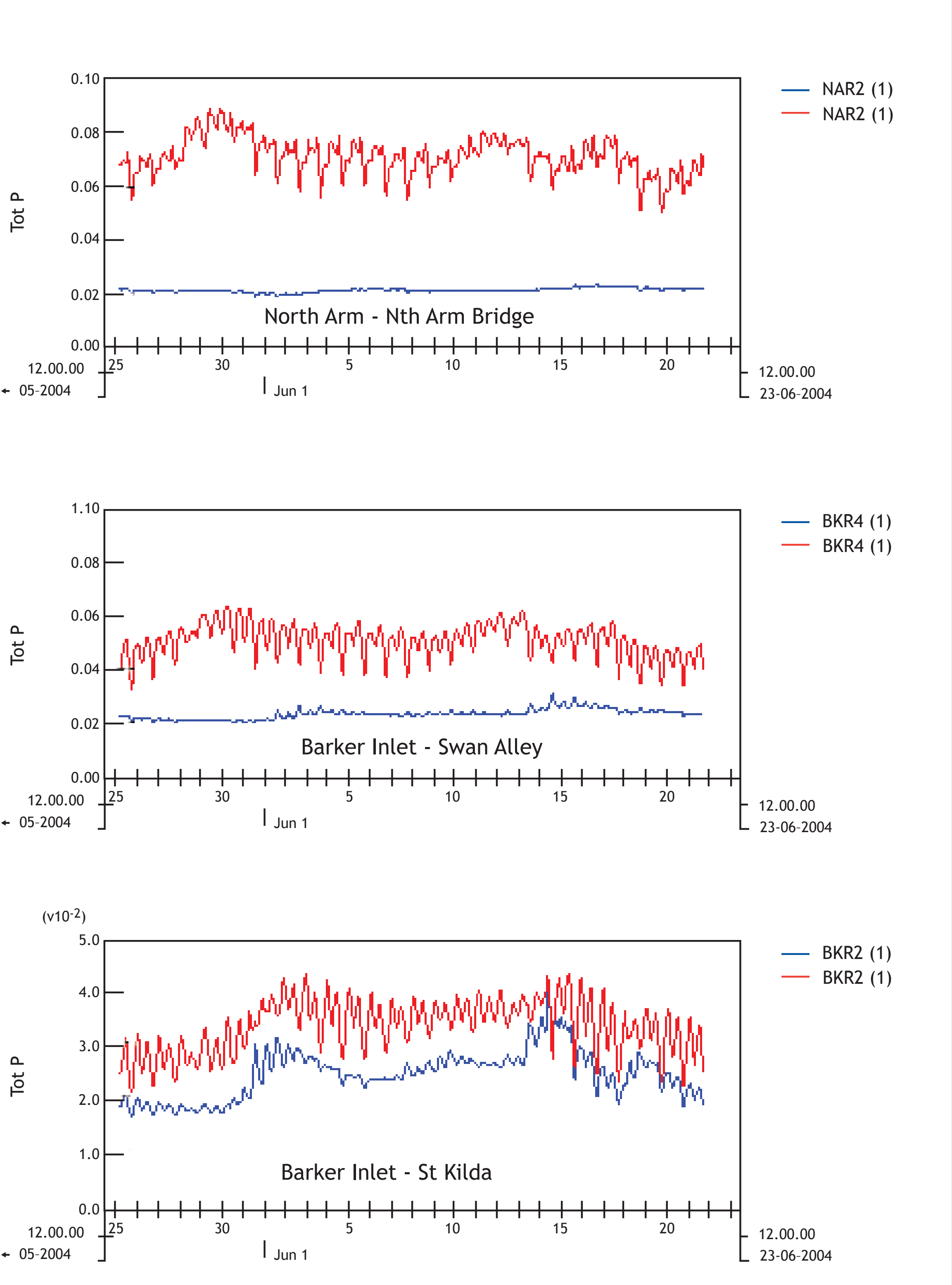
Total Nitrogen as N (mg/L) Comparison of 1998 & 2004 nutrient loads Port Adelaide WWTP loads moved to Bolivar for 2004 data	Red 1998	Blue 2004
	3D hydrodynamics	
Environment Protection Authority of South Australia	Winter	2004

Figure F3 Differences in modelled total nitrogen at three sites in central Barker Inlet following reductions in nutrient discharges between 1998 and 2004



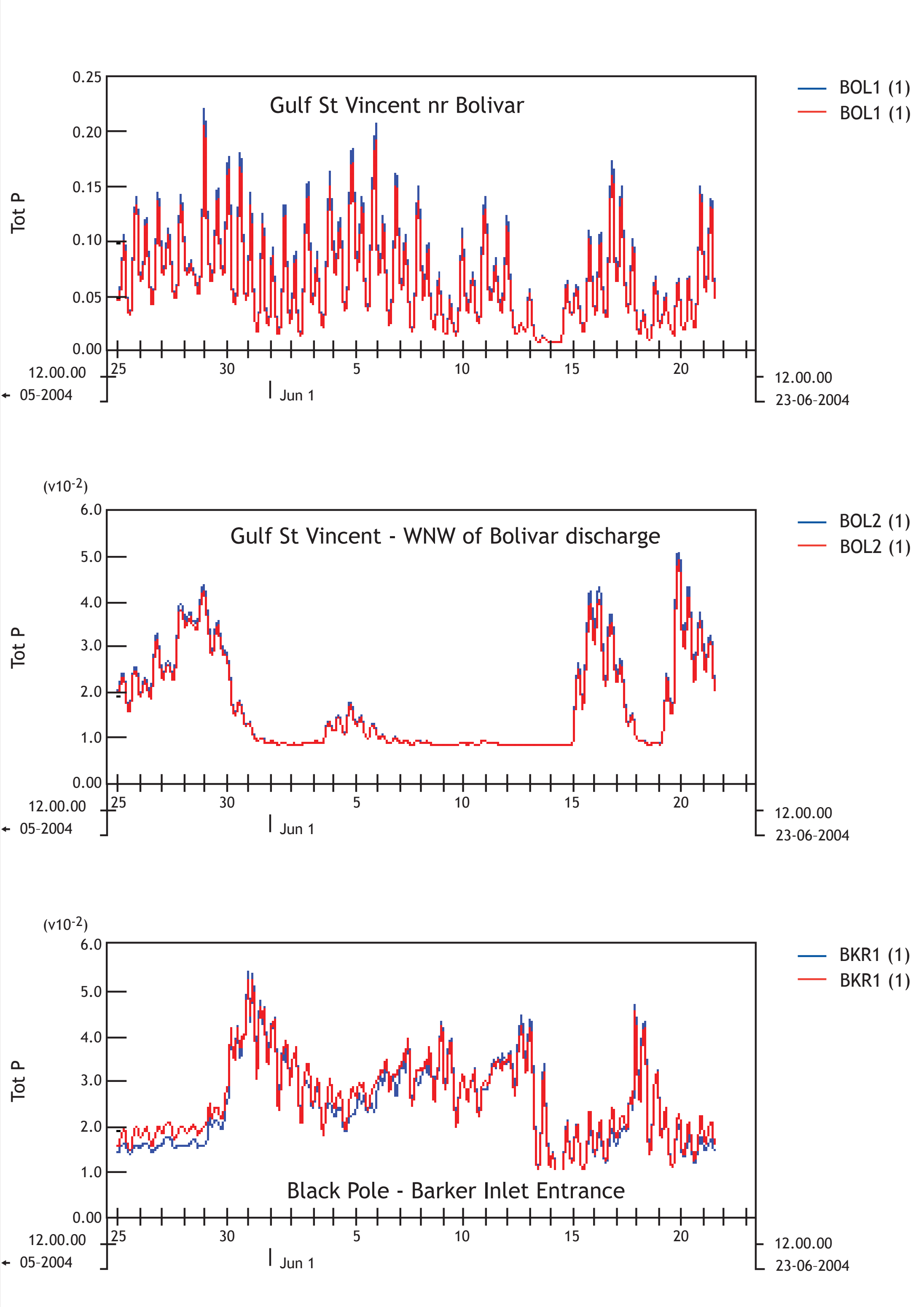
Ammonia as N (mg/L) Comparison of 1998 & 2004 nutrient loads Port Adelaide WWTP loads moved to Bolivar for 2004 data	Red 1998	Blue 2004
	3D hydrodynamics	
Environment Protection Authority of South Australia	Winter	2004

Figure F4 Differences in modelled total ammonium at three sites in central Barker Inlet following reductions in nutrient discharges between 1998 and 2004



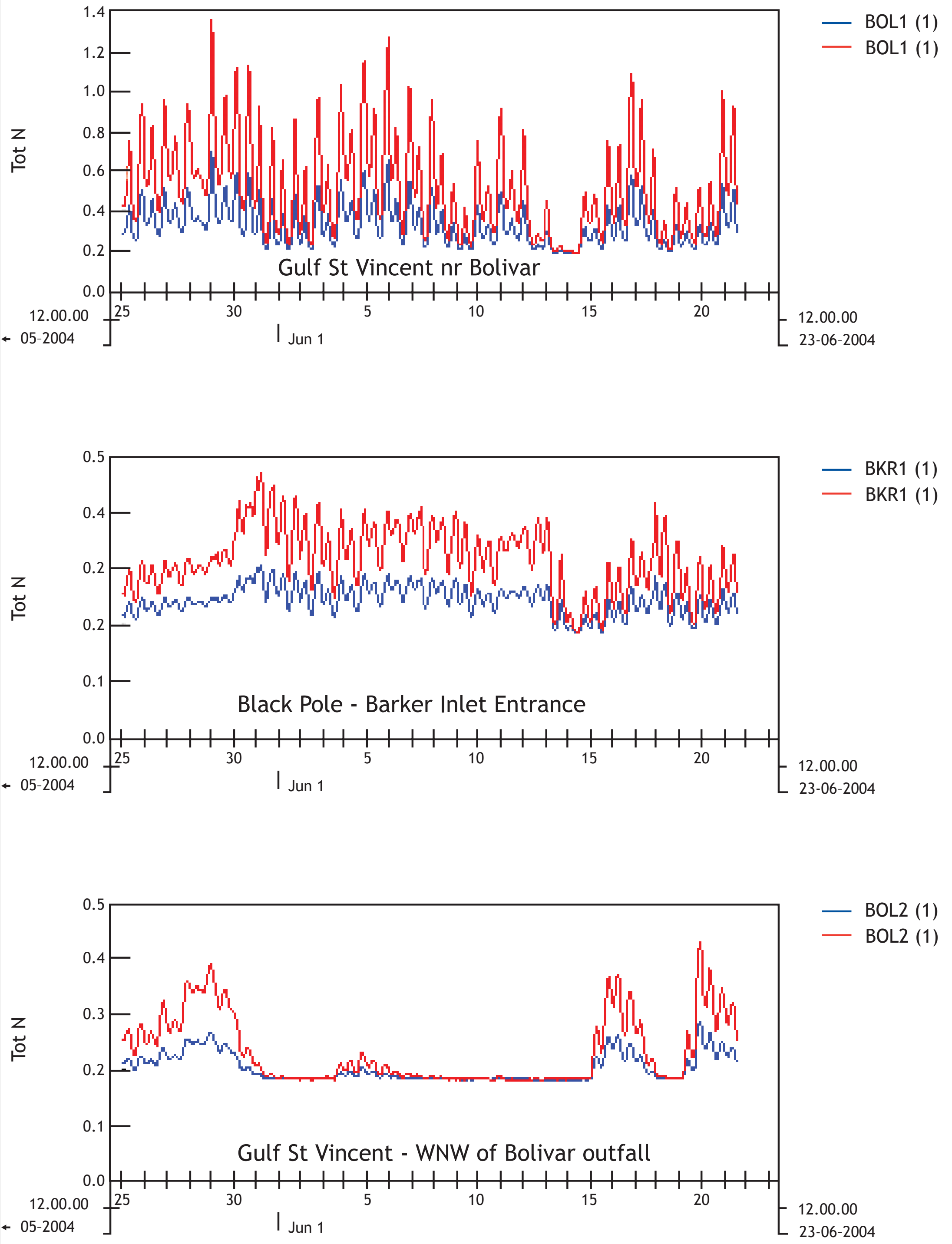
Total Phosphorus as P (mg/L) Comparison of 1998 & 2004 nutrient loads Port Adelaide WWTP loads moved to Bolivar for 2004 data	Red 1998	Blue 2004
	3D hydrodynamics	
Environment Protection Authority of South Australia	Winter	2004

Figure F5 **Differences in modelled total phosphorus at three sites in central Barker Inlet following reductions in nutrient discharges between 1998 and 2004**



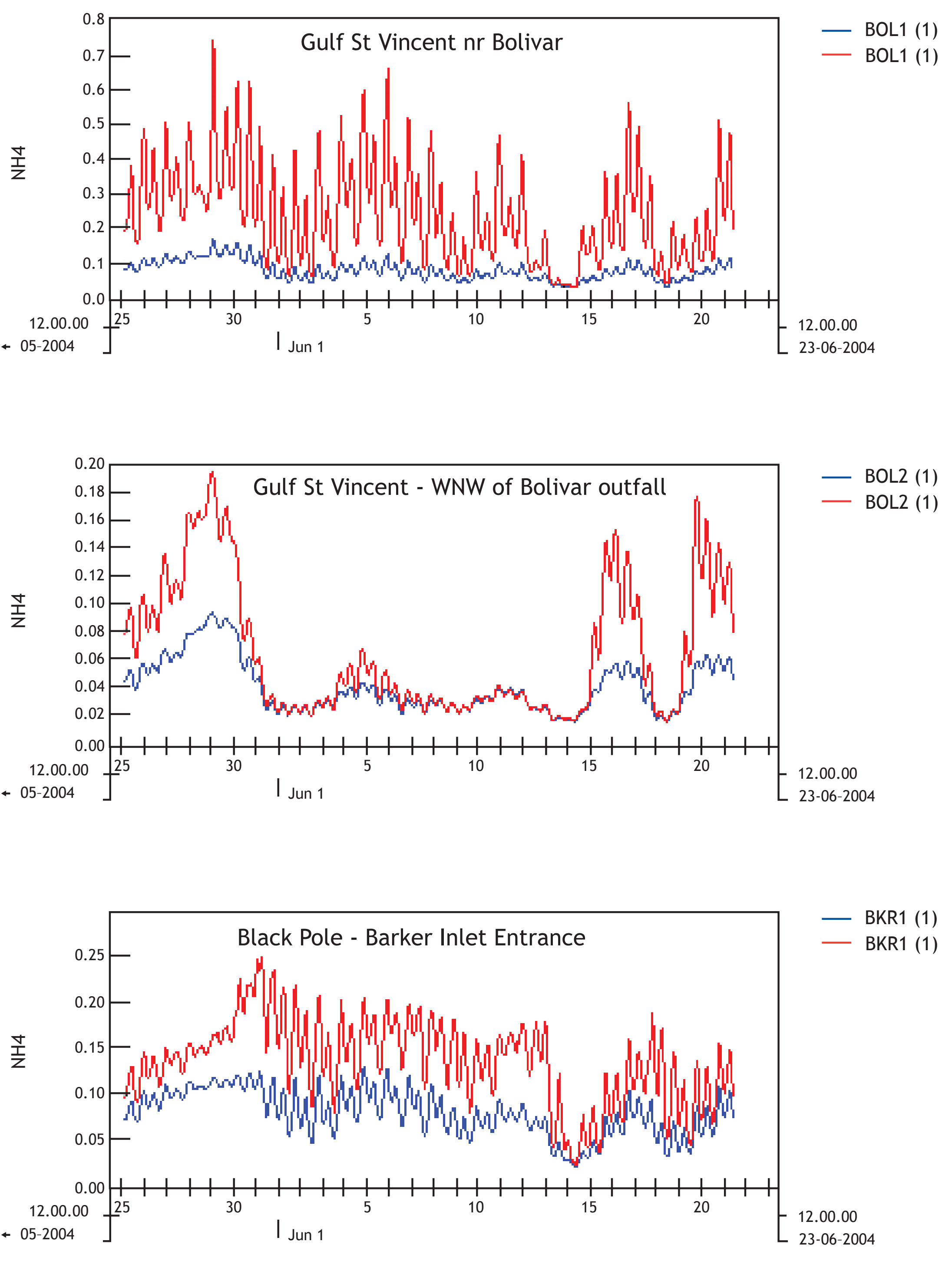
Total Phosphorus as P (mg/L) Comparison of 1998 & 2004 nutrient loads Port Adelaide WWTP loads moved to Bolivar for 2004 data	Red 1998	Blue 2004
	3D hydrodynamics	
Environment Protection Authority of South Australia	Winter	2004

Figure F6 **Differences in modelled total phosphorus at three sites in the region of northern Barker Inlet following reductions in nutrient discharges between 1998 and 2004**



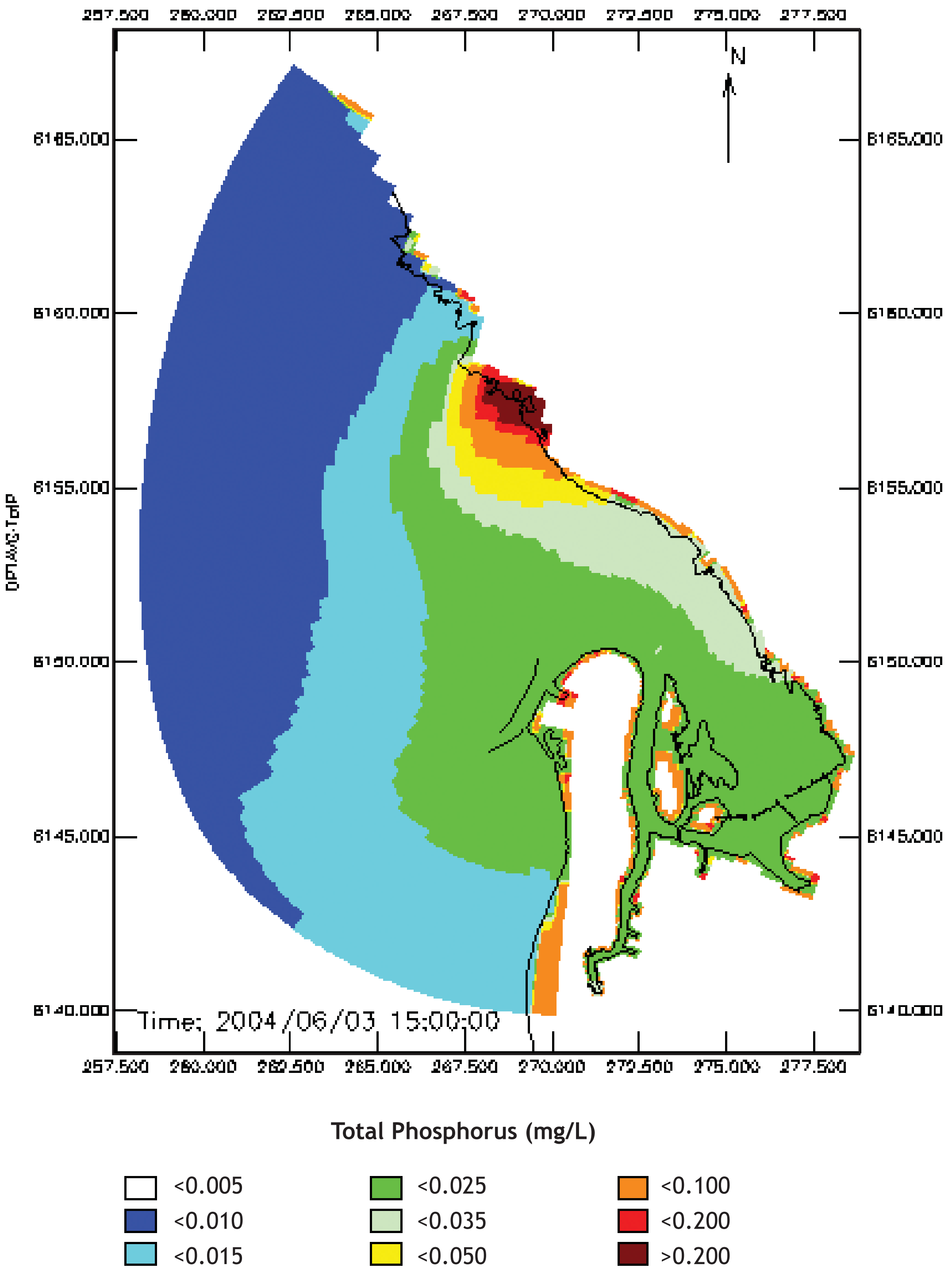
Total Nitrogen as N (mg/L) Comparison of 1998 & 2004 nutrient loads Port Adelaide WWTP loads moved to Bolivar for 2004 data	Red 1998	Blue 2004
	3D hydrodynamics	
Environment Protection Authority of South Australia	Winter	2004

Figure F7 **Differences in modelled total nitrogen at three sites in the region of northern Barker Inlet following reductions in nutrient discharges between 1998 and 2004**



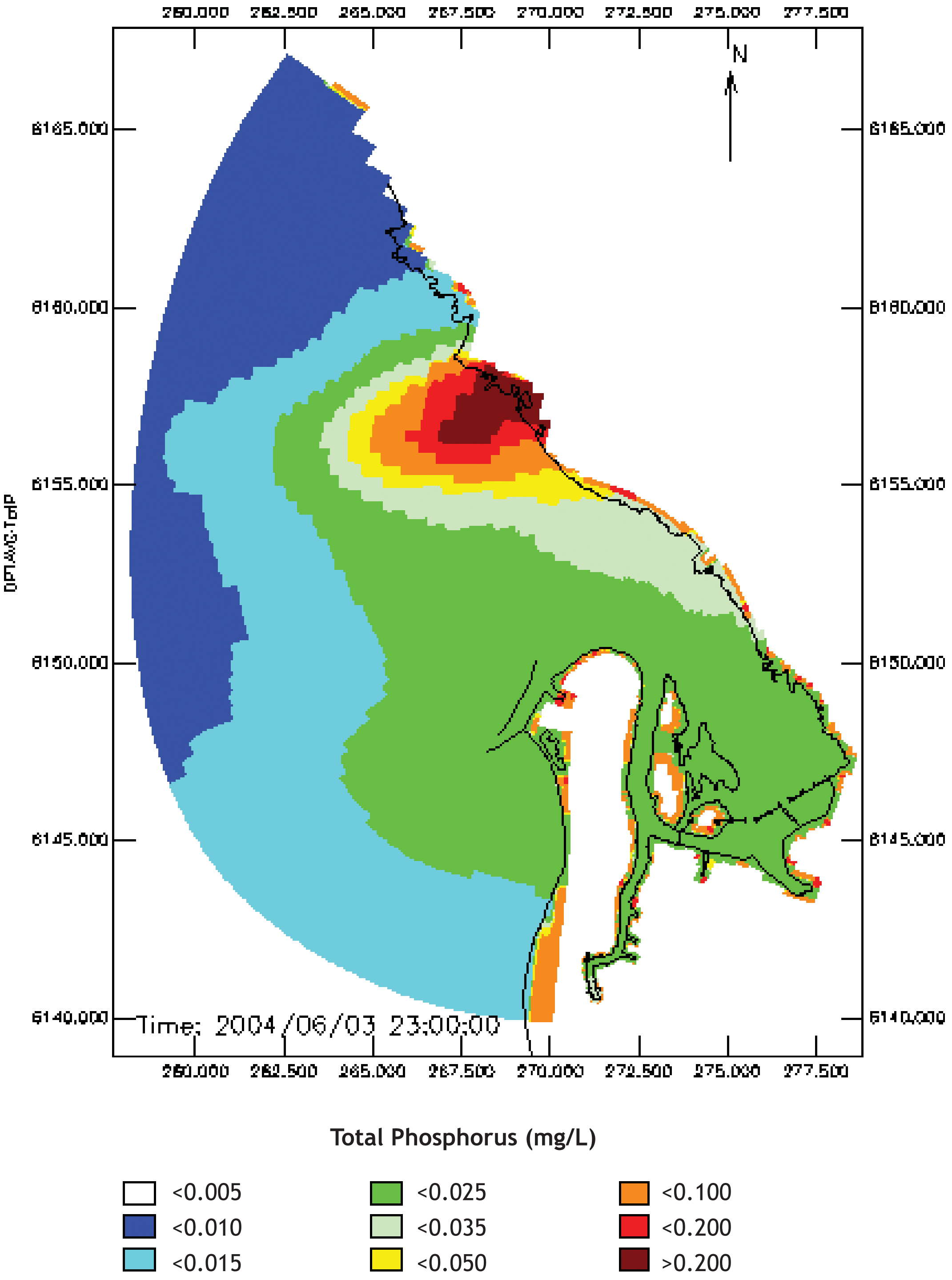
Ammonia as N (mg/L) Comparison of 1998 & 2004 nutrient loads Port Adelaide WWTP loads moved to Bolivar for 2004 data	Red 1998 3D hydrodynamics	Blue 2004
Environment Protection Authority of South Australia	Winter	2004

Figure F8 Differences in modelled total ammonium at three sites in the region of northern Barker Inlet following reductions in nutrient discharges between 1998 and 2004



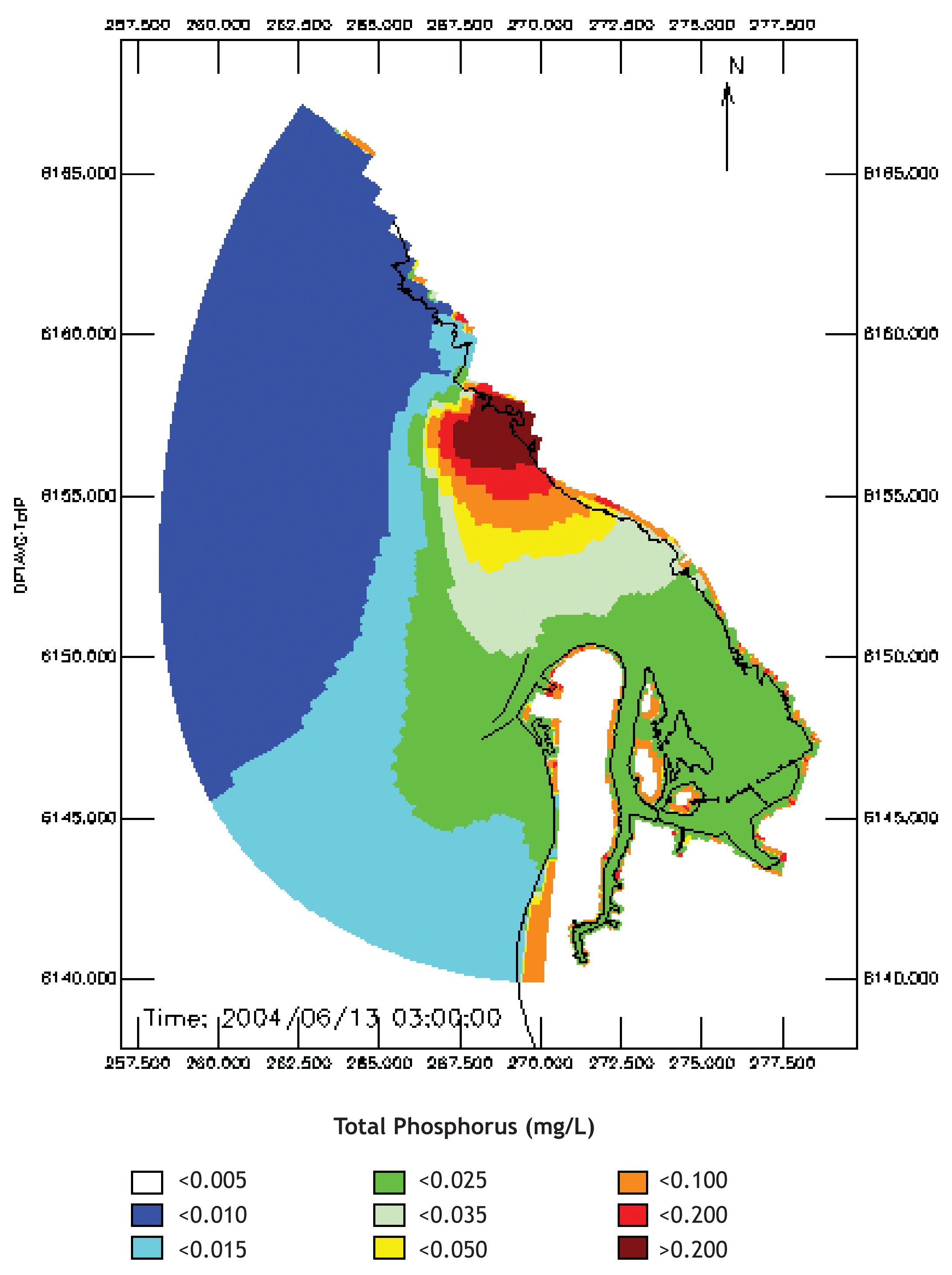
Total Phosphorus (depth averaged) (mg/L) Port Adel to Bolivar, normal 2004 discharges (both WWTP's) Scenario - Penrice 820 tonnes Nitrogen	Winter 2004 3D	run40b
	Spring High tide	
Environment Protection Authority of South Australia	11 May 2005	P Christy

Figure F9 Distribution of total phosphorus in the Port waterways during a spring high tide—normal 2004 discharges of nutrients from the Penrice facility and the Bolivar WWTP



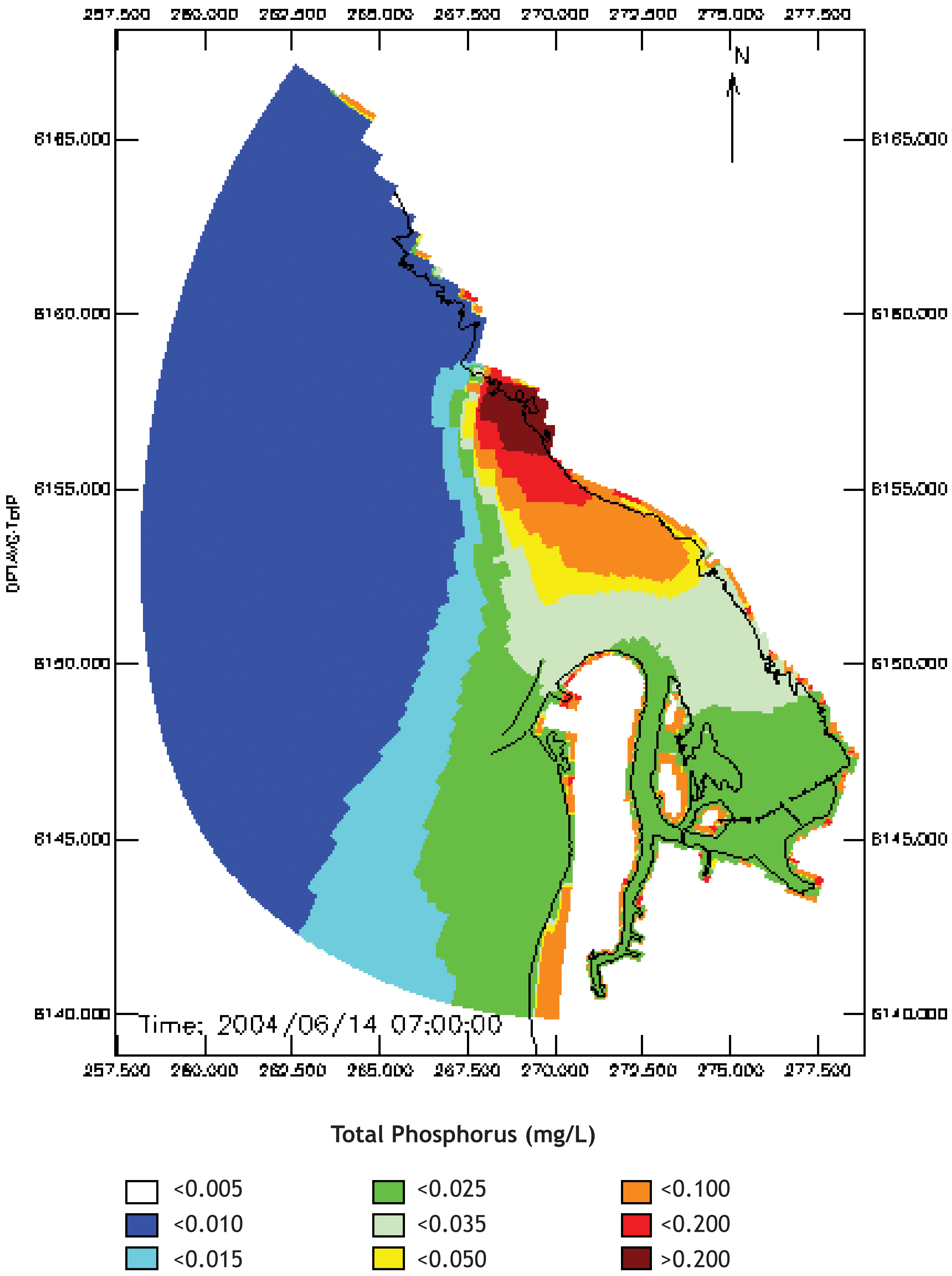
Total Phosphorus (depth averaged) (mg/L) Port Adel to Bolivar, normal 2004 discharges (both WWTP's) Scenario - Penrice 820 tonnes Nitrogen	Winter 2004 3D	run40b
	Spring Low tide	
Environment Protection Authority of South Australia	11 May 2005	P Christy

Figure F10 **Distribution of total phosphorus in the Port waterways during a spring low tide—normal 2004 discharges of nutrients from the Penrice facility and the Bolivar WWTP**



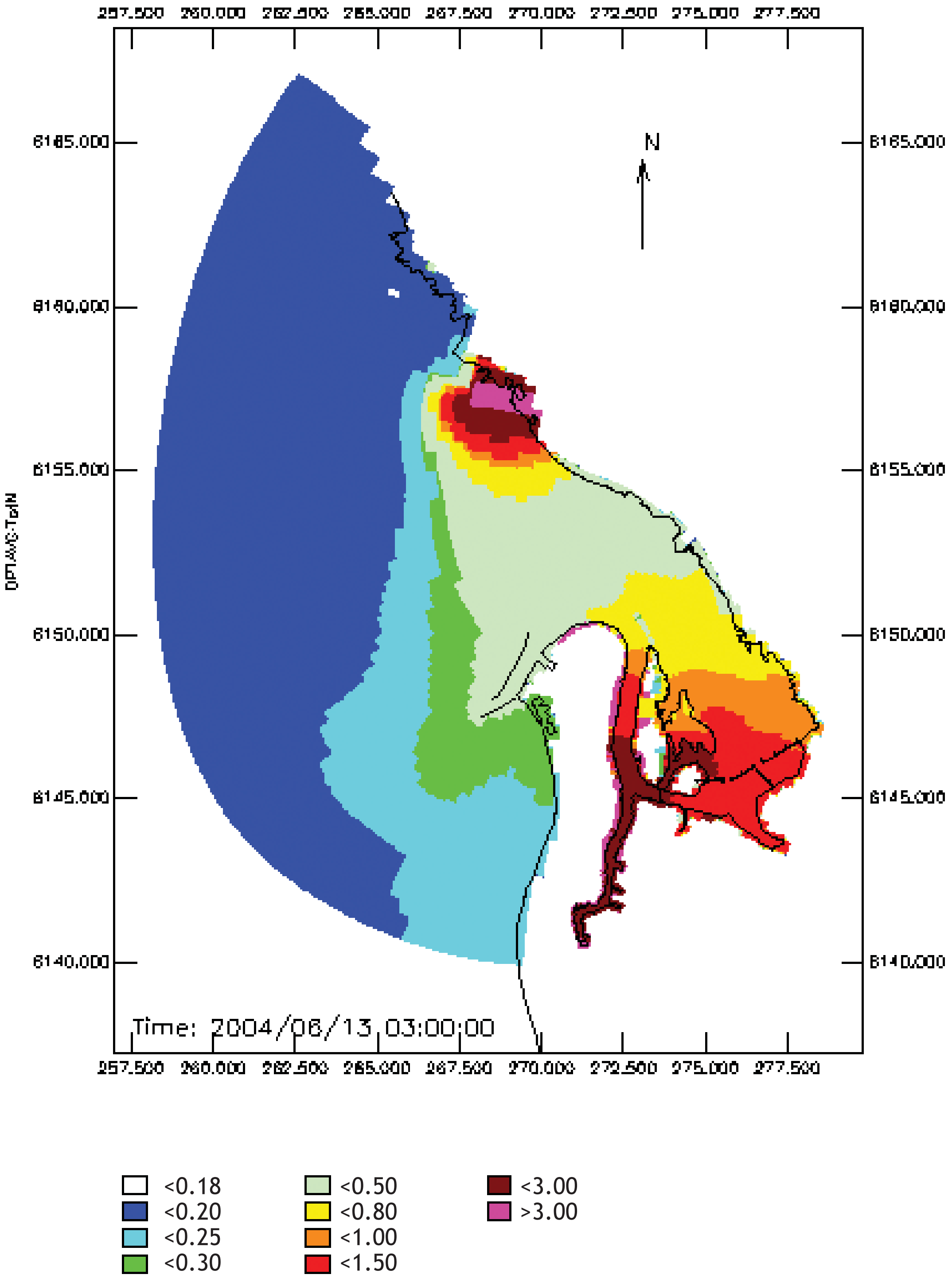
Total Phosphorus (depth averaged) (mg/L) Port Adel to Bolivar, normal 2004 discharges (both WWTP's) Scenario - Penrice 820 tonnes Nitrogen	Winter 2004 3D	run40b
	Neap ebbing tide	
Environment Protection Authority of South Australia	11 May 2005	P Christy

Figure F11 Distribution of total phosphorus in the Port waterways during a neap ebbing tide— normal 2004 discharges of nutrients from the Penrice facility and the Bolivar WWTP



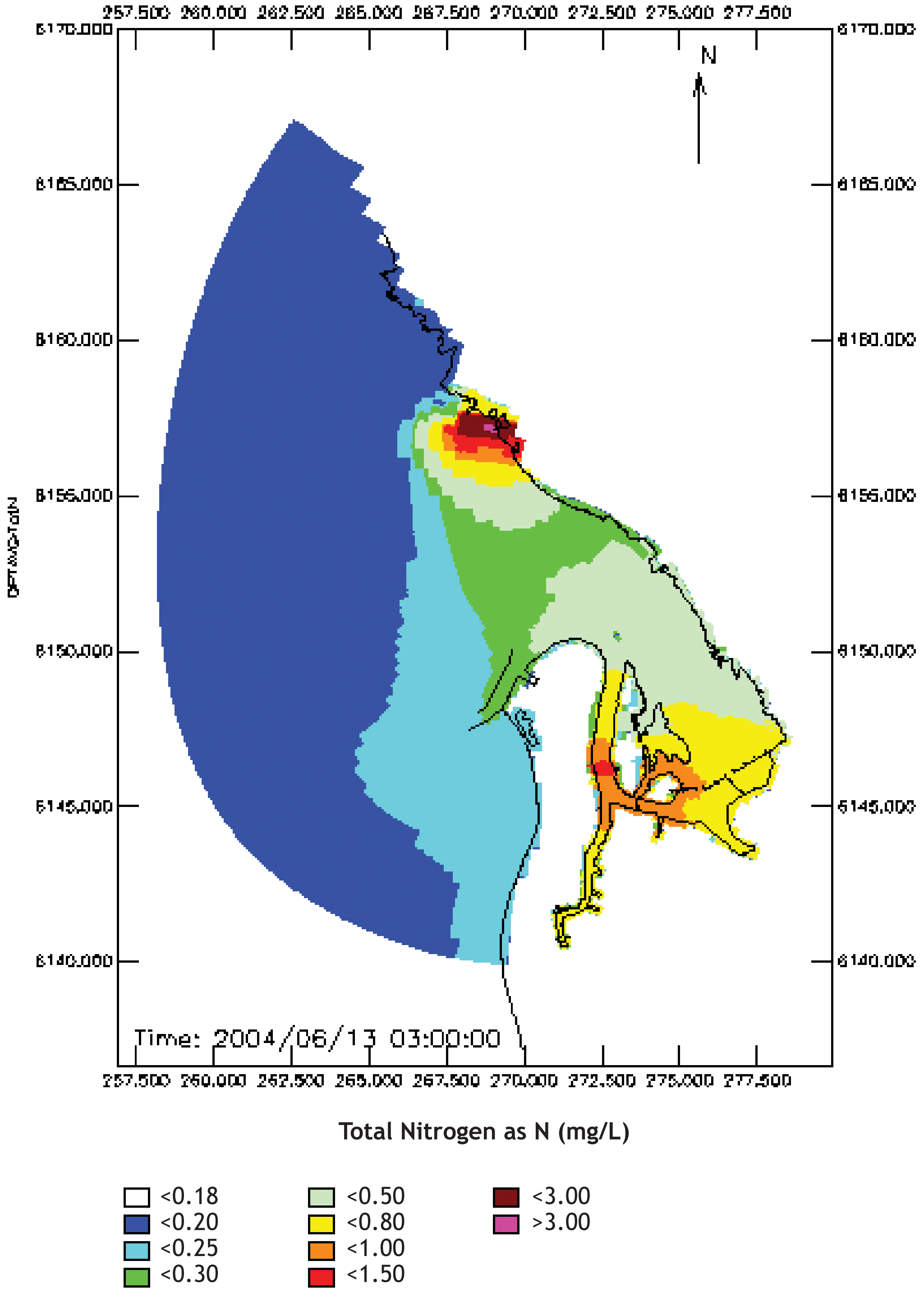
Total Phosphorus (depth averaged) (mg/L) Port Adel to Bolivar, normal 2004 discharges (both WWTP's) Scenario - Penrice 820 tonnes Nitrogen	Winter 2004 3D	run40b
	Nth wind driven current	
Environment Protection Authority of South Australia	11 May 2005	P Christy

Figure F12 Distribution of total phosphorus in the Port waterways influenced by a north wind—normal 2004 discharges of nutrients from the Penrice facility and the Bolivar WWTP



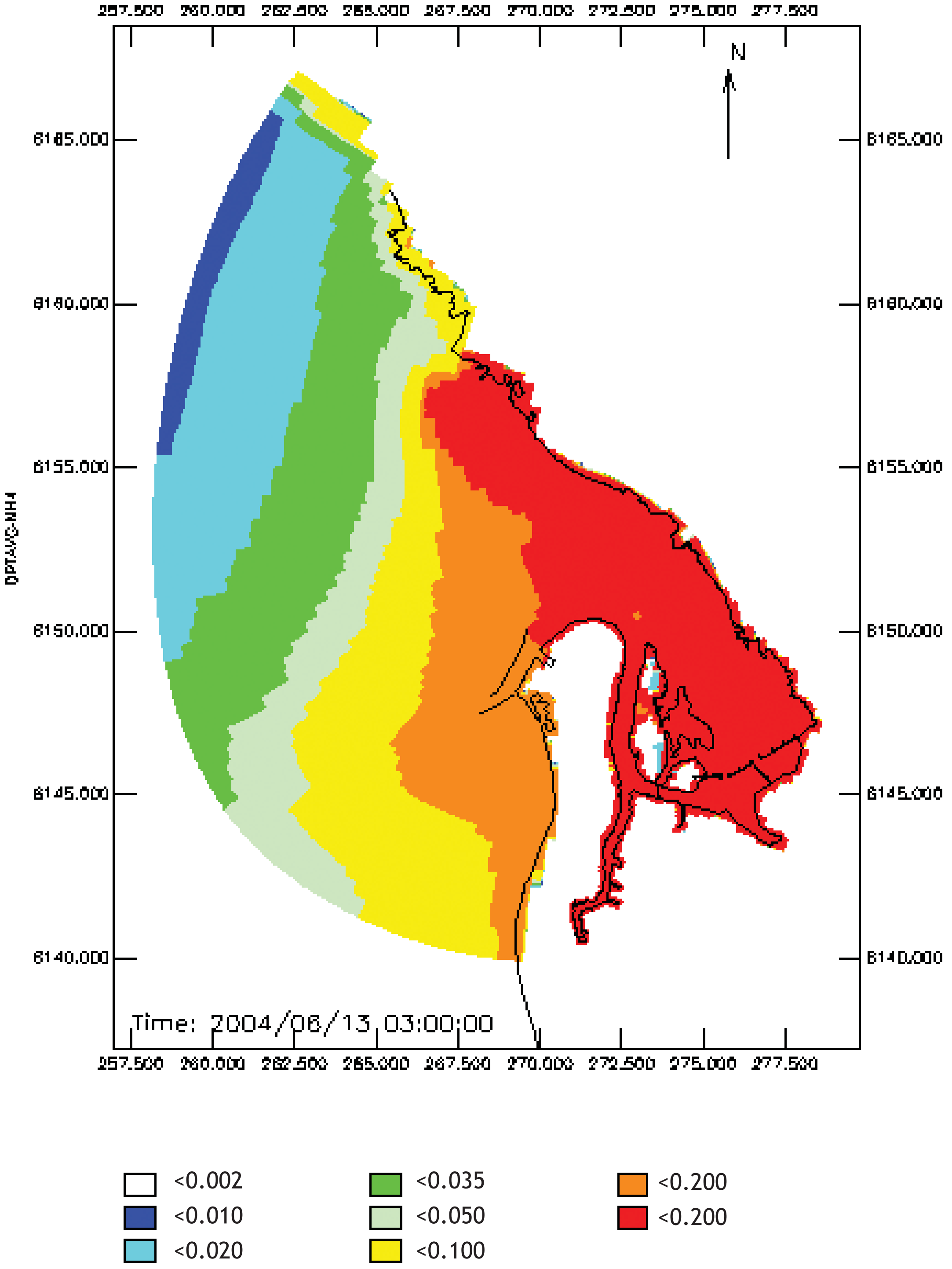
Total Nitrogen - Depth averaged values (mg/L) Bolivar & Pt Adelaide - 1998 discharges (both plants) Penrice 1000 tonnes N	Winter 2004 3D	run40b
	Neap ebbing tide	
Environment Protection Authority of South Australia	11 May 2005	P Christy

Figure F13 Distribution of total nitrogen in the Port waterways during a neap ebbing tide—based on 1998 discharges of nutrients from the Penrice facility, and the Bolivar and Port Adelaide WWTPS



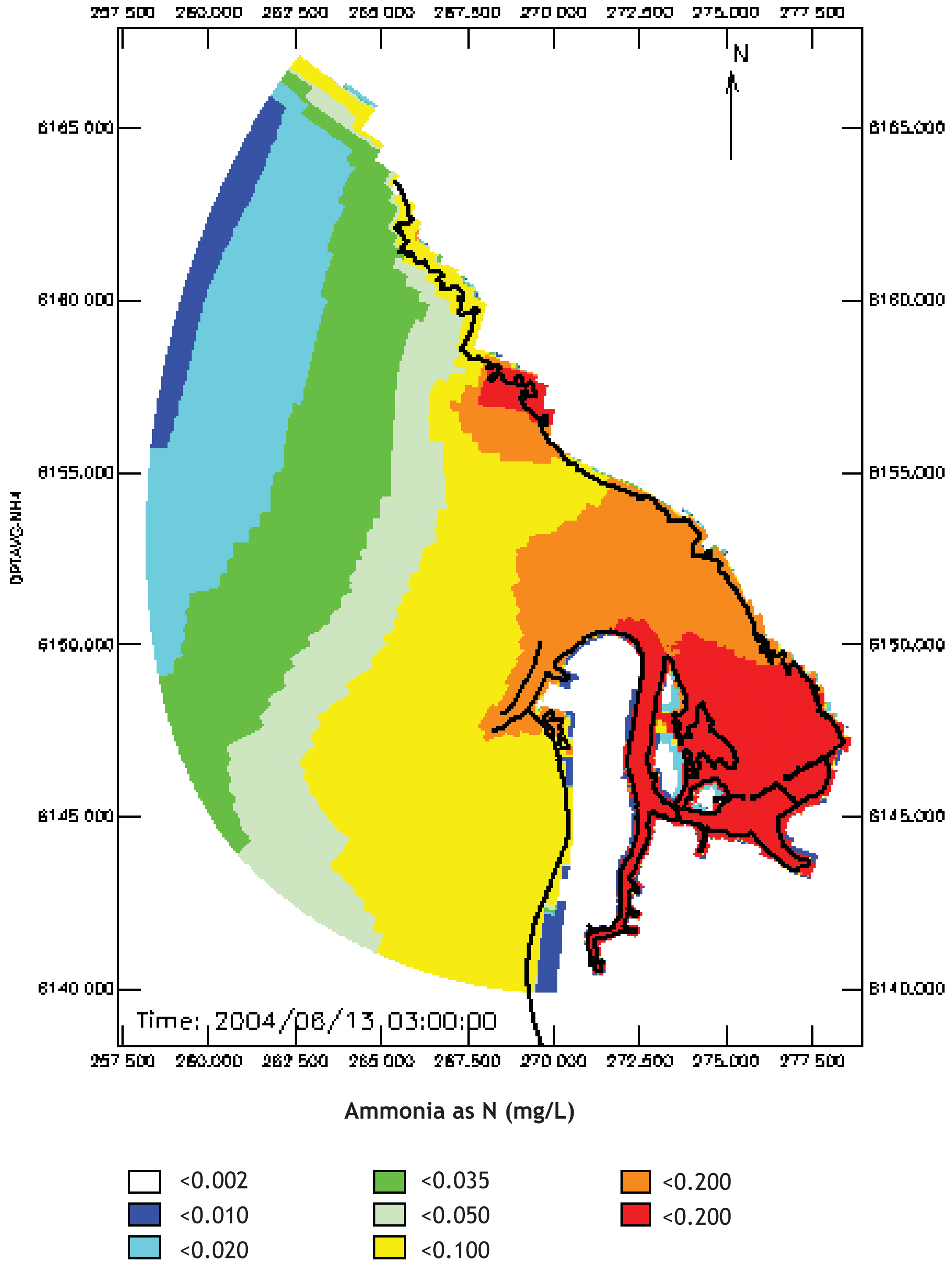
Total Nitrogen - Depth averaged values (mg/L) Pt Adelaide to Bolivar - normal 2004 discharges (both plants) Scenario - Penrice 820 tonnes Nitrogen	Winter 2004 3D	run40b
	Neap ebbing tide	
Environment Protection Authority of South Australia	11 May 2005	P Christy

Figure F14 Distribution of total nitrogen in the Port waterways during a neap ebbing tide—normal 2004 discharges of nutrients from the Penrice facility and the Bolivar WWTP



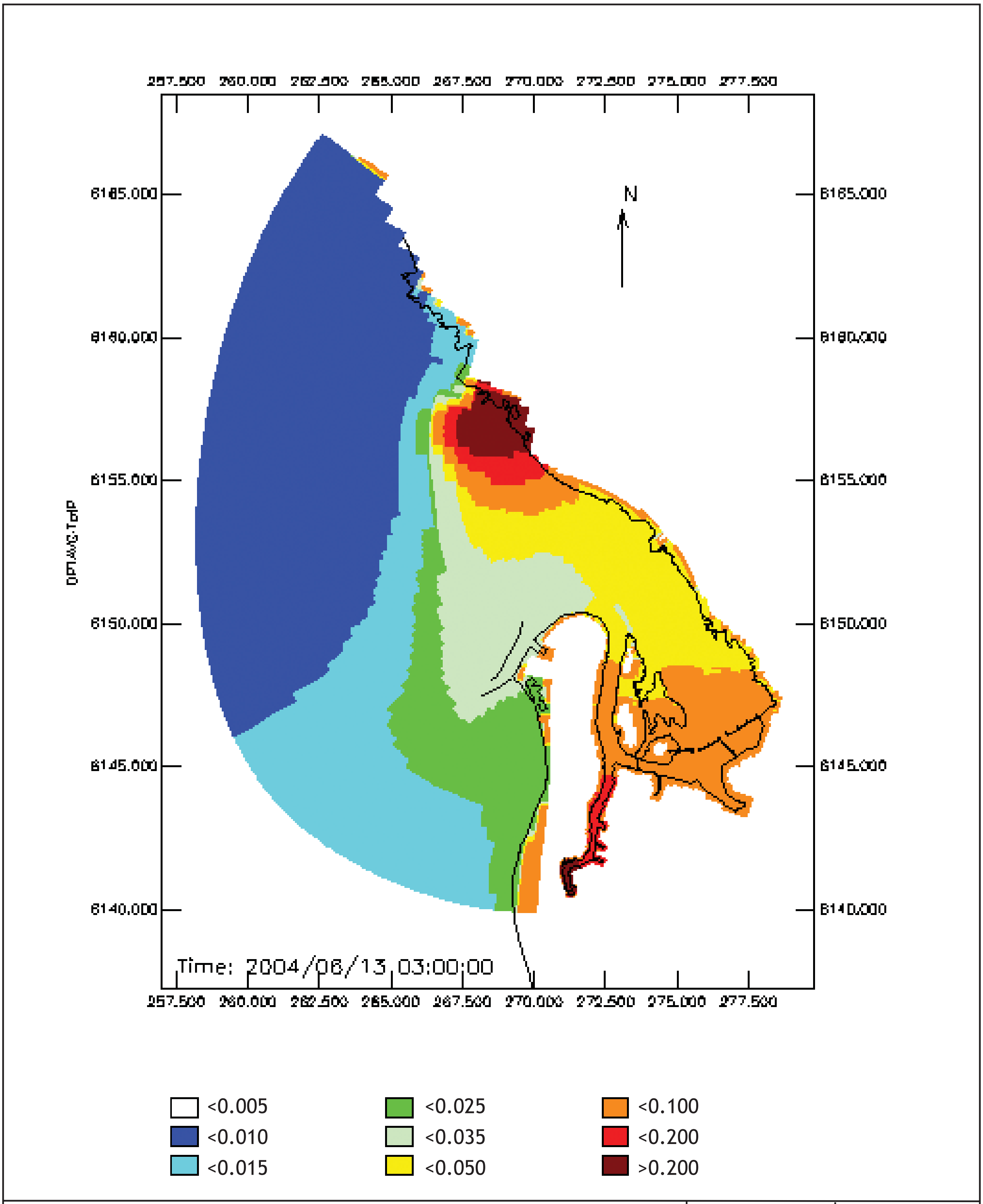
Ammonia Depth averaged values (mg/L) Bolivar & Pt Adel - 1998 discharges (both plants) Penrice 1000 tonnes N	Winter 2004 3D	run18c
	Neap ebbing tide	
Environment Protection Authority of South Australia	11 May 2005	P Christy

Figure F15 **Distribution of total ammonium in the Port waterways during a neap ebbing tide—based on 1998 discharges of nutrients from the Penrice facility, and the Bolivar and Port Adelaide WWTPS**



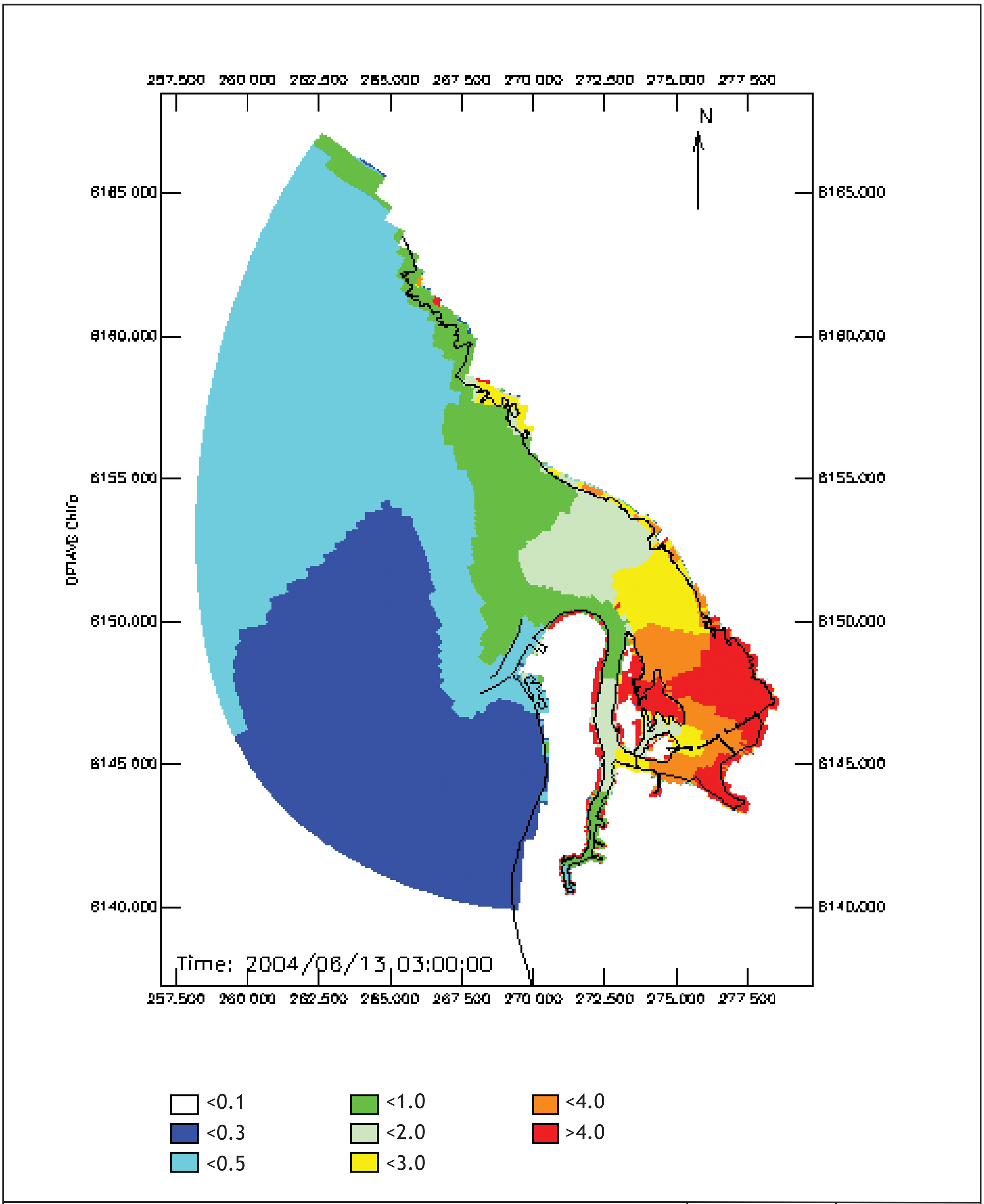
Ammonia Depth averaged values (mg/L) Pt Adel to Bolivar - 2004 discharges normal (both WWTP's) Scenario - Penrice 820 tonnes Nitrogen	Winter 2004 3D	run40b
	Neap ebbing tide	
Environment Protection Authority of South Australia	11 May 2005	P Christy

Figure F16 Distribution of total ammonium in the Port waterways during a neap ebbing tide—normal 2004 discharges of nutrients from the Penrice facility and the Bolivar WWTP



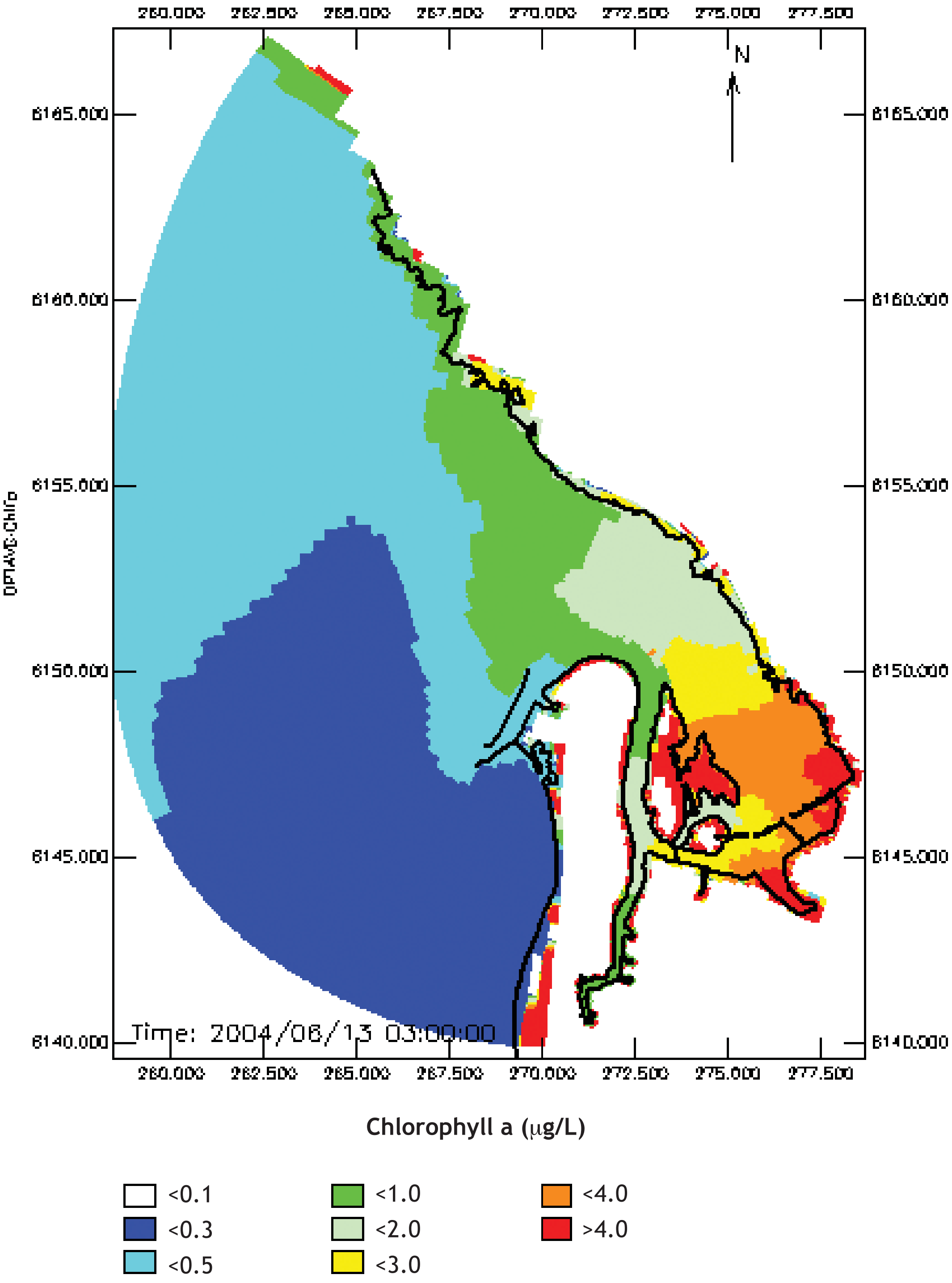
Total Phosphorus (depth averaged) (mg/L) 1998 Bolivar & Pt Adelaide discharges (both WWTP's) Penrice 1000 tonnes Nitrogen	Winter 2004 3D	run18c
	Neap ebbing tide	
Environment Protection Authority of South Australia	10 May 2005	P Christy

Figure F17 Distribution of total phosphorus in the Port waterways during a neap ebbing tide— based on 1998 discharges of nutrients from the Penrice facility, and the Bolivar and Port Adelaide WWTPs



Chlorophyll a - Depth averaged values (µg/L) 1998 Bolivar & Pt Adelaide discharges (both WWTP's) Penrice 1000 tonnes Nitrogen	Winter 2004 3D	run18c
	Neap ebbing tide	
Environment Protection Authority of South Australia	10 May 2005	P Christy

Figure F18 **Distribution of chlorophyll a in the Port waterways during a neap ebbing tide—based on 1998 discharges of nutrients from the Penrice facility, and the Bolivar and Port Adelaide WWTPs**



Chlorophyll a - Depth averaged values (µg/L) Pt Adel to Bolivar, 2004 discharges (both plants) Scenario - Penrice 820 tonnes N	Winter 2004 3D	run18c
	Neap ebbing tide	
Environment Protection Authority of South Australia	10 May 2005	P Christy

Figure F19 Distribution of chlorophyll a in the Port waterways during a neap ebbing tide—normal 2004 discharges of nutrients from the Penrice facility and the Bolivar WWTP

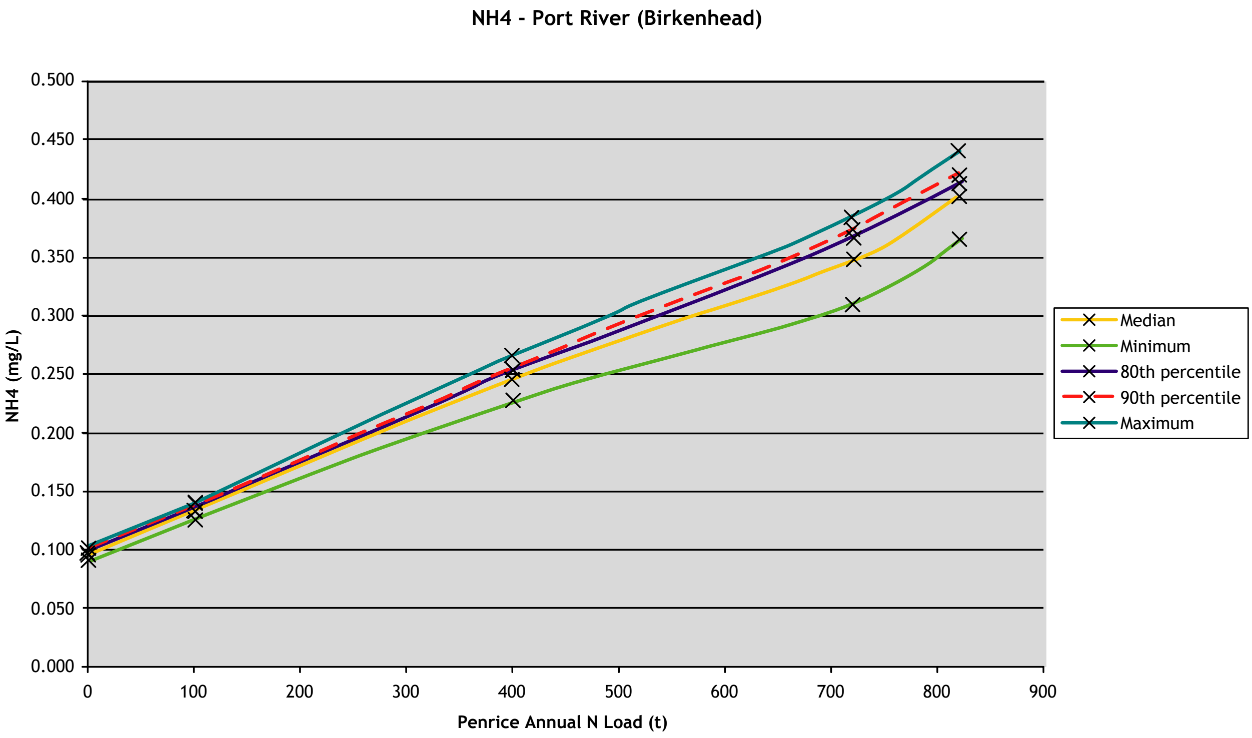


Figure F20 Response of total ammonia levels in the Port River at Birkenhead to progressive reductions in ammonia loads from the Penrice facility

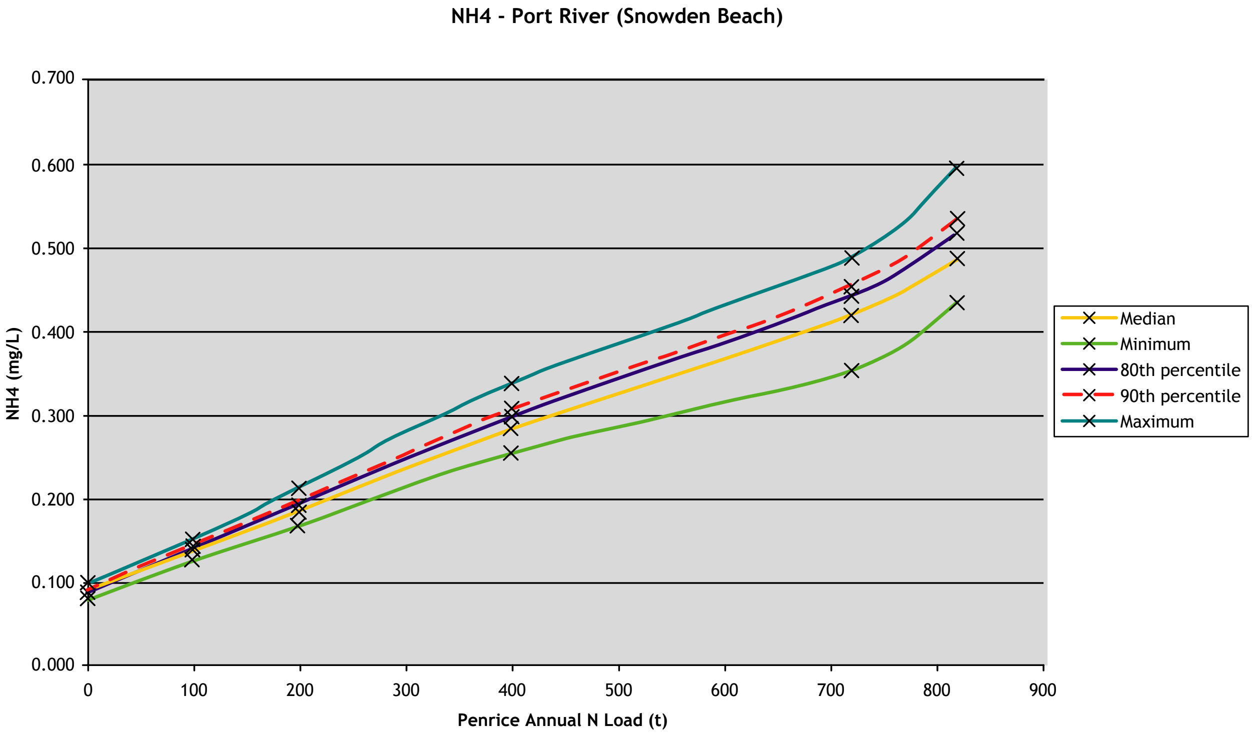


Figure F21 Response of total ammonia levels in the Port River at Snowden Beach to progressive reductions in ammonia loads from the Penrice facility

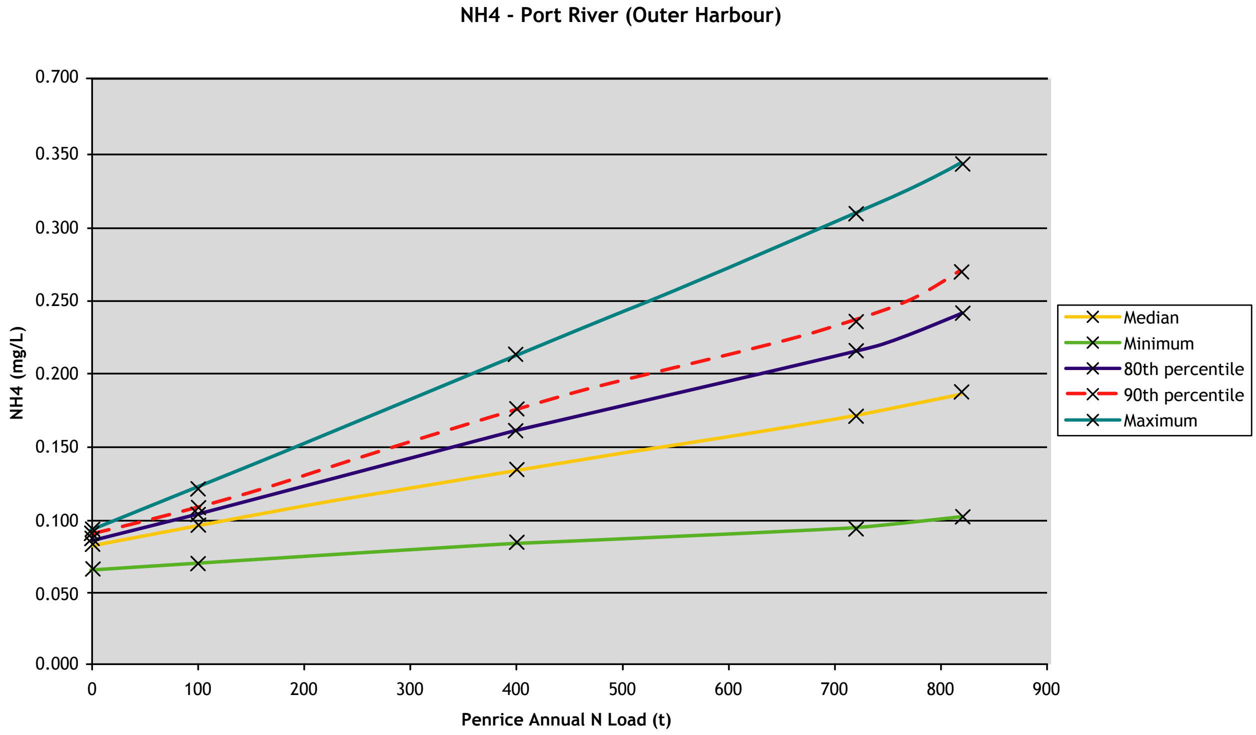


Figure F22 Response of total ammonia levels in the Port River at Outer Harbour to progressive reductions in ammonia loads from the Penrice facility

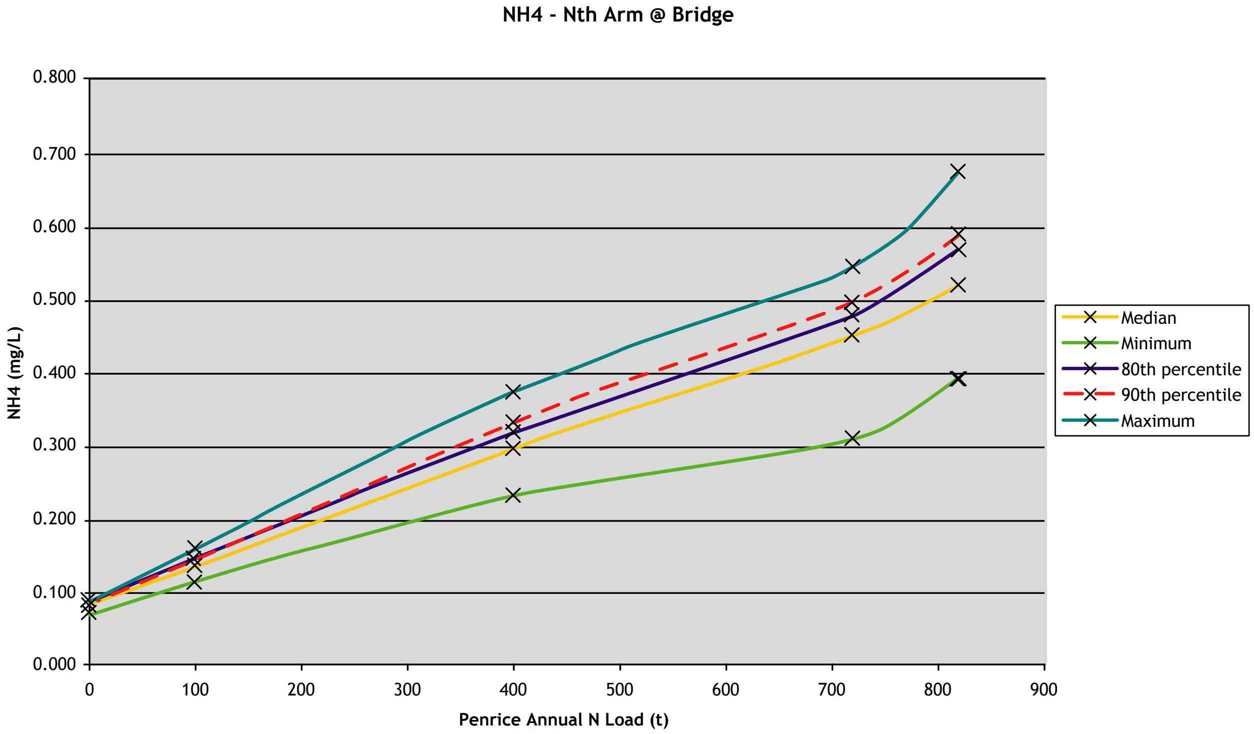


Figure F23 Response of total ammonia levels in the Port River at the North Arm bridge to progressive reductions in ammonia loads from the Penrice facility

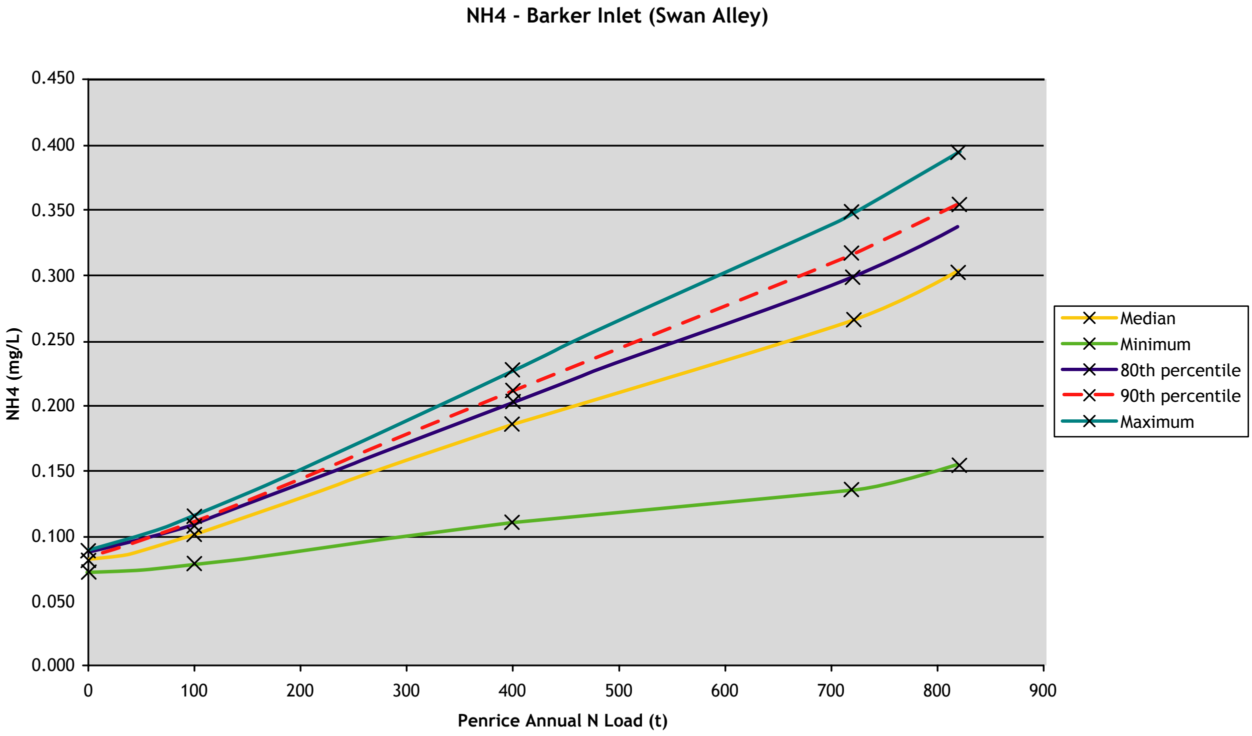
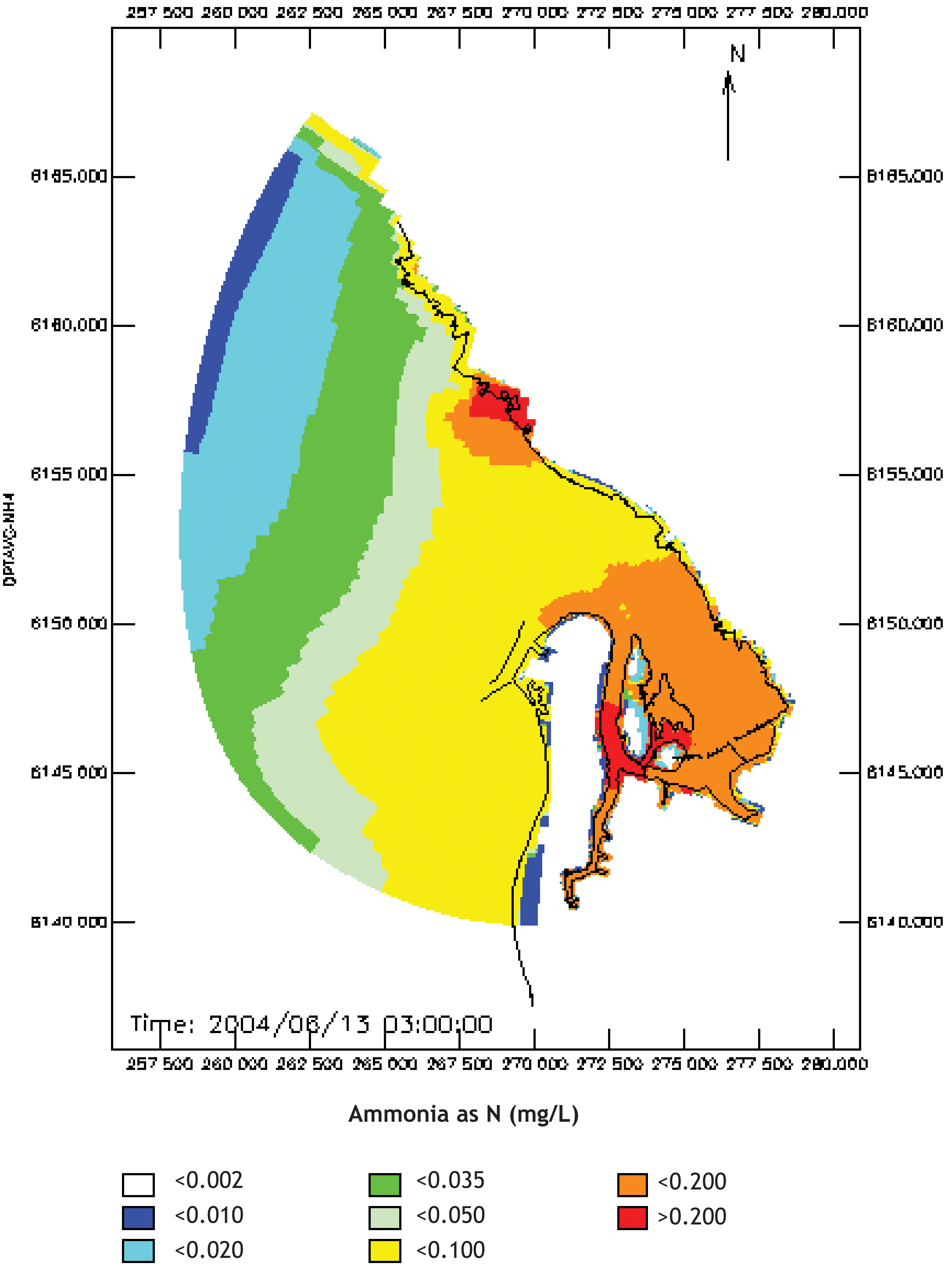
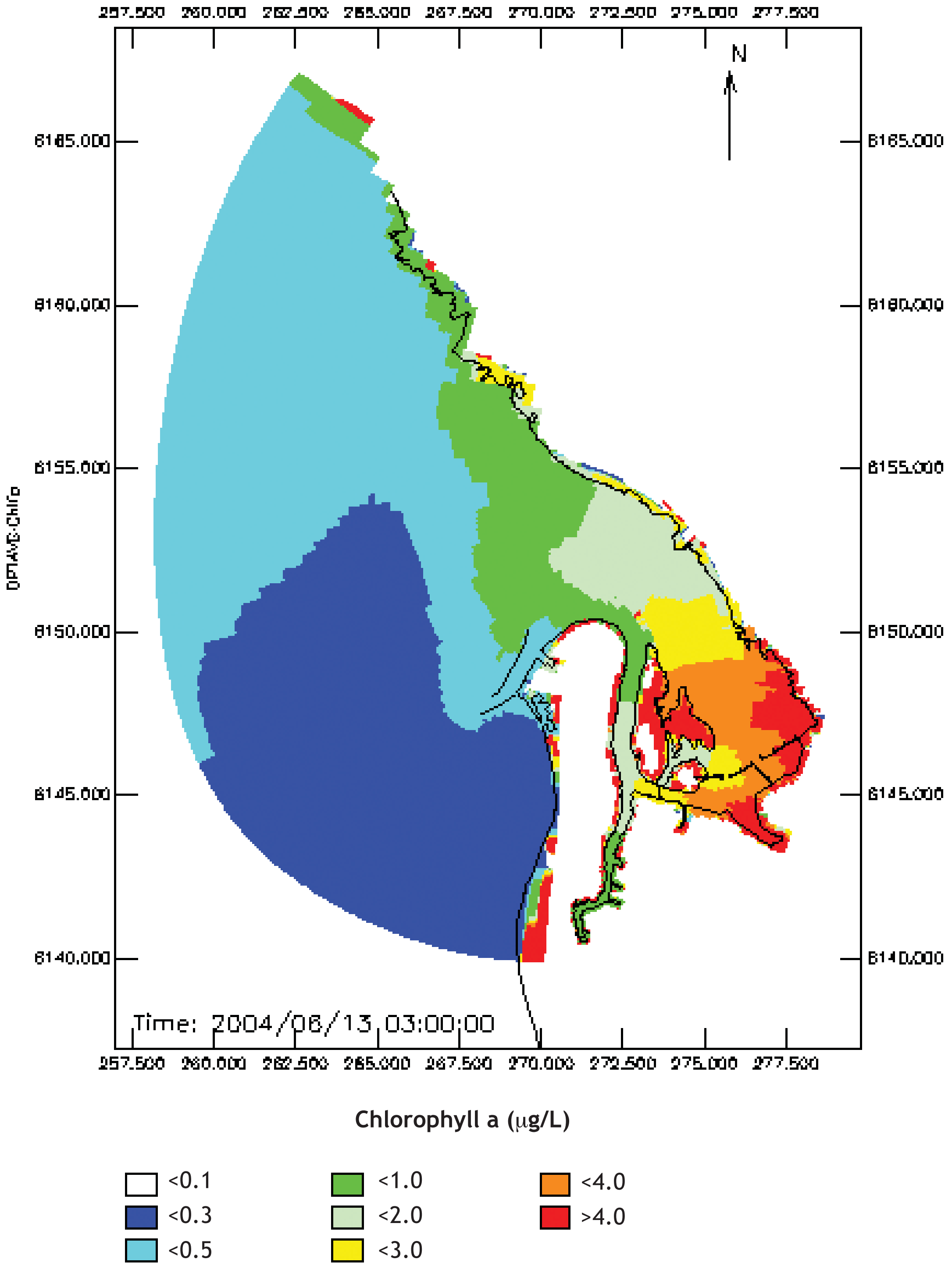


Figure F24 Response of total ammonia levels in Barker Inlet at Swan Alley creek to progressive reductions in ammonia loads from the Penrice facility



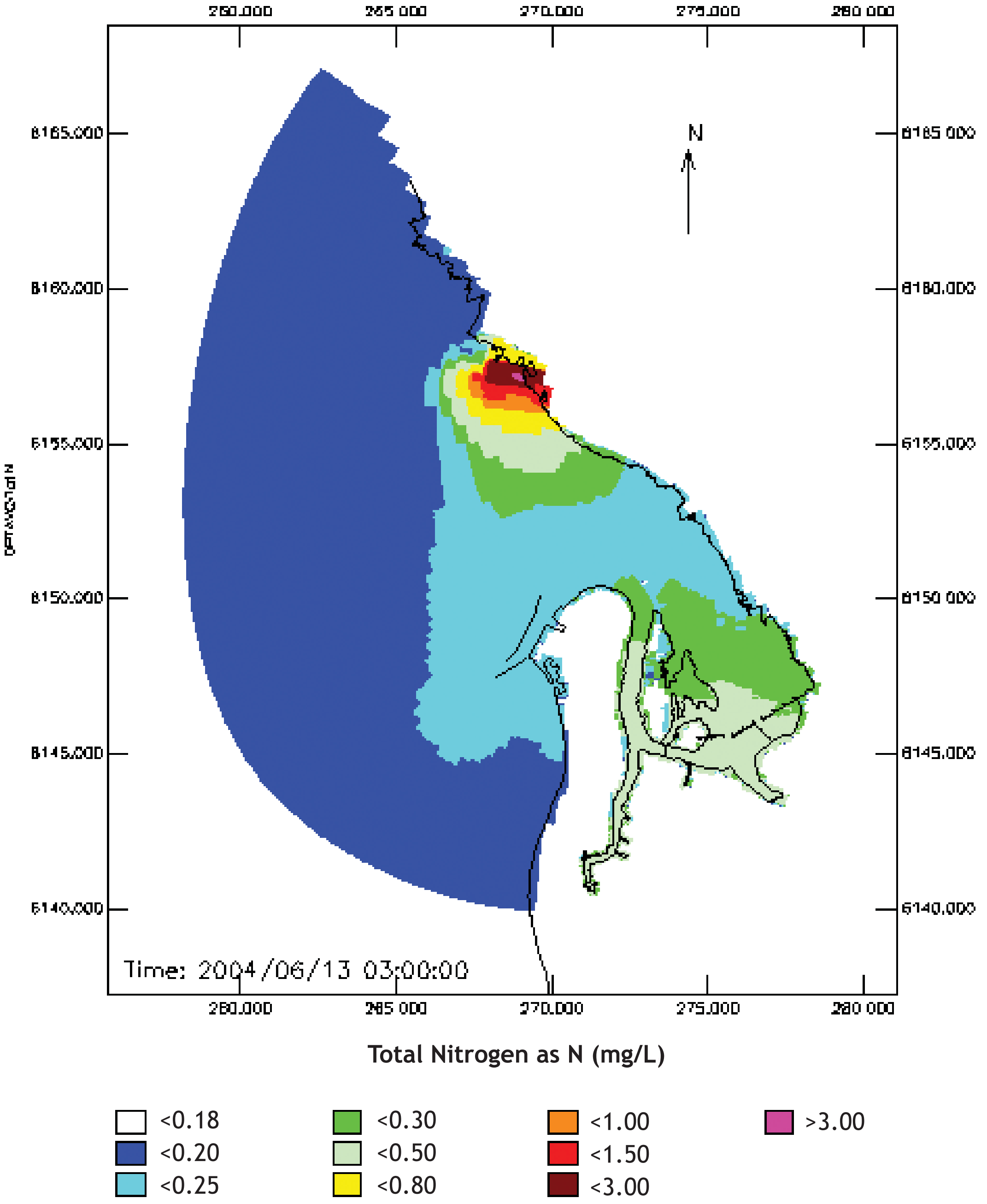
Ammonia - Depth averaged values (mg/L) Bolivar & Pt Adel - 2004 discharges normal (both WWTP's) Scenario - Penrice 200 tonnes N	Winter 2004 3D	run22f
	Neap ebbing tide	
Environment Protection Authority of South Australia	10 May 2005	P Christy

Figure F25 Distribution of total ammonium in the Port waterways during a neap ebbing tide—normal 2004 discharges of nutrients from the Bolivar WWTP and nitrogen discharges from the Penrice facility reduced to 200 tonnes per annum



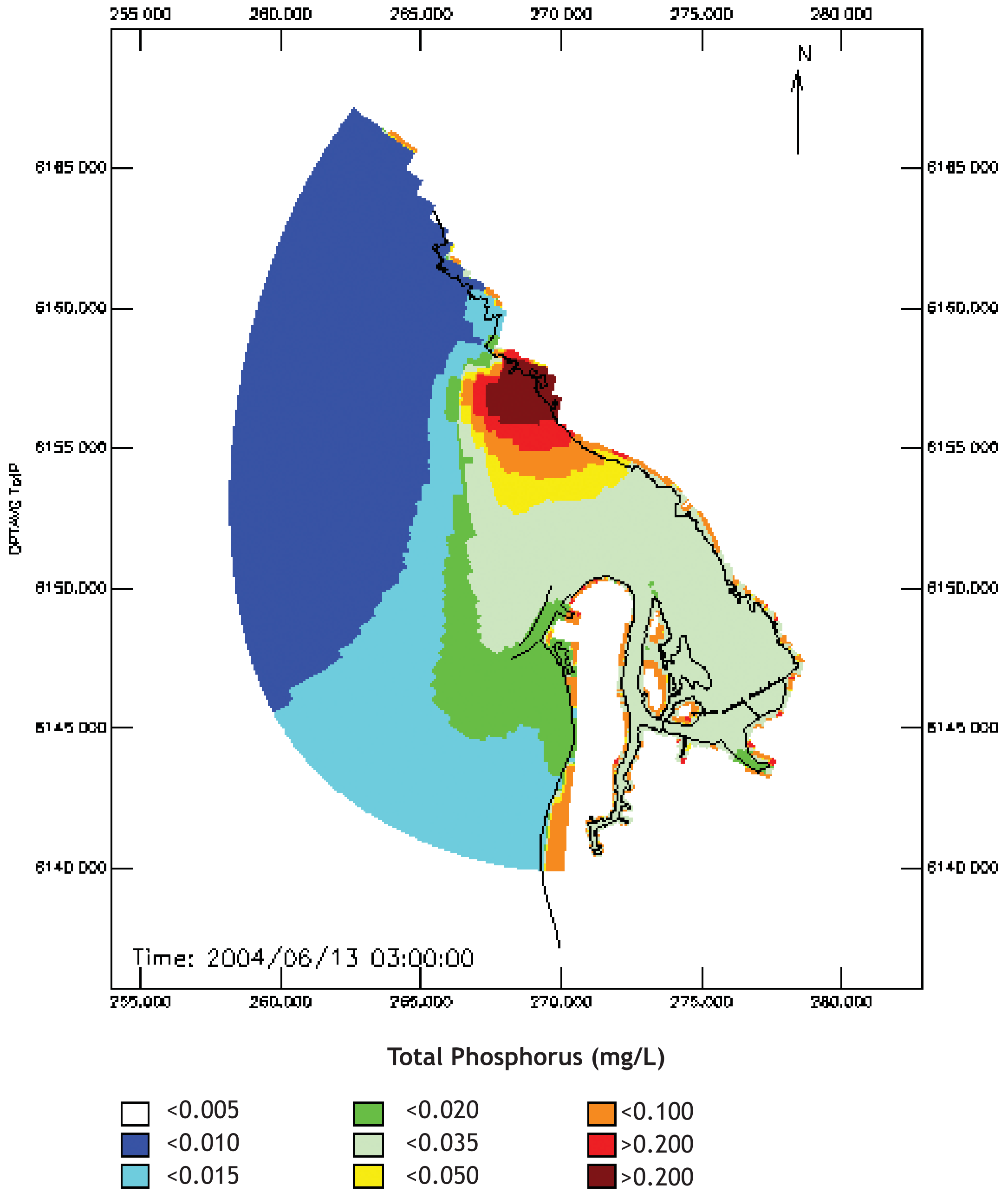
Chlorophyll a - Depth averaged values (µg/L) Bolivar - discharges normal (both plants) Penrice 200 tonnes N	Winter 2004 3D	run22e
	Neap ebbing tide	
Environment Protection Authority of South Australia	9 May 2005	P Christy

Figure F26 Distribution of chlorophyll *a* in the Port waterways during a neap ebbing tide—normal 2004 discharges of nutrients from the Bolivar WWTP and nitrogen discharges from the Penrice facility reduced to 200 tonnes per annum



Total Nitrogen - Depth averaged values (mg/L) Pt Adel to Bolivar - normal 2004 discharges (both WWTP's) Scenario - Penrice 200 tonnes Nitrogen	Winter 2004 3D	run22f
	Spring Low tide	
Environment Protection Authority of South Australia	10 May 2005	P Christy

Figure F27 Distribution of total nitrogen in the Port waterways during a neap ebbing tide—normal 2004 discharges of nutrients from the Bolivar WWTP and nitrogen discharges from the Penrice facility reduced to 200 tonnes per annum



Total Phosphorus (depth averaged) (mg/L) Bolivar to Pt Adel - normal 2004 discharges (both WWTP's) Penrice 200 tonnes Nitrogen	Winter 2004 3D	run22f
	Neap ebbing tide	
Environment Protection Authority of South Australia	10 May 2005	P Christy

Figure F28 **Distribution of total phosphorus in the Port waterways during a neap ebbing tide—normal 2004 discharges of nutrients from the Bolivar WWTP and nitrogen discharges from the Penrice facility reduced to 200 tonnes per annum**

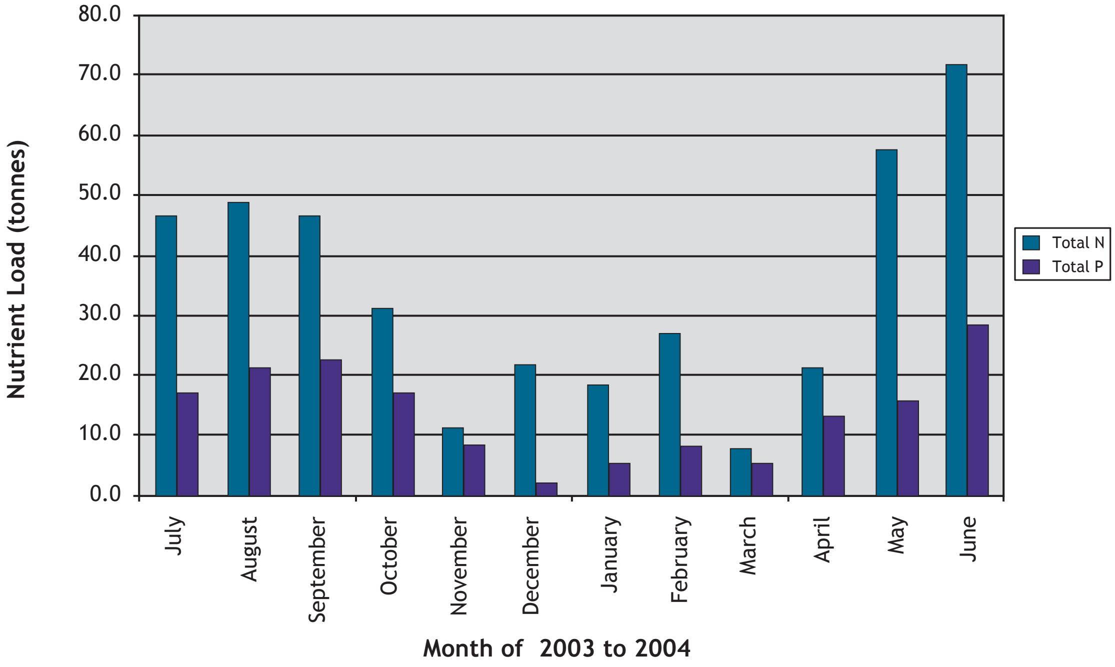


Figure F29 Annual pattern of nutrient load discharge from Bolivar low-salinity WWTP

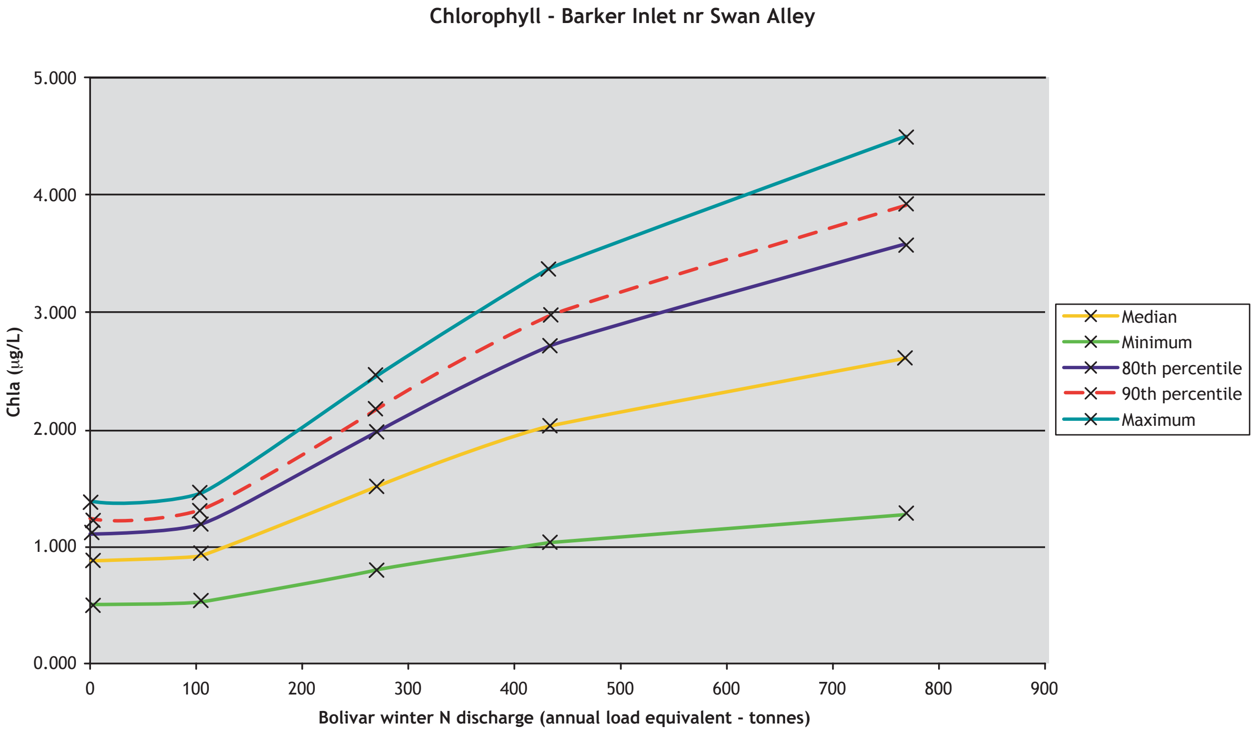


Figure F30 Response of chlorophyll *a* levels in Barker Inlet at Swan Alley creek to progressive reductions in nutrient loads from the Bolivar WWTP

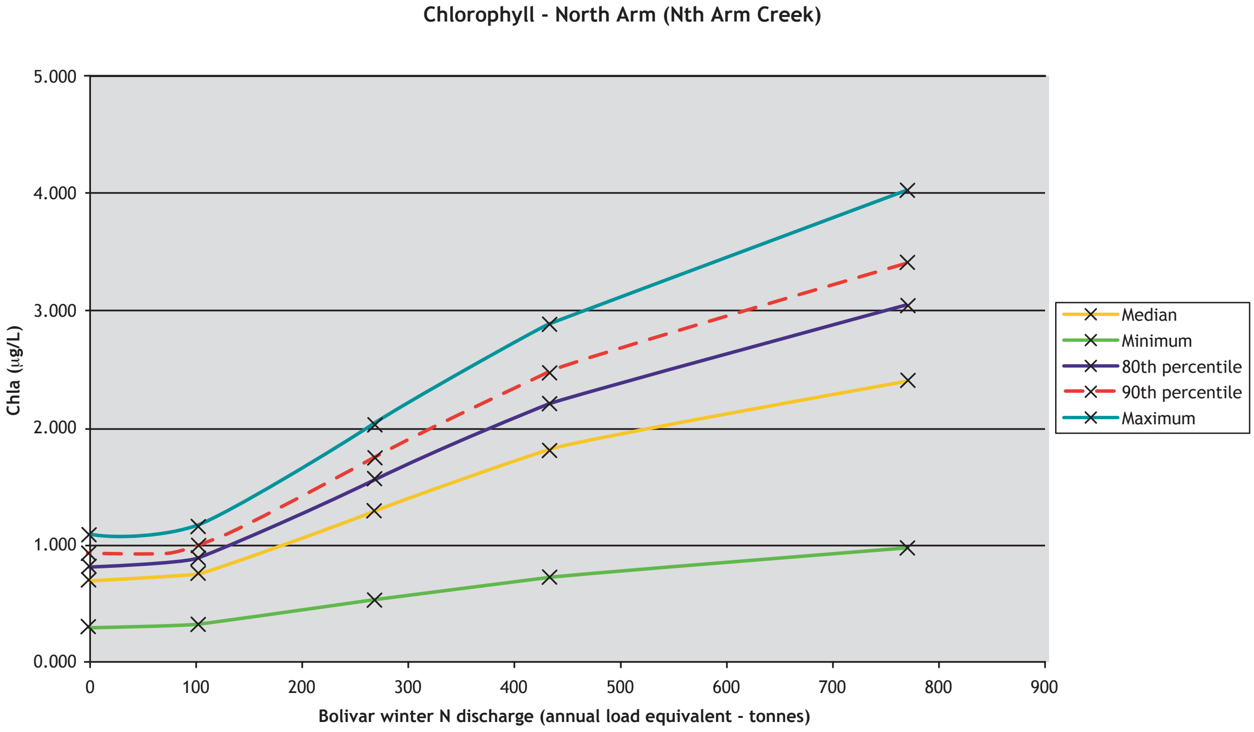


Figure F31 Response of chlorophyll *a* levels in Barker Inlet at Swan Alley creek to progressive reductions in nutrient loads from the Bolivar WWTP

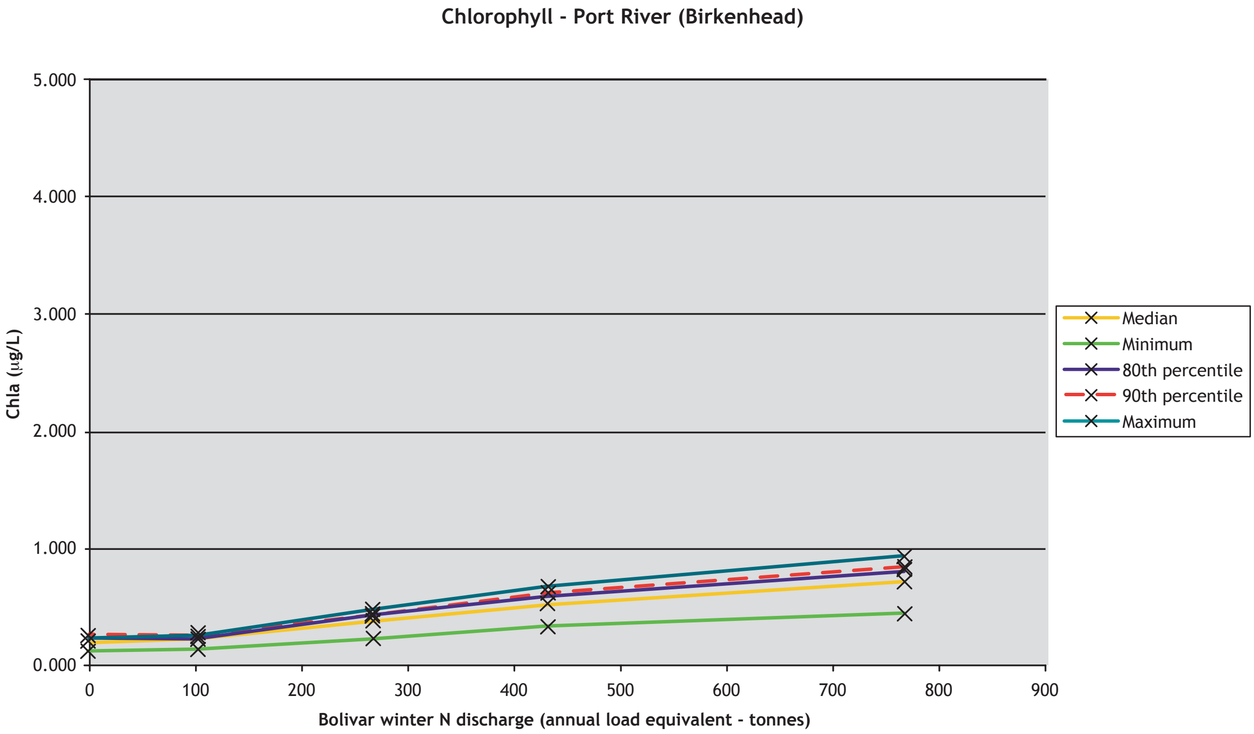


Figure F32 Response of chlorophyll *a* levels in the Port River at Birkenhead to progressive reductions in nutrient loads from the Bolivar WWTP

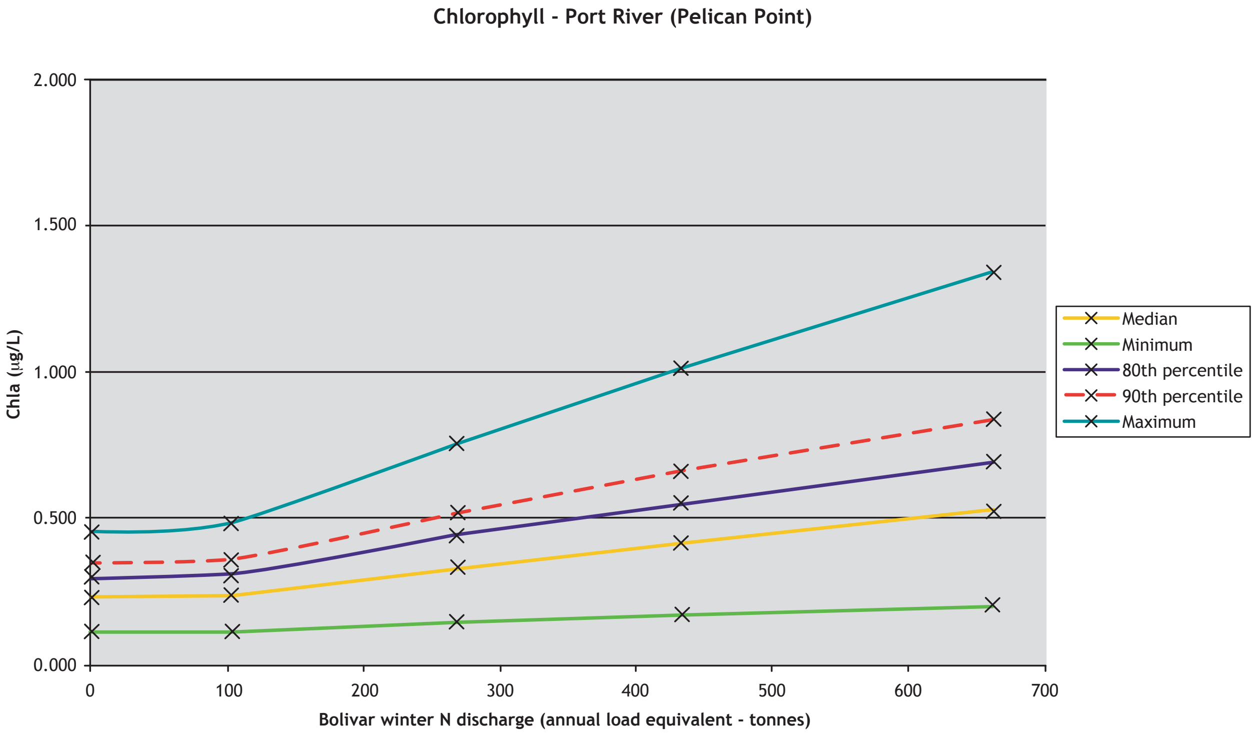
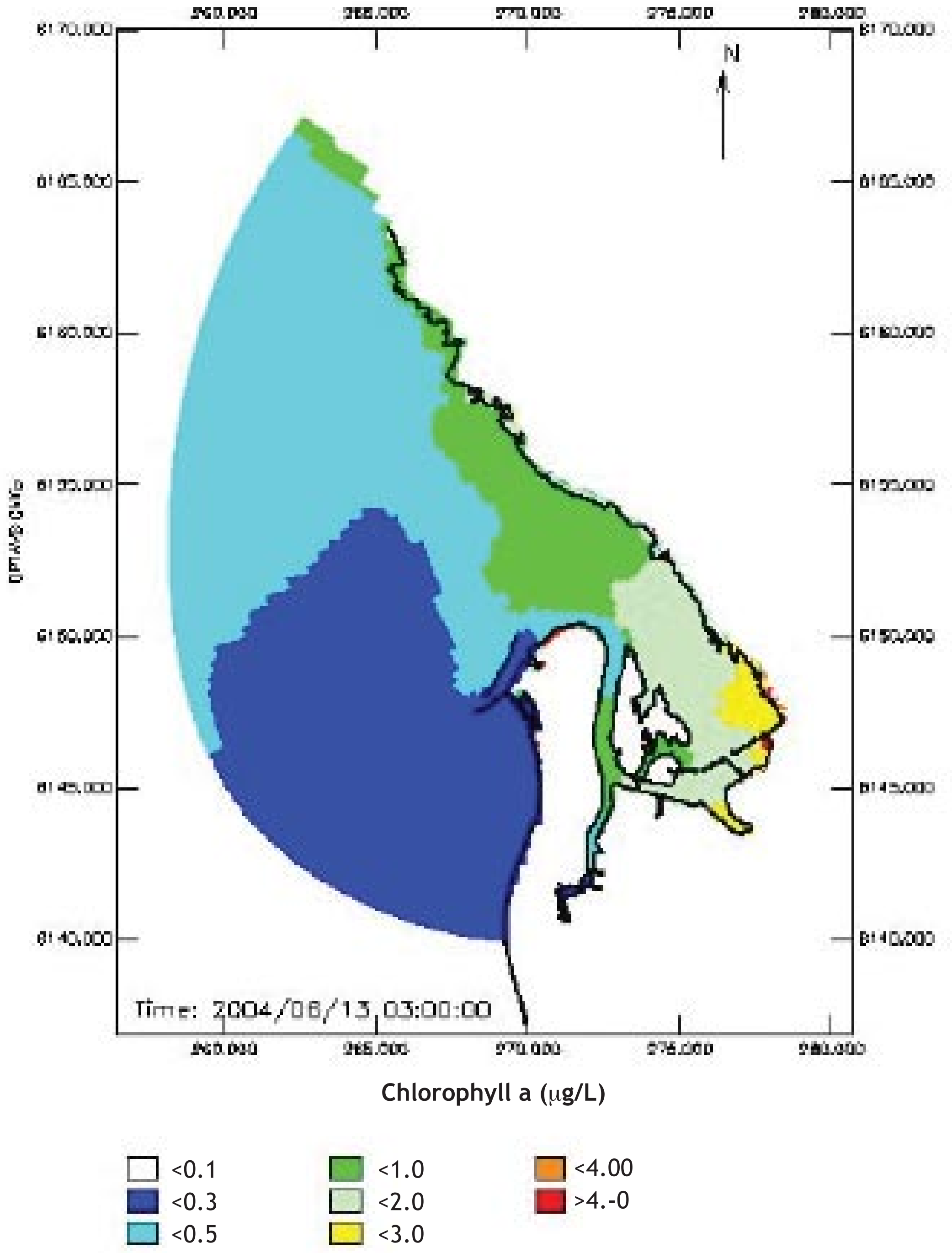
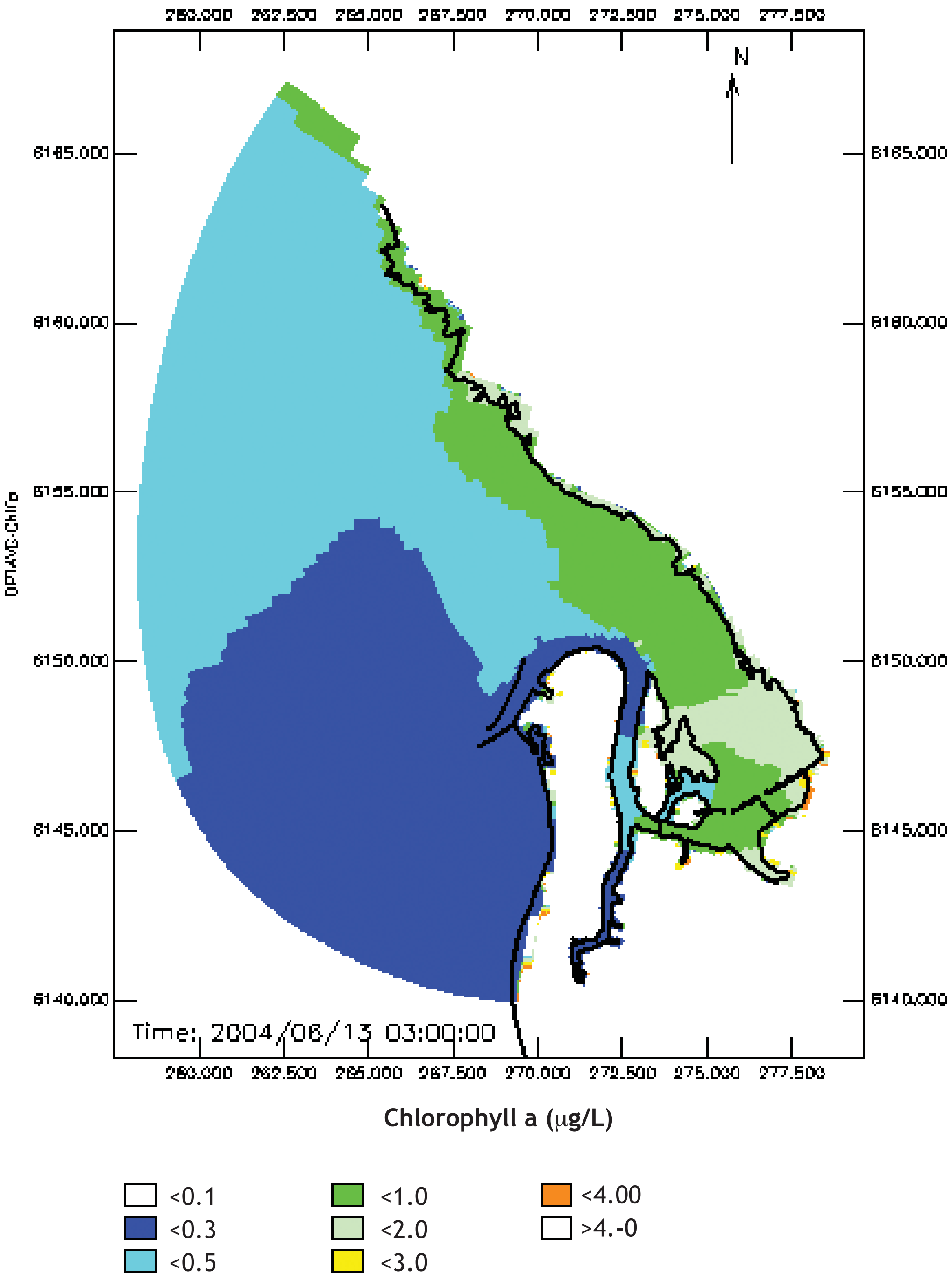


Figure F33 Response of chlorophyll *a* levels in the Port River at Outer Harbour to progressive reductions in nutrient loads from the Bolivar WWTP



Chlorophyll a - Depth averaged values (μg/L) Pt Adel to Bolivar 100% low salinity plant 25% Scenario - Penrice 200 tonnes N	Winter 2004 3D	run46c
	Neap ebbing tide	
Environment Protection Authority of South Australia	24 June 2005	P Christy

Figure F34 Distribution of chlorophyll *a* in the Port waterways during a neap ebbing tide—discharges of nutrients from the Bolivar WWTP reduced from normal 2004 levels to—100% of high salinity plant and only 25% of low salinity plant effluent—and nitrogen discharges from the Penrice facility reduced to 200 tonnes per annum



Chlorophyll a - Depth averaged values (µg/L) No discharge from the Bolivar plants Scenario - Penrice 200 tonnes N	Winter 2004 3D	run49d
	Neap ebbing tide	
Environment Protection Authority of South Australia	8 July 2005	P Christy

Figure F35 **Distribution of chlorophyll *a* in the Port waterways during a neap ebbing tide—no discharges of nutrients from the Bolivar WWTP and nitrogen discharges from the Penrice facility reduced to 200 tonnes per annum**

Table F1 Summary data and water quality classification for BOL1 (mg/L)

	TotN	NH4	NO3	TotP	PO4	Chl *a*
1998						
Mean	0.497	0.224	0.043	0.062	0.029	0.466
Median	0.467	0.208	0.038	0.057	0.027	0.447
Minimum	0.185	0.022	0.002	0.009	0.003	0.293
10th percentile	0.242	0.071	0.010	0.019	0.008	0.370
80th percentile	0.681	0.332	0.069	0.094	0.045	0.541
90th percentile	0.807	0.410	0.081	0.115	0.055	0.592
Maximum	1.146	0.608	0.135	0.174	0.086	0.768
2004						
Mean	0.315	0.067	0.084	0.059	0.030	0.446
Median	0.302	0.063	0.076	0.054	0.027	0.437
Minimum	0.184	0.021	0.002	0.009	0.003	0.290
10th percentile	0.208	0.037	0.018	0.018	0.008	0.365
80th percentile	0.393	0.089	0.131	0.089	0.046	0.501
90th percentile	0.448	0.106	0.166	0.110	0.058	0.547
Maximum	0.597	0.144	0.261	0.168	0.089	0.709
FUTURE Penrice 200t N, Bolivar at 2004 levels						
Mean	0.314	0.065	0.084	0.061	0.031	0.453
Median	0.299	0.062	0.075	0.056	0.028	0.439
Minimum	0.184	0.021	0.002	0.009	0.003	0.292
10th percentile	0.207	0.037	0.018	0.019	0.008	0.368
80th percentile	0.391	0.087	0.131	0.092	0.048	0.515
90th percentile	0.447	0.101	0.167	0.114	0.060	0.566
Maximum	0.591	0.139	0.260	0.173	0.091	0.743
FUTURE Penrice 200t N, Bol High Sal at 2004 levels, low Sal 25%						
Mean	0.228	0.055	0.032	0.027	0.014	0.394
Median	0.224	0.053	0.029	0.025	0.013	0.388
Minimum	0.184	0.021	0.002	0.009	0.003	0.277
10th percentile	0.192	0.034	0.008	0.013	0.005	0.333
80th percentile	0.254	0.069	0.049	0.038	0.021	0.434
90th percentile	0.273	0.085	0.060	0.046	0.025	0.457
Maximum	0.323	0.105	0.097	0.067	0.038	0.580
FUTURE Penrice 200t, Bol High Sal at 2004 levels, Low Sal 0% of 2004						
Mean	0.183	0.048	0.006	0.009	0.003	0.320
Median	0.183	0.046	0.005	0.009	0.003	0.327
Minimum	0.179	0.021	0.002	0.009	0.003	0.220
10th percentile	0.181	0.032	0.003	0.009	0.003	0.225
80th percentile	0.184	0.060	0.008	0.009	0.004	0.366
90th percentile	0.184	0.075	0.014	0.009	0.004	0.379
Maximum	0.187	0.084	0.018	0.009	0.004	0.440

Table F2 Summary data and water quality classification for BOL2 (mg/L)

	TotN	NH4	NO3	TotP	PO4	Chl *a*
1998						
Mean	0.233	0.064	0.011	0.017	0.007	0.390
Median	0.197	0.039	0.004	0.011	0.004	0.381
Minimum	0.181	0.015	0.001	0.009	0.003	0.282
10th percentile	0.184	0.021	0.002	0.009	0.003	0.315
80th percentile	0.289	0.110	0.021	0.027	0.012	0.442
90th percentile	0.340	0.143	0.028	0.035	0.016	0.476
Maximum	0.428	0.194	0.047	0.050	0.023	0.557
2004						
Mean	0.203	0.039	0.015	0.017	0.007	0.383
Median	0.189	0.034	0.006	0.011	0.004	0.380
Minimum	0.183	0.015	0.001	0.009	0.003	0.281
10th percentile	0.184	0.020	0.002	0.009	0.003	0.314
80th percentile	0.225	0.054	0.029	0.025	0.011	0.430
90th percentile	0.245	0.063	0.042	0.032	0.015	0.459
Maximum	0.279	0.091	0.061	0.045	0.022	0.523
FUTURE Penrice 200t N, Bolivar at 2004 levels						
Mean	0.203	0.038	0.015	0.017	0.008	0.387
Median	0.189	0.034	0.006	0.011	0.004	0.380
Minimum	0.183	0.015	0.001	0.009	0.003	0.282
10th percentile	0.184	0.020	0.002	0.009	0.003	0.315
80th percentile	0.224	0.053	0.030	0.027	0.012	0.437
90th percentile	0.244	0.063	0.042	0.034	0.016	0.473
Maximum	0.277	0.088	0.061	0.046	0.023	0.548
FUTURE Penrice 200t N, Bol High Sal at 2004 levels, low Sal 25%						
Mean	0.190	0.037	0.007	0.012	0.005	0.360
Median	0.186	0.033	0.004	0.010	0.004	0.364
Minimum	0.183	0.014	0.001	0.009	0.003	0.275
10th percentile	0.184	0.020	0.002	0.009	0.003	0.304
80th percentile	0.197	0.049	0.014	0.015	0.007	0.389
90th percentile	0.204	0.058	0.019	0.018	0.008	0.408
Maximum	0.216	0.079	0.028	0.022	0.011	0.445
FUTURE Penrice 200t, Bol High Sal at 2004 levels, Low Sal 0% of 2004						
Mean	0.184	0.036	0.004	0.009	0.003	0.332
Median	0.184	0.032	0.003	0.009	0.003	0.331
Minimum	0.182	0.014	0.001	0.009	0.003	0.227
10th percentile	0.183	0.020	0.002	0.009	0.003	0.273
80th percentile	0.184	0.046	0.005	0.009	0.004	0.371
90th percentile	0.184	0.055	0.008	0.009	0.004	0.386
Maximum	0.184	0.075	0.013	0.009	0.004	0.418

Table F3 Summary data and water quality classification for BOL3 (mg/L)

	TotN	NH4	NO3	TotP	PO4	Chl *a*
1998						
Mean	0.233	0.064	0.011	0.017	0.007	0.390
Median	0.197	0.039	0.004	0.011	0.004	0.381
Minimum	0.181	0.015	0.001	0.009	0.003	0.282
10th percentile	0.184	0.021	0.002	0.009	0.003	0.315
80th percentile	0.289	0.110	0.021	0.027	0.012	0.442
90th percentile	0.340	0.143	0.028	0.035	0.016	0.476
Maximum	0.428	0.194	0.047	0.050	0.023	0.557
2004						
Mean	0.272	0.069	0.058	0.041	0.020	0.441
Median	0.264	0.067	0.054	0.038	0.018	0.434
Minimum	0.184	0.023	0.002	0.010	0.004	0.281
10th percentile	0.212	0.041	0.020	0.018	0.008	0.362
80th percentile	0.309	0.084	0.082	0.056	0.028	0.486
90th percentile	0.329	0.105	0.095	0.065	0.032	0.528
Maximum	0.469	0.134	0.185	0.115	0.060	0.673
FUTURE Penrice 200t N, Bolivar at 2004 levels						
Mean	0.266	0.065	0.056	0.042	0.020	0.448
Median	0.258	0.064	0.051	0.039	0.019	0.442
Minimum	0.184	0.023	0.002	0.010	0.004	0.281
10th percentile	0.206	0.041	0.019	0.018	0.008	0.364
80th percentile	0.304	0.077	0.079	0.057	0.028	0.494
90th percentile	0.326	0.092	0.093	0.065	0.033	0.539
Maximum	0.458	0.125	0.182	0.119	0.062	0.703
FUTURE Penrice 200t N, Bol High Sal at 2004 levels, low Sal 25%						
Mean	0.213	0.058	0.024	0.021	0.010	0.375
Median	0.210	0.057	0.023	0.020	0.009	0.367
Minimum	0.184	0.023	0.002	0.009	0.003	0.258
10th percentile	0.193	0.038	0.010	0.012	0.005	0.310
80th percentile	0.226	0.069	0.033	0.026	0.013	0.421
90th percentile	0.232	0.086	0.038	0.029	0.015	0.442
Maximum	0.279	0.101	0.073	0.048	0.026	0.571
FUTURE Penrice 200t, Bol High Sal at 2004 levels, Low Sal 0% of 2004						
Mean	0.184	0.054	0.008	0.009	0.004	0.297
Median	0.184	0.052	0.007	0.009	0.004	0.305
Minimum	0.181	0.023	0.002	0.009	0.003	0.195
10th percentile	0.182	0.036	0.003	0.009	0.003	0.230
80th percentile	0.086	0.065	0.011	0.009	0.004	0.347
90th percentile	0.188	0.081	0.017	0.009	0.004	0.362
Maximum	0.190	0.089	0.021	0.009	0.004	0.424

Table F4 Summary data and water quality classification for BKR1 (mg/L)

	TotN	NH4	NO3	TotP	PO4	Chl *a*
1998						
Mean	0.316	0.136	0.041	0.027	0.012	0.537
Median	0.314	0.141	0.041	0.026	0.012	0.508
Minimum	0.186	0.026	0.002	0.009	0.003	0.245
10th percentile	0.235	0.073	0.015	0.016	0.007	0.356
80th percentile	0.368	0.171	0.059	0.034	0.016	0.651
90th percentile	0.390	0.188	0.066	0.038	0.018	0.743
Maximum	0.464	0.247	0.089	0.052	0.025	1.296
2004						
Mean	0.243	0.081	0.040	0.024	0.011	0.478
Median	0.243	0.081	0.040	0.023	0.011	0.455
Minimum	0.184	0.024	0.002	0.009	0.003	0.242
10th percentile	0.207	0.045	0.017	0.014	0.006	0.337
80th percentile	0.266	0.106	0.054	0.031	0.015	0.569
90th percentile	0.278	0.113	0.060	0.035	0.017	0.639
Maximum	0.309	0.130	0.089	0.049	0.025	1.090
FUTURE Penrice 200t N, Bolivar at 2004 levels						
Mean	0.225	0.068	0.034	0.024	0.011	0.487
Median	0.223	0.069	0.033	0.024	0.011	0.462
Minimum	0.184	0.024	0.002	0.009	0.003	0.242
10th percentile	0.200	0.043	0.014	0.015	0.006	0.342
80th percentile	0.243	0.083	0.046	0.031	0.015	0.584
90th percentile	0.253	0.091	0.052	0.036	0.018	0.656
Maximum	0.289	0.105	0.081	0.051	0.026	1.128
FUTURE Penrice 200t N, Bol High Sal at 2004 levels, low Sal 25%						
Mean	0.201	0.065	0.020	0.015	0.007	0.369
Median	0.200	0.065	0.020	0.014	0.007	0.361
Minimum	0.184	0.024	0.002	0.009	0.003	0.226
10th percentile	0.190	0.041	0.008	0.011	0.005	0.274
80th percentile	0.208	0.081	0.026	0.017	0.008	0.426
90th percentile	0.211	0.089	0.030	0.019	0.009	0.456
Maximum	0.222	0.098	0.042	0.024	0.012	0.713
FUTURE Penrice 200t, Bol High Sal at 2004 levels, Low Sal 0% of 2004						
Mean	0.188	0.064	0.013	0.009	0.004	0.268
Median	0.188	0.063	0.012	0.009	0.004	0.273
Minimum	0.183	0.024	0.002	0.009	0.003	0.154
10th percentile	0.184	0.040	0.004	0.009	0.003	0.198
80th percentile	0.192	0.079	0.019	0.009	0.004	0.316
90th percentile	0.193	0.088	0.022	0.009	0.004	0.330
Maximum	0.201	0.095	0.026	0.010	0.004	0.386

Table F5 Summary data and water quality classification for BKR2 (mg/L)

	TotN	NH4	NO3	TotP	PO4	Chl *a*
1998						
Mean	0.466	0.245	0.111	0.033	0.017	1.470
Median	0.465	0.243	0.111	0.034	0.017	1.409
Minimum	0.302	0.110	0.024	0.021	0.010	0.506
10th percentile	0.382	0.185	0.074	0.026	0.013	0.840
80th percentile	0.529	0.289	0.136	0.037	0.019	1.849
90th percentile	0.558	0.307	0.146	0.039	0.020	2.236
Maximum	0.655	0.377	0.175	0.043	0.022	3.267
2004						
Mean	0.321	0.152	0.072	0.022	0.010	1.214
Median	0.320	0.155	0.073	0.023	0.011	1.162
Minimum	0.232	0.052	0.032	0.015	0.007	0.474
10th percentile	0.280	0.117	0.053	0.017	0.008	0.716
80th percentile	0.350	0.175	0.085	0.025	0.012	1.507
90th percentile	0.363	0.185	0.090	0.027	0.013	1.819
Maximum	0.404	0.214	0.106	0.036	0.017	2.665
FUTURE Penrice 200t N, Bolivar at 2004 levels						
Mean	0.237	0.095	0.047	0.023	0.011	1.256
Median	0.240	0.096	0.048	0.023	0.011	1.209
Minimum	0.210	0.048	0.025	0.016	0.007	0.482
10th percentile	0.221	0.080	0.035	0.018	0.008	0.738
80th percentile	0.247	0.104	0.054	0.026	0.012	1.556
90th percentile	0.250	0.106	0.056	0.028	0.013	1.882
Maximum	0.259	0.112	0.063	0.036	0.017	2.788
FUTURE Penrice 200t N, Bol High Sal at 2004 levels, low Sal 25%						
Mean	0.218	0.094	0.035	0.014	0.007	0.763
Median	0.218	0.096	0.036	0.015	0.007	0.730
Minimum	0.199	0.044	0.014	0.012	0.005	0.336
10th percentile	0.208	0.079	0.026	0.012	0.005	0.486
80th percentile	0.225	0.104	0.042	0.015	0.007	0.938
90th percentile	0.227	0.107	0.044	0.016	0.008	1.102
Maximum	0.237	0.115	0.051	0.019	0.009	1.548
FUTURE Penrice 200t, Bol High Sal at 2004 levels, Low Sal 0% of 2004						
Mean	0.207	0.095	0.030	0.010	0.004	0.378
Median	0.207	0.097	0.031	0.010	0.004	0.361
Minimum	0.185	0.042	0.006	0.009	0.003	0.206
10th percentile	0.198	0.079	0.021	0.009	0.004	0.278
80th percentile	0.241	0.105	0.036	0.010	0.004	0.444
90th percentile	0.217	0.109	0.039	0.010	0.005	0.498
Maximum	0.225	0.119	0.046	0.010	0.005	0.642

Table F6 Summary data and water quality classification for BKR4 (mg/L)

	TotN	NH4	NO3	TotP	PO4	Chl *a*
1998						
Mean	0.879	0.535	0.243	0.051	0.028	3.255
Median	0.899	0.547	0.284	0.052	0.028	3.051
Minimum	0.475	0.242	0.109	0.032	0.016	1.546
10th percentile	0.681	0.396	0.179	0.042	0.022	2.221
80th percentile	0.991	0.613	0.282	0.056	0.031	4.209
90th percentile	1.043	0.650	0.299	0.058	0.032	4.671
Maximum	1.143	0.706	0.337	0.064	0.035	5.317
2004						
Mean	0.509	0.295	0.132	0.022	0.010	2.768
Median	0.516	0.301	0.135	0.022	0.010	2.613
Minimum	0.331	0.153	0.070	0.019	0.007	1.284
10th percentile	0.415	0.223	0.103	0.020	0.008	1.895
80th percentile	0.561	0.335	0.150	0.023	0.010	3.575
90th percentile	0.585	0.353	0.157	0.024	0.011	3.923
Maximum	0.640	0.390	0.172	0.029	0.013	4.498
FUTURE Penrice 200t N, Bolivar at 2004 levels						
Mean	0.277	0.127	0.067	0.023	0.010	2.872
Median	0.278	0.129	0.069	0.022	0.010	2.713
Minimum	0.235	0.088	0.041	0.020	0.008	1.310
10th percentile	0.258	0.110	0.057	0.021	0.009	1.969
80th percentile	0.289	0.138	0.074	0.023	0.011	3.713
90th percentile	0.294	0.142	0.076	0.250	0.011	4.077
Maximum	0.302	0.151	0.081	0.029	0.013	4.720
FUTURE Penrice 200t N, Bol High Sal at 2004 levels, low Sal 25%						
Mean	0.261	0.133	0.059	0.015	0.007	1.514
Median	0.263	0.135	0.061	0.015	0.007	1.463
Minimum	0.220	0.089	0.032	0.130	0.006	0.778
10th percentile	0.240	0.113	0.047	0.014	0.006	1.061
80th percentile	0.273	0.145	0.067	0.015	0.007	1.908
90th percentile	0.279	0.150	0.069	0.015	0.007	2.099
Maximum	0.291	0.158	0.075	0.017	0.008	2.387
FUTURE Penrice 200t, Bol High Sal at 2004 levels, Low Sal 0% of 2004						
Mean	0.252	0.138	0.056	0.010	0.005	0.577
Median	0.254	0.014	0.057	0.011	0.005	0.569
Minimum	0.210	0.090	0.027	0.010	0.004	0.341
10th percentile	0.230	0.116	0.043	0.010	0.005	0.413
80th percentile	0.265	0.150	0.064	0.011	0.005	0.706
90th percentile	0.272	0.156	0.067	0.011	0.005	0.770
Maximum	0.284	0.165	0.072	0.011	0.006	0.836

Table F7 Summary data and water quality classification for NAR2 (mg/L)

	TotN	NH4	NO3	TotP	PO4	Chl *a*
1998						
Mean	1.396	0.922	0.380	0.072	0.043	2.210
Median	1.393	0.919	0.384	0.072	0.043	2.078
Minimum	0.990	0.641	0.250	0.050	0.029	0.811
10th percentile	1.232	0.800	0.327	0.063	0.037	1.328
80th percentile	1.513	1.004	0.415	0.077	0.047	2.799
90th percentile	1.566	1.045	0.431	0.080	0.049	3.317
Maximum	1.700	1.161	0.461	0.089	0.055	4.402
2004						
Mean	0.775	0.519	0.190	0.021	0.010	2.104
Median	0.775	0.516	0.192	0.021	0.010	2.030
Minimum	0.603	0.389	0.134	0.018	0.008	0.779
10th percentile	0.696	0.455	0.167	0.020	0.009	1.270
80th percentile	0.834	0.564	0.207	0.021	0.010	2.735
90th percentile	0.857	0.587	0.211	0.022	0.011	3.131
Maximum	0.935	0.671	0.223	0.022	0.011	3.912
FUTURE Penrice 200t N, Bolivar at 2004 levels						
Mean	0.342	0.188	0.088	0.021	0.010	2.159
Median	0.343	0.188	0.090	0.021	0.010	2.070
Minimum	0.301	0.154	0.067	0.019	0.009	0.803
10th percentile	0.322	0.170	0.079	0.021	0.010	1.130
80th percentile	0.356	0.199	0.094	0.022	0.011	2.790
90th percentile	0.362	0.206	0.096	0.022	0.011	3.214
Maximum	0.383	0.230	0.099	0.023	0.011	4.021
FUTURE Penrice 200t N, Bol High Sal at 2004 levels, low Sal 25%						
Mean	0.330	0.193	0.082	0.015	0.007	1.035
Median	0.330	0.192	0.084	0.015	0.007	1.004
Minimum	0.287	0.156	0.059	0.014	0.007	0.406
10th percentile	0.309	0.174	0.072	0.014	0.007	0.637
80th percentile	0.344	0.205	0.089	0.015	0.008	1.326
90th percentile	0.350	0.211	0.090	0.015	0.008	1.499
Maximum	0.371	0.233	0.094	0.015	0.008	1.889
FUTURE Penrice 200t, Bol High Sal at 2004 levels, Low Sal 0% of 2004						
Mean	0.323	0.196	0.080	0.012	0.006	0.363
Median	0.323	0.195	0.081	0.012	0.006	0.352
Minimum	0.279	0.157	0.055	0.011	0.005	0.163
10th percentile	0.301	0.177	0.069	0.011	0.006	0.232
80th percentile	0.337	0.208	0.086	0.012	0.006	0.458
90th percentile	0.344	0.214	0.088	0.012	0.006	0.506
Maximum	0.364	0.234	0.092	0.012	0.007	0.627

Table F8 Summary data and water quality classification for PTR3 (mg/L)

	TotN	NH4	NO3	TotP	PO4	Chl *a*
1998						
Mean	1.950	1.128	0.635	0.174	0.121	0.622
Median	1.939	1.118	0.635	0.174	0.120	0.606
Minimum	1.816	1.046	0.581	0.155	0.107	0.406
10th percentile	1.849	1.069	0.590	0.160	0.111	0.451
80th percentile	2.016	1.169	0.666	0.182	0.127	0.754
90th percentile	2.069	1.209	0.677	0.186	0.130	0.817
Maximum	2.176	1.257	0.713	0.202	0.144	0.898
2004						
Mean	0.719	0.399	0.255	0.023	0.012	0.684
Median	0.716	0.400	0.252	0.023	0.012	0.719
Minimum	0.685	0.363	0.238	0.022	0.012	0.443
10th percentile	0.699	0.379	0.241	0.023	0.012	0.484
80th percentile	0.737	0.411	0.268	0.024	0.012	0.822
90th percentile	0.744	0.418	0.271	0.024	0.013	0.847
Maximum	0.757	0.439	0.278	0.024	0.013	0.930
FUTURE Penrice 200t N, Bolivar at 2004 levels						
Mean	0.352	0.170	0.117	0.024	0.013	0.702
Median	0.352	0.170	0.116	0.024	0.013	0.733
Minimum	0.345	0.158	0.111	0.023	0.012	0.457
10th percentile	0.347	0.163	0.112	0.023	0.012	0.499
80th percentile	0.356	0.175	0.123	0.024	0.013	0.839
90th percentile	0.358	0.176	0.124	0.024	0.013	0.865
Maximum	0.359	0.181	0.127	0.025	0.013	0.962
FUTURE Penrice 200t N, Bol High Sal at 2004 levels, low Sal 25%						
Mean	0.342	0.171	0.113	0.018	0.010	0.328
Median	0.342	0.171	0.112	0.018	0.010	0.346
Minimum	0.335	0.160	0.108	0.017	0.009	0.214
10th percentile	0.337	0.164	0.109	0.017	0.009	0.234
80th percentile	0.347	0.175	0.118	0.019	0.010	0.392
90th percentile	0.349	0.177	0.119	0.019	0.010	0.404
Maximum	0.350	0.182	0.122	0.019	0.010	0.438
FUTURE Penrice 200t, Bol High Sal at 2004 levels, Low Sal 0% of 2004						
Mean	0.200	0.172	0.111	0.016	0.008	0.113
Median	0.199	0.172	0.111	0.016	0.008	0.121
Minimum	0.184	0.161	0.106	0.014	0.008	0.074
10th percentile	0.187	0.165	0.107	0.015	0.008	0.081
80th percentile	0.210	0.175	0.116	0.016	0.008	0.133
90th percentile	0.217	0.177	0.117	0.017	0.009	0.143
Maximum	0.236	0.183	0.120	0.017	0.009	0.154

Table F9 Summary data and water quality classification for PTR5 (mg/L)

	TotN	NH4	NO3	TotP	PO4	Chl *a*
1998						
Mean	1.629	1.008	0.504	0.109	0.071	1.355
Median	1.636	1.010	0.506	0.110	0.072	1.339
Minimum	1.383	0.879	0.395	0.077	0.047	0.744
10th percentile	1.511	0.941	0.450	0.094	0.060	0.903
80th percentile	1.709	1.055	0.535	0.119	0.078	1.651
90th percentile	1.752	1.079	0.555	0.124	0.081	1.882
Maximum	1.831	1.115	0.591	0.138	0.093	2.543
2004						
Mean	0.776	0.489	0.227	0.022	0.011	1.362
Median	0.771	0.485	0.227	0.022	0.011	1.384
Minimum	0.717	0.431	0.189	0.020	0.010	0.759
10th percentile	0.729	0.449	0.208	0.021	0.011	0.906
80th percentile	0.811	0.516	0.238	0.022	0.011	1.659
90th percentile	0.826	0.533	0.245	0.022	0.014	1.832
Maximum	0.876	0.594	0.254	0.022	0.012	2.345
FUTURE Penrice 200t N, Bolivar at 2004 levels						
Mean	0.351	0.186	0.104	0.022	0.011	1.398
Median	0.351	0.186	0.104	0.022	0.011	1.414
Minimum	0.332	0.170	0.088	0.021	0.010	0.783
10th percentile	0.337	0.173	0.097	0.022	0.011	0.934
80th percentile	0.359	0.193	0.109	0.022	0.012	1.696
90th percentile	0.362	0.197	0.111	0.023	0.012	1.884
Maximum	0.373	0.213	0.116	0.023	0.012	2.410
FUTURE Penrice 200t N, Bol High Sal at 2004 levels, low Sal 25%						
Mean	0.340	0.189	0.099	0.016	0.008	0.666
Median	0.339	0.189	0.099	0.016	0.008	0.675
Minimum	0.318	0.173	0.082	0.015	0.008	0.371
10th percentile	0.325	0.176	0.091	0.015	0.008	0.444
80th percentile	0.348	0.196	0.104	0.016	0.009	0.811
90th percentile	0.351	0.200	0.106	0.016	0.009	0.883
Maximum	0.361	0.216	0.111	0.017	0.009	1.143
FUTURE Penrice 200t, Bol High Sal at 2004 levels, Low Sal 0% of 2004						
Mean	0.333	0.191	0.096	0.013	0.007	0.234
Median	0.333	0.191	0.097	0.013	0.007	0.236
Minimum	0.311	0.175	0.079	0.011	0.006	0.132
10th percentile	0.318	0.178	0.088	0.012	0.006	0.159
80th percentile	0.342	0.198	0.101	0.014	0.007	0.287
90th percentile	0.345	0.202	0.104	0.014	0.007	0.312
Maximum	0.354	0.217	0.108	0.014	0.007	0.387

Table F10 Summary data and water quality classification for PTR9 (mg/L)

	TotN	NH4	NO3	TotP	PO4	Chl *a*
1998						
Mean	0.507	0.279	0.133	0.033	0.018	0.619
Median	0.485	0.263	0.128	0.032	0.017	0.582
Minimum	0.316	0.144	0.054	0.020	0.010	0.234
10th percentile	0.370	0.189	0.084	0.024	0.013	0.378
80th percentile	0.607	0.349	0.168	0.038	0.021	0.773
90th percentile	0.670	0.387	0.190	0.042	0.023	0.943
Maximum	0.869	0.538	0.243	0.050	0.030	1.486
2004						
Mean	0.360	0.196	0.080	0.019	0.009	0.558
Median	0.351	0.187	0.079	0.019	0.009	0.528
Minimum	0.253	0.102	0.040	0.014	0.007	0.205
10th percentile	0.282	0.136	0.057	0.016	0.008	0.341
80th percentile	0.418	0.240	0.098	0.021	0.010	0.695
90th percentile	0.453	0.269	0.108	0.022	0.011	0.848
Maximum	0.556	0.342	0.132	0.028	0.014	1.350
FUTURE Penrice 200t N, Bolivar at 2004 levels						
Mean	0.242	0.110	0.048	0.020	0.010	0.572
Median	0.241	0.109	0.048	0.020	0.010	0.542
Minimum	0.210	0.074	0.027	0.015	0.007	0.211
10th percentile	0.220	0.092	0.037	0.016	0.008	0.349
80th percentile	0.257	0.122	0.056	0.021	0.011	0.712
90th percentile	0.267	0.130	0.060	0.022	0.011	0.866
Maximum	0.294	0.152	0.071	0.028	0.014	1.383
FUTURE Penrice 200t N, Bol High Sal at 2004 levels, low Sal 25%						
Mean	0.228	0.109	0.040	0.013	0.006	0.345
Median	0.226	0.108	0.039	0.013	0.006	0.322
Minimum	0.201	0.073	0.020	0.011	0.005	0.142
10th percentile	0.208	0.090	0.029	0.012	0.006	0.223
80th percentile	0.242	0.122	0.047	0.014	0.007	0.432
90th percentile	0.251	0.130	0.051	0.014	0.007	0.508
Maximum	0.276	0.153	0.063	0.016	0.008	0.730
FUTURE Penrice 200t, Bol High Sal at 2004 levels, Low Sal 0% of 2004						
Mean	0.220	0.109	0.036	0.010	0.005	0.185
Median	0.217	0.108	0.035	0.010	0.005	0.178
Minimum	0.195	0.072	0.016	0.009	0.004	0.092
10th percentile	0.201	0.089	0.025	0.010	0.004	0.132
80th percentile	0.234	0.121	0.043	0.010	0.005	0.223
90th percentile	0.243	0.130	0.047	0.010	0.005	0.266
Maximum	0.267	0.153	0.059	0.011	0.005	0.325

Proceedings from Port Waterways and Adelaide Coastal Waters Study Stakeholder Workshop

Thursday 18 May
Hosted by Environment Protection Authority

Attendees

Name	Organisation
Prof Rod Connolly	Griffith University
Prof Charitha Pattiaratchi	University of Western Australia
Tony McAlister	BMT-WBM
Doug Treloar	Cardno Lawson & Treloar
Paul Manning	Eco Management Services Pty Ltd
Peter Christy	EPA
Sam Gaylard	EPA
Peter Pfennig	EPA
Lester Sickerdick	SA Water
Tim Kildea	SA Water
Tim Moore	SA Water
Ewa Cierchorska	Penrice Soda Products
Peter Shultz	A&MLR NRM Board
Dr Garry Tong	Computational Fluid Mechanics
Dr Peter Petrusevics	Oceanique Perspectives/Flinders University
Natasha Davis	Sustainable Focus—Facilitator

Agenda
See Attachment 1

Workshop Aims

1 Provide information about:
   - Pt Waterways Water Quality Improvement Plan
   - Adelaide Coastal Waters Study (ACWS)
   - Port Waterways Water Quality Model (WAQ)

2 Explore linkages between the models (ACWS and Pt Waterways)

3 Identify areas for improving the Pt Waterways Water Quality model

4 Identify priority areas for next steps in developing the Pt Waterways Water Quality Model

Port Waterways Water Quality Improvement Plan—Peter Pfennig

Objectives

Deliver a strategy and tools to reduce nutrient levels in the Port waterways consistent with stakeholder expectations:

- develop environmental values for waterway
- set targets for the water quality
- how much, where reductions to achieve WQ (model)
- set target loads for discharges
- implement, report and review

Key issues

Region was divided into segments to look at specific issues such as red tides, macro algal growth, toxicity, seagrass loss in the slightly and/or moderately disturbed regions and separating the high conservation ecological values.

- Community involvement in process; particularly setting of Environmental Values.
- Work may be repeated in 5/6 years in consultation with community?
- Main sources of nutrients are SA Water and Penrice.
- Catchment sources are not significant.
- West Lakes may have additional issues.

Focus on nutrients

Nutrients were selected because:

- identified as a problem from EPA's 10 year ambient monitoring program
- strategies to reduce nutrients will also reduce other pollutants
- environmental values will feed into all water quality—not just nutrients
- other specific pollutant types to be integrated over time if required.

Implementation status

- Some independent examination of costs/feasibility.
- Used the Environmental Values and model information to set Objectives > Targets.
- Model relates discharges to targets so we can try of various discharge options.
- Derive load reductions from major sources to achieve targets.
- Examination of historical catchment flows.
- Communication with stakeholders > on-going.
- Related programs >Codes of Practice (Marinas) and (Wharfs), Market Based Instruments.
- WQ Monitoring program continuing to provide better catchment information.

Outlook

- Nutrient reduction is technically difficult and costly—to achieve targets that have been set in the current WQIP requires substantial investment from SA Water, and achieving no flow from the low salinity plant.
- Long lead times to develop and implement
- Little change until major discharges drop sufficiently
- Integrate Port Waterways and Adelaide Coastal Waters Study implementation

Status of work

- Penrice > significant drop (820 t Nitrogen/y to 575 t Nitrogen/y) guaranteed through EPA license by 2010
    - * Aspirational target of 250 tonnes/year as technology and cost allow—aim is 2015. 'Aspirational' target not part of EIP.
    - * Over next five years Penrice will be doing considerable research into new technology.
- SA Water > just finished Port discharge removal and Bolivar upgrade $200m
    - * Notional target (no environmental harm)—actual load targets subject to agreement post Adelaide Coastal Water Study (ACWS).
    - * Overall strategy for all metro discharges informed by ACWS in mid 2006—BUT
    - * Opportunities for interim reductions but not yet developed to a point of commitment. Not much opportunity for reduction in high salinity plant. All modelling of Port Waterways (see below) is based on assumption that discharges will continue from high salinity plant.

Workshop Comments & Questions

Q How much confidence do you have in the nutrient values? (eg error bars and confidence in numbers) What research was undertaken into sediment fluxes?

A There is some discrepancy between monitoring and modelling which is mainly attributable to chlorophyll and the impact of not being able to model macro algal communities. There has been quite a bit of investigation into sediment fluxes; but the numbers generated by laboratory and field studies are not reliable at this stage as there is a large discrepancy between lab data and modelled data.

It was agreed that a 'feedback loop' might need to be incorporated into the Port Waterways model to account for reductions in sediment fluxes.

- SA Water supports a staged approach to setting and reaching targets. As further research is undertaken, the WQIP can be adapted.
- There is time for implementation. Peter Pfennig believes that provided that there is commitment, community will probably exercise some patience
- Relative impacts of nitrogen & phosphorous need consideration.
- Re catchment sources: 2,500 ha of highly urbanised catchment drains directly to West Lakes which in turn drains directly to the Port River. For comparison, 4,500 ha of urban catchment drains to the Barker Inlet Wetlands)
- West Lakes may have additional issues in the form of a not insignificant freshwater pollutant source as above

Adelaide Coastal Waters Study Model—Chari Pattiaratchi

Objectives

To model the seasonal patterns of water movement along the metropolitan coast so that the possible role of suspended solids and nutrients in seagrass losses along the Adelaide coastline are better understood.

Overview of model

A 'hydrodynamic' model that describes wave patterns, water circulation and the transport of dissolved materials and particles in the Adelaide Coastal Waters between Port Gawler and Sellicks Beach.

Model components

- SWAN—looked at bottom currents; whether re-suspension occurs and how much

- Sediment transport—considers particle size and re-suspension. Criteria used for re-suspension were the measured wave currents and sheer stresses. This gave resultant bottom sheer stresses and whether this data resulted in re-suspension of particles.
- Hydrodynamics uses the Estuary and Lake Computer Model (ELCOM)
- Field measurements were obtained from buoyant drifters (pictured below off the mouth of the River Torrens during March 2005) which have been used to help validate the model

There is no water quality component to the model.

Scenarios
Model was used for prediction of past (1965), present (2004) and future (2020) scenarios. The model is run over two separate six-week periods; one 'dry' and one 'wet'. The scenarios are run with identical weather conditions to aid comparisons. Post–1965 there was significant reduction in flow from Torrens due to Kangaroo Creek Reservoir.

Outcomes
Key outcome relevant to Port Waterways is the confirmation of the scale and timing of the eddy that forms at the entrance to the Port River.

- Particle tracking information shows that water from Bolivar moves south into Barker inlet during winter, this was observed in the Port River model. These circulation patterns were observed independently in both models.
- The majority of the suspended solids in the Adelaide Coastal waters were due to Penrice, which is located within the Port River.

Port Waterways model—Doug Treloar & Peter Christy

Objectives
Provide a basis for developing a more comprehensive/effective ambient monitoring program linked to WQ targets in WQIP.

Overview of model
Delft3D uses a curvilinear grid with a much finer resolution that what was used in the ELCOM model. There are 10 vertical sigma layers, which change in thickness with varying water depth. The Port River model took a great deal of information from the MFP modelling done in the mid 1990's. Simulations are undertaken for a typical winter scenario.

Model components
- Delft3D software used
- 3-Dimensional Hydrodynamic modelling of the waterway during winter 2004 (May & June).
- Model set up by Cardno Lawson & Treloar
- Water quality model coupled to the hydrodynamic model so that dispersion, dilution and mixing of pollutants are properly described.
- Water quality model takes into account stratification in the water column.
- Model incorporates a wide range of biological & non-biological processes.
    - Assimilation of nutrients by phytoplankton
    - Growth & mortality of phytoplankton & grazers
    - Deposition & release of nutrients from sediments
    - Nitrogen & phosphorus transformations
    - Light attenuation & day length
    - Turbulence

- Measurement criterion—90th percentile value for each key water quality parameter was determined during a modelling scenario at each reference location

Background

The principal sources of nutrient discharges to the Port waterways at the start of this project are outlined in Table DW1: The main contributors are:

- Penrice Soda Ash plant @ Osborne (ammonia)
- Port Adelaide WWTP @ Bower Road (ammonia, nitrate, nitrite, phosphorus & silica)
- Bolivar WWTP (ammonia, nitrate, nitrite, phosphorus & silica).

Note that the Port Adelaide WWTP was decommissioned in October 2004 and replaced with a new facility co-located at Bolivar

Comments on model operation

- Chlorophyll *a* is the main component of the model (Chl *a*)
- Model run without waves; purely tidal movements.
- Very strong tidal influence at all sites.
- Atmosphereric deposition may be quite variable due to errors in calculation.
- Secondary stratification is due to hyper saline discharge at Penrice.
- Reference data (baseline for targets) was 2004.
- Many of the modelled processes are temperature dependent.
- Algae separated into diatoms and non-diatomic algae: good data was available and diatoms are the majority of flora.
- Includes regional circulation patterns from AWCS model.

Modelling scenarios and results

- A number of scenarios were modelled.
    - Progressive reductions of ammonia discharges from Penrice.
    - Progressive reductions in nitrogen & phosphorus discharges from Bolivar.

Note that all scenarios included the relocation of the Port Adelaide WWTP to Bolivar.

WAQ model determines the NH4 concentration throughout the entire modelling grid for each of the varying Penrice discharge scenarios:

- Reference locations about 1,500 m from the Penrice effluent discharge point were used to track the reductions in ambient NH4 as the Penrice discharges were decreased.

Table DW1 Nutrient sources, October 2005

Annual nutrient loads—Port Waterways (as at October)

	Total Nitrogen	Total phosphorus
	tonnes	tonnes
Point Source Loads		
Pt Adelaide WWTP	0	0
Bolivar WWTP (high salinity)	104	44
Bolivar WWTP (low salinity)	408	163
Penrice Soda Ash facility	820	0.7
Diffuse Sources		
Groundwater	10	0.25
Internal loads (net sediment flux)	<100	<10
Atmospheric	32	2
West Lakes	43	6.3
Net tidal import	Not determined	Not determined
Stormwater discharges—Local	2	>0.2
Stormwater discharges—Barker Wetlands	7	0.9
Stormwater discharges—Range & Magazine Ck wetlands	2.5	1
Stormwater discharges—Dry Creek	11	1.0
Stormwater discharges	0.4	0.04
Stormwater discharges—Helps R drains	1.1	0.2

Modelling uncertainties

- Macro algal biomass and growth not measured in the preliminary field studies yet macro algae are probably a significant component of primary production.
- The model was calculating more chlorophyll production in Barker Inlet than was measured in the water column.
- Contribution towards total chlorophyll production by macro algae was estimated and included in the data used to calibrate the model.
- Modelling period covered winter.
- Growth responses are lower.
- Discharges from Bolivar are at their very maximum.
- Water quality objectives were difficult to apply to this study.
- Is the Port waterway a true estuary or should it be regarded as a marine embayment?
- Nutrient sediment interactions were proven very difficult to quantify.
- Flux rates chosen by trial and error until the model ‘worked’.
- Made the more difficult by the closing down of the Port Adelaide wastewater treatment plant in October 2004.
- Is it desirable to recalibrate the model to field data collected since the Port Adelaide WWTP closed down?

Table DW2 Modelling issues/questions and workshop response

Issue	Comment/Recommendation
Chlorophyll as key indicator WAQ model – Chl *a* is main focus Do we accept Chl *a* as an indicator of ecosystem health? Would there be residual Chl *a* in dead but not mineralised cells?	Chl *a* can be seen as a manifestation of nutrients. However the causal link between Chl *a* and environmental values has not been demonstrated. Need to translate Chl *a* and macroalgal growth to provide that link. Need to understand whether the target of 1 ug/L will meet WQ objectives, ie Ulva growth. Is it worthwhile using the Delft3D ECO module to refine the macro algal portion of the system/model? Might need to compartmentalize Chl *a* targets throughout the study region in order to reflect current conditions. Note: Coastal monitoring shows that Chl *a* concentrations inshore are higher in summer
Was **phytoplankton** in drain channel at Bolivar considered?	No—it was considered to be a detrital nutrient, which is believed to be a good estimate due to the probability that the freshwater algae will die once entering the marine environment.
Ulva Is Ulva naturally present—or is the WQ objective unrealistically aiming for elimination of Ulva?	Ulva is naturally present however we need to make an assessment of what we would like to achieve for an amount to be present and a target to achieve this.
Seasonality No simulation in summer—modeling took place over 6 week period from 25 May to 21 June.	With more resources, it would be desirable to simulate a summer scenario. The study would benefit from a supporting laterally averaged modeling facility able to be run continuously over the seasons and over some years (two or more). One that fully resolves through the water column and captures the hydrodynamics, thermodynamics, pollutant transport, water quality and primary production.
What is the **annual cycle of nutrients** within the Barker Inlet?	It is higher in winter due to more discharges and slower uptake processes. Phosphorous discharges into Barker Inlet from Bolivar have a long residence. A model as above will be able to yield this information.

Issue	Comment/Recommendation
Stratification: Stratification in the upper River (due to Pt River WWTP) is embedded in the model. In summer this may be different?	Stratification still occurs despite closure of WWTP. There are also thermal stratifications. Perhaps need to run the hydrodynamic model again without the Port Adelaide WWTP to get the flow and density data particularly in the upper Port. River and see any stratification. The Port Adelaide WWTP was never a large influence on stratification. Stratification in the upper Port River should be examined with regard to drainage off the 2,500 ha of West Lakes catchment.
Impact of eddy Does the model replicate the eddy from the Port River outlet as shown in ACWS model?	Yes, but needs verification. Suggested approach: Select an offshore point that is in both models and compare results of cross sections. Also need to consider that the northern region above both models.
Shipping impacts on WQ in the shipping channel	Field surveys in the Port River for validation demonstrated turbidity plumes after each ship passes through the channel.
Pt Adelaide WWTP SAW closed Port Adelaide WWTP shortly after calibration. This resulted in a significant reduction in nutrient levels. This data should have remained in the calibration. Is there a measurable change since the change in discharge @ Port Adelaide WWTP? This may provide an indicator of time to recover.	May need to look at running the hydrodynamic model again without the Pt Adelaide WWTP to get the flow and density data particularly in the upper Port River. Again with reasonably correct impact from West Lakes for a complete picture. WWTP closure represents an 'event' change in conditions. Any monitoring either side of this is valuable with a view to a model running six months before and after the 'event' (Oct 2004).
Catchment Impacts Dry Creek higher than other catchments	This was predicted as it is hard to install gauging weir.
Modeling of Bolivar nutrient discharge loads Discharge loads used in the WAQ model were based on the higher winter values ñ no diversion of nutrients through horticultural re-use as occurs in summer.	Extrapolation from the winter based modeling to summer conditions (including the reduced discharges from Bolivar) may not be valid. Reconfiguring the WAQ model for the summer period would be desirable. This would require additional field work to gather data during summer to validate the model.

Issue	Comment/Recommendation
Choice of model It was suggested using a laterally averaging 2D model for the channels, which may allow for the larger running of a model for several years.	This will not resolve the tidal flats. Need to understand the processes before we run it for a longer time series and only a 3D model will do this. A laterally-averaged model DOES take into account tidal flats. Indeed it resolves the geometry of tidal flats and their flooding/drying very well.
	The only thing it does not do is provide any variation across the thin segments, which constitute the vertical resolution. The Port River waterways are predominantly channels and ideally suited to this approximation. What such a formulation gives in return is the vertical resolution that is important in getting the hydrodynamics, the thermodynamics, the transport of pollutants, the water quality and the primary production reasonably correct over long periods of time so that seasonal trends can be extracted. It is also the best modeling vehicle for the Port waterways in which to include a comprehensive sediment diagenesis module which will demand runs over long terms to enable the longer term and often seasonal or stratified dependent sediment processes to manifest themselves in the model.
Validation It is important to verify the results. (Although the validation process is always incomplete.) Some values were different from modeling results. Some of the inconsistencies may be due to Port Adelaide WWTP coming offline (which is not included in the model)	It was suggested convening another forum to work out methods for further verification of the model, through targeted monitoring .Adaptive management approach requires a loop linking monitoring and further model development.
Boundary of the model: Deficiency in modelling north of Bolivar	Acknowledged, unsure whether the region will be expanded in future.
Understanding of ecological processes	- Last aerial photography was in 1998—due to be repeated. - Need greater coordination of monitoring efforts with different agencies, including A&MLR NRM Board. - The interaction between macro algal, Chl *a*, phytoplankton and sediment is the key issue in relation to water quality. - An additional indicator is red tides. Need to reduce the spatial and temporal scale of the blooms and include this in objectives.

Issue	Comment/Recommendation
The big picture: It is important to recognize that reducing nutrient levels will have impacts that are not necessarily predicted or well understood—or example, potential reduction in King George Whiting abundances in the Barker Inlet. Some of the indicators in the WQIP may be impossible to change—for example mangrove/samphire loss due to land reclamation.	Need a strategic overview of water quality interactions and a communication strategy to highlight the uncertainties in the process and set priorities for monitoring that have community relevance as well as scientific relevance. WQIP needs to communicate the 'bigger picture' of a changing system and some of these impacts may not be what people are expecting.
Nitrogen: Phosphorous ratio: While Phosphorus is the limiting nutrient, is it a priority for reduction? How does Nitrogen concentration in Port River affect ACWS? How confident are we on the persistence of Nitrogen from the Pt River into the ACWS?	Need to know where and how Nitrogen limited region of ACWS overlap with the Phosphorus limited Port River. Nutrient limitation bio-assays would be needed to show N&P limitation.

Other workshop comments

- Important to get silica right as it is a key component of diatom growth.
- Take a long term view to modelling and WQ improvement—through 'step changes', Ongoing monitoring and development of the model.

Selecting WQ targets

- Derivation of permissible discharge limits for each facility
  * Used the South Australian Water Quality Environment Protection Policy (EPP) guideline value for ammonia in the marine environment.
  * Used the ANZECC 2000 default water quality guideline values for nutrients in marine environments (chlorophyll *a* in particular) (ANZECC states that when there are no reference sites —the median should be adopted).
- It is believed the ANZECC guidelines for central marine waters are too high as they were based on the only data, which was available for SA at the time from the Port River. EPA has therefore created targets based on the average values from South Eastern Australia, South Western and South. Used marine values, as Port waterways are not typical estuarine.
- It was noted the current targets are 'interim' targets.
- WQ value of total ammonia (NH4) may be incorrect due to its effect as a toxicant rather than a nutrient. Should have been 910ug/L, not 200 µg/L.

Table DW3: ANZECC 2000 default water quality guidelines

	Chl *a*	TP	FRP	TN	OxN	NH4
	ug/L	*ug/L*	*ug/L*	*ug/L*	*ug/L*	*ug/L*
Marine						
SE Australia	1	25	10	120	5	15
SW Australia	0.7	20	5	230	5	5
Average values	**0.85**	**22.5**	**7.5**	**175**	**5**	**10**
Sth Central Aust	1	100	10	1000	50	50
Estuarine						
SE Australia	4	30	5	300	15	15
SW Australia	3	30	5	750	45	40
Average values	**3.5**	**30**	**5**	**525**	**30**	**27.5**
Sth Central Aust	5	100	10	1000	100	50
Gulf St Vincent						
SVG_184		6	5	170	<2	<2
SVG_188	0.8	31	4	350	<2	<2
SVG_203	0.5	12	4	200	<2	<2
Average values	**0.65**	**16.3**	**4.3**	**240**	**<2**	**<2**

Workshop responses and comments

- In relation to setting targets, it was suggested that reference sites of estuaries in more pristine condition with similar characteristics could provide a useful context for the relevance of Chl a values as indicators of a healthy system. This has been the approach taken in Queensland for Moreton Bay. Possible reference sites include:
    * Venus Bay
    * Coffin Bay.
- SA Water is happy to consider these as ‘interim’ targets. They prefer to set targets within a range – with current targets included in WQIP as the bottom end. (Current targets are 90th percentile). The most important objective is meeting environmental values—and this may be achieved without meeting the lowest targets
- N:P rations are in the systems are currently 80/100:1. Phosphorous is the limiting nutrient in the model

Previous modelling in the region

- MFP most detailed and only 3D model.
- Other 2D models developed for region, including West Lakes as a 2D laterally averaged and Barker Inlet wetlands [CFM did this model development work in the early 1990s. We offer a different range of models now but recently (a few years ago) we ran our original ESTRAFPH (ESTuary River And Flood Plain Hydrodynamics) model on West Lakes to indicate the movement (concentrations) of copper sulphate through West Lakes and through the Port River up as far as North Arm prior to proposed dosings to eradicate the infestation of Caulerpa taxifolia. ESTRAFPH is a verified model of West Lakes and the Port River with accurate scalar transport and has the feature that the West Lakes outlet gates at Bower Road

are represented as an 'internal boundary condition' in the model which makes it a seamless model between West Lakes and the Port River using a measured (and theoretically supported) rating curve for the head difference-discharge through the outlet conduits fitted with non-return flap-valves].

- May provide some good information to put forward a case for lowering levee banks to allow tidal flow into samphire areas.
- Garry Tong (CFM) has some information about the partings and the hot water outlet from Torrens Island (The partings area is not a reduction of diffusion/dispersion in Barker Inlet).

Table DW4 Integration of ACWS and WQIP

Issues/questions	Comment/Recommendation
Need to know confidence of discharges from Port River into ACWS	It was recommended creating a cross section between the two models and measuring flow velocities and concentrations in order to integrate the results. Create a line between the outside boundary to approximately Largs jetty.
Are they based on same data?	Each model has been developed for specific regions and purposes; however they are both based on the same wind data and nutrient sources/inputs. It is important to cross reference each model.

Table DW5 Priorities for future work

Priorities	Resources/Timing
Summer modeling/data – 2 stages + validation	Modeling ~ $50 K Data ~ $100 K Time ~ 6 months Total budget ~ $150,000
Macro algae in model – 2 options including sediments/macro	Total budget ~ $200–$500,000 (depending on option) Time ~ 6–12 months
Reference site(s)	Method: Desktop study Budget ~ $1k/site Total ~ $5,000–$10,000
Reverse bio-assay	Method: university research project

Other Action items

- Chl *a*: Applicability of 1mg/L Chl a target (ANZEC target) and its representation in the model.
- Terms of reference for future ACWS and WQIP—ensure integration and cross referencing.
- Communication strategies in relation to WQIP.

Additional comments received after the workshop

Peter Petrusevics (Oceanique Perspectives/Flinders University)

Comment re Page 9 'understanding of ecological processes'

Not exactly in total agreement with comment 'interaction between macro algal, Chl *a*, phytoplankton and sediment is the key issue in relation to water quality'. I suggest there are other factors such as the high presence of coloured dissolved organic matter (CDOM), which could be used as an indicator of ecosystem health.

I borrow the following comments from a study on Spatial and Temporal Distribution of CDOM in Narragansett Bay Rhode Island: Implications for Phytoplankton in Coastal Waters by Keith et al (2002).

> The ability of coastal and estuarine waters to transmit sunlight affects planktonic productivity as well as submerged aquatic vegetation (SAV). Changes in light transmissivity may be due to natural and anthropogenic factors. Nutrient enrichment from point and non-point sources can stimulate water column production, which reduces light transmission to SAV. Monitoring the optical properties of local waters at several sites on a temporal basis could provide diagnostic information on natural and anthropogenic factors affecting the capacity of waters to provide sufficient sunlight to planktonic and macrophytic vegetation for photosynthesis and growth etc....

The Barker Inlet region, based on results from the ACWS, exhibits one of the most striking examples of a CDOM environment in Adelaide metro area. Attached is a Observations of the Bolivar WWTP discharge using SeaWiFS satellite data in a CDOM-dominated marine environment (Petrusevics and Dekker 2005) which shows the strong absorption by CDOM in relation to algal material and phytoplankton in Barker Inlet. Absorption due to CDOM is 88% of total absorption. These data show a positive and reasonable correlation with Nitrogen as Ammonia from the Bolivar WWTP. However I expect other local factors such as decomposition of marine and terriginous material play an important role.

In this respect I would like to propose a simple study to use MODIS satellite data to measure the spectral response in the blue-green band at three stations positioned along an east-west transect to measure the variability and trend in water quality in Barker Inlet and coupling between the Barker Inlet and the Adelaide Coastal waters. The MODIS measurements would be calibrated by spectrophotometer analysis conducted by AWQC to measure the percentage absorption of the main constituents present, thus quantifying the MODIS measurement.

Garry Tong (Computational Fluid Mechanics)

Impact of Eddy

Eddying structures in models is a tricky business. Their simulation primarily tests a model's ability to transfer momentum across mean streamlines (inducing flow) to a region of closed streamlines (recirculating or eddying flow). A 'one-point' comparison would be insufficient. Size and shape of eddying zone should at least be considered along with the turbulence model employed (to effect the turbulence momentum transfer) and the numerics of the model to ascertain whether this transfer is physical or an artifact of the numerical scheme itself, which is quite common.

Acknowledgements
The workshop was held as part of the development of the WQIP for the Port waterways. The Australian Government Department for Environment and Heritage has provided considerable financial assistance towards this work. The financial contribution of SA Water to the cost of holding the workshop and the provision of a venue are also acknowledged.

The lively and robust discussions held during the workshop were facilitated by Natasha Davis of Sustainable Focus <www.sustainablefocus.com.au>.

Attachment 1—Agenda for Port Waterways and Adelaide Coastal Waters Study Stakeholder Workshop

8:45-9:00	*Coffee served*	
9:00	**Welcome**	*Peter Pfennig*
9:05	**Overview** - Workshop content and process - Desired outcomes - Housekeeping	**Natasha Davis** (Facilitator)
9:15	**Introductions**	*Participants*
9:25	**Session 1: Background Information**	
	Port Waterways WQIP and ACWS	**Peter Pfennig**
	Model for Adelaide Metro Coast	**Chari Pattiaratchi**
	Questions and Discussion	
10:30	*Morning Tea*	
	Continue Session 1	
10:50	- Port Waterways Mode	**Peter Christy and**
	- Questions	**Doug Treloar**
11:30	**Session 2: Hydrodynamic Model** Facilitated Discussion: - How do the results of the ACWS and Waterways Models differ? - Is there consistency between previous modelling work and the current study? - What gaps are there in the models and how can these be resolved?	**Natasha Davis**
12:30	**Roundup and confirm agenda for afternoon**	**Natasha Davis**
12:45	*'Working' Lunch* - Are there opportunities to combine the information derived from the models used in the ACWS and the WQIP?	
1:45	**Session 3: Water Quality Issues** Facilitated Discussion: - modelling the nutrient characteristics of the Port Waterways —how sound are the nutrient targets? - What further information on nutrient status is needed? - What is applicability of water quality criteria (from ANZECC 2000)	**Natasha Davis**
3:00	*Afternoon Tea*	
3:30	**Session 4: Developing the Models and Recommendations** - Priorities for dealing with gaps in models - Priorities for nutrient modelling - Strategies for assessing WQ criteria	**Natasha Davis**
4:45	**Conclusion and where to from here**	**Peter and Natasha**

Appendix G

Nutrient reduction options discussion paper, November 2005

1. INTRODUCTION

As part of the preparation of the WQIP, an independent assessment of nutrient reduction options was undertaken for the Penrice soda ash production plant and the Bolivar Wastewater Treatment Plant. The following presents the findings from this investigation.

2. Penrice

2.1 Current Wastewater Management Systems

2.1.1 Wastewater Generation

At the Penrice site at Osborne, around 370,000 tonnes per annum of crude soda ash are produced by the Solvay process. The Solvay process can be summarised by the overall reaction:

$$2\ NaCl + CaCO_3 \rightarrow Na_2\ CO_3\ + CaCl_2$$

Ammonia (NH_3) is used as an intermediary to allow the above reaction to occur. Whilst ammonia is not actually consumed in the process, the nature of the process is such that some ammonia loss to the wastewater is inevitable. Also any spills or leaks of process fluids will result in ammonia contamination of the wastewater.

The wastewater from the soda ash production facility comprises of spent seawater from cooling systems (nominally 90% of the volume) and process wastewater. The process wastewater includes the residue from an ammonia recovery distillation process and miscellaneous spills and leaks from the process (minor amounts). If a distiller is at the end of its operating cycle (2-3 years) and needs a clean, hold ups and flooding (from its internal condition) will contribute additional ammonia loss. The volume of wastewater varies according to climatic conditions, which affects the cooling water requirement but ranges from around 70 to 100 ML/d with an average of around 80 ML/d.

2.1.2 Wastewater Management

Currently all wastewater is directed to a main channel which, after dosing with a flocculent, is then directed to a sedimentation basin for removal of solids. The overflow from the sedimentation basin is directed to the Port River.

2.1.3 Final Effluent Characteristics

Final effluent characteristics are presented in Table 1. The significant contaminant from the point of view of managing the Port Waterway is ammonia (represented as NH_3-N in Table 1).

Table 1 – Penrice's Discharge Effluent Quality

Parameter	Unit	Value	Source (Giles, 2003)
Ammonia (as N)	mg/L	39[1]	Average
Total Oxidised Nitrogen	mg/L	0.6	Average
Total Nitrogen	mg/L	35	Average
Phosphorus (Reactive)	mg/L	<0.04	Range
Total Suspended Solids	mg/L	74.8	Average
pH	7.2-9.6	Range	
Total Dissolved Salts	mg/L	~45,000	Average

2.2 National and International Practice

Approximately 25 million tonnes per annum of soda ash is produced worldwide by the Solvay process. Penrice is the only Australian producer of soda ash. In all Solvay plants, there is discharge of significant amounts of ammonia to a waterway. Reduction of ammonia discharges is being achieved by improving the control of the process but complete ammonia removal is not feasible. No firm evidence of sites using processes to remove ammonia from the wastewater was identified, although at a plant in the UK there has been a trial of a new technology for "ammonia digestion in saline conditions" (Brunner Mond, 1998).

Data on ammonia losses from Solvay plants was obtained from the Internet and this is summarised in Table 3 . Also data provided by Penrice is presented in Table 5. According to the ESAPA (2004), "with modern and adequate equipment and with the objective to remain economically sustainable, it is possible to keep the annual average ammonia losses as low as 0.9 kg NH_3-N/t soda ash. However older equipment may no (sic) be able to achieve these conditions and yet may not be economically replaced." It also reports an indicative range of 0.3 to 2 kg NH_3-N/t soda ash As can be seen in Table 3 Penrice operates outside this range, which may be due in part to the plant being relatively old. It should also be noted that ammonia loss from the distillers is a function of ambient temperature with lower temperatures favouring lower levels of ammonia (Reilly, 2005). Therefore Solvay plants operating in the Australian climate may not be able to achieve as low levels as their European counterparts.

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[1] The fact that average NH3 –N is greater than total nitrogen is an outcome of the statistical analysis. For individual analyse NH3 –N would be less than total nitrogen.

Table 2 - Ammonia Emissions To Water For Soda Ash Plant

Site	**Soda Ash Production** tpa	**Ammonia Discharge To Water tpa as N**	**kg NH_3 -N /t soda ash**
Indicative Range	-	-	0.3-2[1]
Solvay – European Union	4,200, 000[1]	2300[2]	0.5
Solvay – Devnya (Bulgaria)1,200,000[1]	1,300[2]	1.1	
Brunner Mond (Northwich, Cheshire, UK)	1,000,000[1]	901[2]	0.9
Penrice	370,000	~900	2.65[3]

Sources:
1. ESAPA, 2004
2. Brunner Mond, 2002
3. Penrice, 2005b

Table 3 Ammonia Losses (Data Provided By Penrice, 2005a)

PLANT	Ammonia Usage (kg/t soda ash)	Ammonia Discharge (kg/t soda ash)	Data Source	Comment
INDIA	2.8-3.0	n/a	PSP direct	-
Europe 1	2.73	1.27	PSP direct	-
Europe 2	1.92	0.171	PSP direct	End of Pipe Sol.
Europe 3	2.0	1.0-1.2	PSP direct	(to 6 month retention pond)-
CHINA 1 Quindao	5.0	1.65	State EPA China	-
CHINA 2 Shandong	4.8	1.27	State EPA China	-
CHINA 3 Dalian	18.8	4.1	State EPA China	50 % Dual Process
CHINA 4 Tangshan	6.0	1.98	State EPA China	-
CHINA 5 Tainjing	10.4	1.8	State EPA China	50 % Dual Process
CHINA 6 Shinjang	6.0	1.67	State EPA China	-
CHINA 7 Henan	6.1	1.86	State EPA China	-
CHINA 8 Guengdou	9.87	3.25	State EPA China	-
CHINA 9 Inner Mongolia	3.82	3.45	State EPA China	-

The Penrice current discharges appear to be above the ESAPA indicative range and the practice from some European plants. If Penrice met the ESAPA guideline of 0.9 kg NH_3-N/t soda ash the ammonia discharge would be around 333 tonnes per annum. However their ability to do this may be limited by the age of the plant and the different climatic conditions.

The conclusion from this is that there is no example of 'international best practice' where ammonia emissions are reduced to the type of levels that are likely to be acceptable for the Port Waterways. Consequently there are no 'ready made' technical solutions to achieve the required ammonia removal of about 75% from the wastewater stream. However it appears that Penrice's ammonia emissions are relatively high compared to European industry standards (see Table 3).

2.3 Nutrient Reduction Options

2.3.1 In Plant Modifications

2.3.1.1Alternative Methods of Soda Ash Production
The commercial methods of synthetic production of soda ash do not differ significantly worldwide. A modified "dual process" used in China produces ammonium chloride, which is used as a fertiliser for rice (ESAPA, 2004). By freezing the ammonium chloride out of feeder liquor, a liming distiller is not needed. The viability of such a process is dependent on the competitive manufacture of, and a market for, the ammonium chloride. The ammonium chloride produced by an Osborne sized "dual process" is multiples of Australia's total imports. However, this type of process does not assure zero loss of ammonia and therefore environmental concerns remain.

2.3.1.2 Relocation
Removal of the Penrice facility from Osborne would reduce the annual total load of nitrogen discharged to the Port River marine environment by more than half, from 1830 tonnes per year in 2002/03 to approximately 730 tonnes per year. It would also contribute a small reduction in phosphorous discharge of approximately 0.7 tonnes per year.

Relocation or closure of the production facility would raise many social, environmental and economic concerns. Closure would be uneconomical for Penrice and unlikely to be an acceptable outcome. Relocation of the facility would also be a complex task and not an economically viable option for Penrice. The social effect of relocation on the staff and local community at Osborne, must be taken into account, along with the likelihood that Penrice will be capable of acquiring an alternative suitable site that can be adequately staffed. Currently, the Penrice soda ash production facility employs approximately 185 staff.

Relocation would require the new facility to be located near the coast due to the process demand for huge volumes of brine as well as the requirement for a receptacle water body for disposal of waste brines. Therefore this option would rely on locating a marine environment less sensitive than the Port River in order to minimise the impact of ammonia discharge. Requirements for the process include economically available steam and limestone. Currently 1.2 million tonnes of low cost steam each year is provided by the Osborne Cogeneration Plant and limestone is sourced from a mine owned by Penrice at Angaston.

Consideration must be given to the distribution of product from a new location. Penrice uses road rail and sea to supply products to Australia and the world. About half of the soda ash produced at Penrice is sold to glass manufacturers, including ACI (West Croydon SA, Brisbane, Melbourne, Perth, Sydney) and Pilkington (Ingleburn & Alexandria in NSW and Dandenong in Victoria).

Other considerations include the impact of air dust emissions, odour and noise control and the installation of a solids recovery and disposal system. Of course it must be ensured that ammonia discharge does not cause the same environmental problems in new location.

Taking all of the above-mentioned points into consideration, this option is not feasible.

2.3.1.3 Process Optimisation

Penrice are currently pursuing ways to reduce ammonia emissions by optimising the existing process. Reductions in ammonia emissions of around 300 tonnes between 2002 and 2004 were targeted by various initiatives.

Failures of tubes used in towers for cooling ammonia containing liquors have been identified by Penrice as a source of ammonia loss. A program to replace these tower tubes is currently underway. Regular maintenance and replacement of tower tubes is sound plant management and should not be considered as reducing the ammonia losses.

The equilibrium of ammonia and ammonium ions in water is altered by pH, temperature and pressure. Good control of these conditions will reduce loss of gaseous ammonia throughout the plant. Several other process areas have been looked at by Penrice to reduce ammonia use and loss. These include stabilising distillers by allowing liquor stocks to float up and down between set points, increasing gas washer cleans, reviewing rapid or unplanned shut down procedures and optimising steam stripping of ammonia. Attention to these aspects of plant operation is sound practice but would not make fundamental changes to the amount of ammonia discharged per tonne of soda ash produced.

Containment of ammonia can also be improved, particularly by installation of comprehensive overflow equipment and by upgrading ammonia pipe networks.

Steam stripping of ammonia appears the obvious process step to look at improving since the yield of recovered ammonia is dependent on the amount of steam used for stripping. However it should be noted that:

Plant operation is an optimisation of many parameters to achieve the lowest cost operation; there is not an infinite supply of low pressure steam as it arises from the steam-power balance

To remove additional ammonia with the existing plant would require additional plates in the distiller proper. This would increase the required steam pressure with impacts on the power-house operation (increased compression costs) or would require a compensating reduction in the pressure drop over the distiller heater by replacing the plates with packing. This strategy would not be without process risk.

Also, there are diminishing returns from increasing steam flows in ammonia removal and therefore it is not likely to be economical to increase steam flows in order to recover higher proportions of ammonia.

In conclusion, process optimisation will deliver some reduction in ammonia discharge but would be able to achieve target levels.

2.3.1.4 Process Stream Separation

This is not a nutrient reduction option per se but could be considered as a way of aiding economic use of treatment technologies.

Ammonia in the distiller outlet is diluted by its mixing with relatively uncontaminated cooling water (seawater). This is advantageous to the current operation as distiller outlet is supersaturated with gypsum and would rapidly block the drains that direct the wastewater to the sedimentation basins. The seawater reacts with excess lime in the distiller liquor to improve the settling characteristics of the solids in the sedimentation basin and dilution of the distiller outlet with seawater reduces the calcium chloride concentration and improves the drying properties of the settled solids.

Separation of the distiller outlet from the rest of the wastewater would in theory provide a stream higher in ammonia and possibly less costly to treat. However handling of an undiluted distiller outlet would be problematic and it appears unlikely that this approach would offer net benefits.

2.3.2 Alternative Disposal Sites

2.3.2.1 Diversion of Wastewater to Bolivar WWTP

The diversion of some or all of the wastewater to the Bolivar WWTP was considered. This does not appear to be feasible due to the high salinity of the wastewater and the fact that biological treatment may not be the best treatment technology for this effluent (refer Section 2.3.3.1). Also the materials of construction of the Bolivar WWTP would not be suitable due to the corrosion potential of the wastewater.

2.3.2.2 Long Ocean Outfall

The effluent could be directed further out to sea such that impacts on fragile coastal environments are reduced. A dual pipe system may be required to allow a pipe to be taken off-line for cleaning. The location of the outfall would have to be carefully researched to ensure that it would indeed provide a better overall environmental outcome, i.e., not simply relocate the problem. The cost of this would be significant and political and community acceptance would be unlikely.

2.3.3 End of Pipe Treatment

2.3.3.1 Biological Treatment

Ammonia could be removed from the wastewater by biological nitrification and de-nitrification. This is routinely done for domestic wastewater. There is a range of technologies available but for the purpose of determining first order costs an attached growth bio-filter type process was considered. The high salinity of the water may tend to inhibit the process leading to larger process units. Biological processes require a carbon source with a ratio of around 10:1 for COD:TKN (IWES, 2003), this is approximately equivalent to a BOD:TKN ratio of 5:1. There is little carbon in the wastewater and therefore there would be a significant cost associated with the purchasing of a carbon source in order to achieve the required level of nitrogen removal (e.g., molasses, methanol).

2.3.3.2 Ion Exchange

Ammonium can be removed by ion exchange. One such technology is NanoChem that utilises a zeolite base resin. Prima facie this approach does not appear feasible on its own due to:

High levels of other ions that would compete with the ammonium.

Need to convert all ammonia to ammonium by lowering the pH of the water to below 7.
However ion exchange may have a role to play in tandem with other technologies.

2.3.3.3 Breakpoint Chlorination

Ammonia can be removed from water by dosing of chlorine at high levels to completely oxidise ammonia to nitrogen gas. Usually it is considered economical if the ammonia level is low, the order of 2 mg/L. To operate in this application, lime may have to be dosed to replace alkalinity and the chlorine remaining in the wastewater would have to be removed by further chemical dosing before entering the waterway.

2.3.3.4 Air Stripping - Tower

Air stripping is used to remove ammonia from wastewater in concentrations of 10-100 mg/L with an efficiency of 60-95%. Large doses of lime are added to increase the pH to approximately 11 and the high pH pushes the equilibrium towards gaseous ammonia. The water is delivered to a gas-liquid contactor (e.g. packed tower) for contact with air delivered by a blower. Usually the gaseous ammonia transferred to the air stream is released into the atmosphere in concentrations of around 6 mg/L. This can cause further environmental concerns and some ammonia will still enter local waterways. For higher concentrations of ammonia steam stripping is recommended to be more economical (USEPA, 2000).

The scaling potential of this wastewater would be problematic for this process. There would need to be removal of scaling species (predominantly gypsum) prior to entering the gas liquid contactor. The best way to manage and/or remove scaling species requires investigation but for the purpose of developing order of magnitude cost estimates, lime softening was assumed. Use of a scale inhibitor may be another alternative.

Another problem with this process it that in order to minimise the impact of the discharged wastewater on the receiving environment, the wastewater's pH would have to be reduced prior to discharge to the waterways.

2.3.3.5 Air Stripping - Ponds

Penrice already achieves significant removal of ammonia from the wastewater as it travels from the process to the discharge point. It is likely that this is due to stripping of ammonia by contact with ambient air. This would occur at the surfaces of the channels and ponds and would be promoted by any turbulence such as that occurring at the flow measurement flume. This could be promoted by increasing the pond area, installing cascade devices (i.e., non-mechanical aeration) and/or installing surface aerators into new holding ponds. It is likely that these approaches would not achieve high levels of ammonia removal as they tend not be very efficient. Also the amount ammonia that can be removed will depend on the proportion of ammonia in the gaseous form, a function of pH. An advantage may be that scaling would be less of a barrier than more highly engineered stripping systems. The potential of this approach needs further investigation but for the purpose developing order of magnitude costs it is assumed that 50% of the remaining ammonia can be removed.

2.3.3.6 Membrane Distillation

Membrane distillation is a technology under development for various applications including the removal of gases from liquids. It is used commercially on the small scale from removal of some gases such as oxygen. It may be applicable to removal of ammonia from water and there have been some laboratory studies. However it does not appear to have been commercially proven at this stage and is therefore not a viable option for Penrice in the short to medium term.

2.3.3.7 Reverse Osmosis

Ammonia can be captured from water by reverse osmosis (RO), whereby a membrane is used to concentrate the ammonia in a waste stream. The waste stream is referred to as concentrate and represents between 25 and 60% of the feed volume. RO is a relatively high cost process and would require substantial pre-treatment to be able to manage the highly scaling effluent from a soda ash operation. Given these limitations and the fact that another treatment would be required for the concentrate, RO is not a viable option for Penrice.

2.3.4 Summary of Options

The options considered are summarised in Table 5 below.

Table 4 Penrice Ammonia Management Options

	Key Issues	**Consider Further**
In Plant Modifications		
Alternative Soda Ash Process	None available	No
Relocation	Uneconomic and socially disruptive. Environmental problems not solved, only moved.	No
Process Optimisation	Important although required NH_3 reduction unlikely.	Yes
Process Stream Separation	Not a solution in itself but may assist in the application of treatment technologies.	Yes
Alternative Disposal Sites		
Wastewater To Bolivar	Bolivar does not have capacity to treat the waste. Bolivarís construction materials arenít appropriate.	No
Long Ocean Outfall	Unacceptable politically. Environmental problems not solved, only moved.	Yes[1]
End of Pipe Treatment		
Biological Treatment	Technically possible. High cost.	Yes
Ion Exchange	Does not appear technically viable.	No
Breakpoint Chlorination	Technically possible. High cost.	Yes
Air Stripping – Packed Tower	Technically possible.	Yes
Air Stripping – Ponds	Technically possible.	Yes
Membrane Distillation	Not commercially developed for NH_3	No
Reverse Osmosis	High cost. Produces concentrate that must be treated further.	No

1. Only considered for cost comparison purposes.

The end of pipe solutions that may be applicable were investigated in further detail and indicative costs developed. These are presented in Table 5 below, with the cost of an ocean outfall provided for comparison.

Table 5 Penrice End of Pipe Ammonia Removal Options Indicative Costs

Option	Nominal Reduction In Nitrogen Discharge (%)	Present Value	Unit Cost[2]
Biological Treatment	85	Extreme (> $100 M)	Extreme (>$10/kg N)
Breakpoint Chlorination	90	High ($50-100M)	High ($5-9/kg N)
Air Stripping-Tower	90	Extreme (> $100 M)	High ($5-9/kg N)
Air Stripping - Ponds	50	Moderate ($10-49 M)	Moderate ($1-4/kg N)
Ocean Outfall	100	Moderate ($10-49 M)	Moderate ($1-4/kg N)

The ocean outfall, which was only included for comparative purposes, and the air stripping using ponds were the only 2 options estimated to have moderate costs. All the other treatment options have high to extreme costs. All options appear to be difficult for Penrice to afford given that its annual turnover is around $100M and forecast annual profit after tax for 2005/2006 of $10.2M.

2.4 Conclusions

The following conclusions are drawn:

- Ammonia discharge from the Solvay process as used at Penrice is inevitable and there is no viable alternative process to avoid this.
- Ammonia discharge by Penrice is relatively high in comparison with some European producers. Contributing factors may include the plant being relatively old and the climatic differences. If Penrice could achieve the ESAPA target then the annual ammonia discharge would be 333 tonnes per annum, which is still insufficient to meet the WQIP target reduction of nutrients .
- 'In-plant' modifications are unlikely to achieve desired ammonia discharge reductions of around 90%. However they should continue to be pursued as any reduction in nutrients is to be encouraged.
- Relocation of the operations or re-direction of the wastewater to another location does not appear viable.
- Technologies for removal of high proportions of ammonia from wastewater are available but have not been applied specifically to soda ash wastewater. The costs may exceed Penrice's capacity to pay.

2.5 Future Strategy

Based on this review of industry practice and ammonia management options the following future strategy is envisaged:

- Continued optimisation of the process to reduce ammonia discharge.
- Undertake feasibility study of 'end of pipe' solutions including any necessary effluent characterisation, bench scale tests and pilot plant test-work.

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3. BOLIVAR WWTP

3.1 Current Wastewater Management Systems

3.1.1 Wastewater Generation

The Bolivar Wastewater Treatment Plant (WWTP) collects industrial and domestic wastewater from the Adelaide region. There are two streams treated separately, one the main wastewater stream and the other a 'high salinity' stream that comes from a catchment with high saline water ingress. As with all domestic and industrial wastewater streams there are significant levels of nitrogen and phosphorus.

3.1.2 Wastewater Management

3.1.2.1 Main Stream

The main flow to the Bolivar WWTP of around 160 ML/d is treated by an activated sludge process designed to achieve a high degree of nitrification and 24 mg/L of total nitrogen. The activated sludge process is not conFigured to remove phosphorus. Following this, the wastewater passes through lagoons where de-nitrification occurs lowering the nitrogen level to around 12 mg/L. After this the water is either discharged to the marine environment or further treated in a dissolved air flotation filtration plant and directed to a reuse scheme for irrigation. The proportion of water directed to the reuse scheme is up to 56% during the summer months and is around 25% on an annual basis.

3.1.2.2 High Salinity Stream

A high salinity stream is directed to a 32 ML/d sequencing batch reactor plant that is designed to produce 10 mg/L of total nitrogen. It is not conFigured for phosphorus removal and the treated wastewater is directed to the marine discharge.

3.1.3 Treated Wastewater Characteristics

Bolivar WWTP's average treated wastewater characteristics for 2003/2004 are presented in Table 6.

Table 6 - Bolivar WWTP's Treated Wastewater Quality

Parameter	Units mg/L	Main Stream	High Salinity Stream
Total Nitrogen	mg/L	**10.7**	**9.2**
Total Kjeldahl Nitrogen	mg/L	5.9	3.8
Total Oxidised Nitrogen	mg/L	4.8	5.4
Ammonia NH_3 -N	mg/L	1.5	0.4
Total Phosphorus	mg/L	4.3	3.1

The contaminants in the treated wastewater from the Bolivar WWTP of relevance to managing the Port Waterway are total oxidised nitrogen, ammonia and total phosphorus. Approximately 40% of the total nitrogen of the treated wastewater is organic nitrogen (4.4 mg/L and 3.4 mg/L for the main and high salinity streams respectively)[3]. Organic nitrogen is not considered an important contributor to the nutrient problems in the Port Waterway as organic nitrogen is less likely than other nitrogen forms to contribute to algal or plant growth or be toxic to aquatic species.

3.2 National and International Practice

National and international practices arise from a balance between the capacity of the community to pay for treatment technologies and the public health and environmental outcomes desired by the community. Environmental objectives can manifest as discharge regulations, which are usually informed by some consideration of the capacity of the waterway to assimilate the discharge. As a result of the interplay between economic, public health and environmental objectives there is a wide range of practices throughout the world.

Of relevance to this assignment are those locations where the community considers the receiving waters sensitive and worthy of protection, and where the community has some capacity to pay for the required measures. In the advanced economies of the USA, Europe and Australia, municipal wastewater treatment plants are being installed which are achieving high levels of nutrient reduction. By employing biological processes supplemented by tertiary filtration, median total nitrogen levels of below 5 mg/L are being reported. Biological processes are achieving 1 mg/L of phosphorus and chemical dosing combined with filtration can deliver less than 0.5 mg/L if required.

To achieve levels significantly less than 5 mg/L of total nitrogen, additional wastewater treatment steps would be considered such as ion exchange, air stripping, reverse osmosis and breakpoint chlorination. However these are not commonly employed due to the high capital and operating costs ,unfavourable Life Cycle Analysis and possible other environmental impacts. Despite this there are moves in Queensland to set targets of median total nitrogen levels of less than 2 mg/L.

3.3 Nutrient Reduction Options

3.3.1.1 Process and Plant Optimisation

As with any plant, performance can be improved by optimising the equipment and/or operating practice. For example, during a visit to site, it was observed that the aeration system for the mainstream activated sludge plant was being upgraded. It would be expected that this would improve control of nitrogen removal and show a marginal reduction in nitrogen in the treated wastewater. However whilst there may be other potential improvements, it is unlikely that simply 'tweaking' the process will achieve the required reduction in the nutrients in the Port Waterway

3.3.1.2 Upgrade Activated Sludge Plants To Increase Nitrogen Removal

Both biological treatment streams could be upgraded to remove nitrogen to around 5 mg/L. In the

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[3] SA Water have noted in a response to a draft of this document that "of the TKN, approximately 0.5-1 mg/L is in the suspended solids and that the non-biodegradable TKN (i.e. filtered) is about 2 or 3mg/L. This means that to achieve TN of about 5mg/L (section 3.2) means NH4+NOx <2.5 to 1, which is very difficult."

case of the main stream, this would primarily involve construction of additional tankage and modification of the existing tankage to increase the volume of the anoxic zones. The existing aeration tanks were located with space allowed for enlarging the tanks. In addition, pumping stations for recirculation of mixed liquor would be required and possibly also carbon dosing facilities.

Increasing nitrogen removal in the high salinity plant would be more challenging. The sequencing would have to be reconFigured to incorporate carbon addition or some recycling of mixed liquor. This would serve to reduce the capacity of the plant necessitating additional basins. It appears that there has been no provision for such an upgrade in the design of the plant.

3.3.1.3 Biological Phosphorus Removal

Both plants could theoretically be upgraded with additional tankage to remove phosphorus biologically, as well as increased nitrogen removal. Typically 1 mg/L of TP is the lowest that can be achieved but in the case of the main stream, preliminary calculations suggest that only around 2.5 mg/L could be achieved. Also it is noted that the process is notoriously difficult to control. The sludge handling system would also need to be reassessed and possibly reconFigured to prevent re-release of bound phosphorus. In conclusion, it appears that this approach may involve significant costs and process risks for limited gain.

3.3.1.4 Chemical Phosphorus Removal

A coagulant (probably alum) could be dosed to both treatment plants to reduce phosphorus levels to around 1 mg/L. Combined with tertiary filtration this could be improved to achieve 0.5 mg/L. There would be a significant increase in sludge generation meaning that additional sludge management capacity would be required (pumps, digesters, drying lagoons).

From initial water quality modelling of the Port Waterway, it appears that the Barker Inlet is phosphorus deficient and biological growth can be triggered when currents direct the Bolivar discharge in this direction. This raises the possibility that removal of phosphorus at certain times of the year may produce the desired environmental outcomes. This needs further exploration but if it is the case, then intermittent chemical phosphorus removal may have role to play.

3.3.1.5 Reverse Osmosis

If the treated wastewater was processed in a reverse osmosis plant, 75-95% of the water would report to a high quality stream and 5-25% to a concentrate stream containing virtually all of the salt and nutrients. This in itself does not achieve much in regard to nutrient management as they are still present in the concentrate. The concentrate must then be further processed, usually by evaporation if discharge to a waterway is not possible. It is a high cost technology and does not appear to be worthy of further consideration.

3.3.1.6 Temporary Storage

There are indications that nutrients from the Bolivar discharge only enter the Port waterway under certain meteorological conditions. This raised the possibility of temporary storage during these events to control and delay the discharge of nutrients until more favourable conditions. This has not been explored at this stage and would require further modelling work to determine if this would achieve the desired results.

3.3.1.7 Increase Reuse For Irrigation
Use of treated wastewater for irrigation in the Virginia area prevents nutrients from entering the marine environment. Annually around 25% of the main flow is used on average although during summer peak reuse periods about 55% of the flow is used. Clearly increasing reuse will reduce nutrients discharged to the marine environment. The amount of reuse is set to increase with expansion of the scheme to the Angle Vale area. The scale of further increases will be limited in the first instance by the demand for the water by irrigators during summer and once summer flows are fully committed further reuse would be limited by the capacity to store water generated outside of the irrigation seasons.

Finding new users for the water is not a simple exercise. There is some capacity for increased consumption by industries with access to the existing network but this would not be expected to provide sufficient demand to consistently utilise all the water, even during the irrigation season. This means that new areas would need to be serviced and these may not necessarily have potential consumers. Therefore new businesses would need to emerge and this would be driven by market conditions and the willingness of investors to inject capital.

Wastewater is generated all year round whereas irrigation occurs predominantly during the hotter months. Therefore to expand the amount of water reuse storage of flows generated during winter is required. Storages of up to 20 GL would be required . For surface storages this would require a large amount of land (the order of 500 ha) and considerable costs. Aquifer storage and recovery may offer a lower cost storage but the environmental sustainability and acceptance by the community and the EPA of this technology is yet to be confirmed.

Increasing reuse appears to be the most attractive option for reducing nutrient discharges with the added advantage of facilitating development of the local primary production industry. However the challenges in fostering demands and in the provision of storage are limitations on the extent and the rate of the increase.

3.3.1.8 Reuse For Industrial or Urban Demands
Industrial or urban uses of treated wastewater potentially offer year round demand, negating or minimising the need for storage. A minor amount of the treated wastewater is being used for this purpose at the Mawson Lakes development. However at this time it would appear that there is limited scope for expanding such uses to an extent where it would materially affect the discharge of nutrients.

3.3.2 Comparison of Options
Table 12 below summarises the options considered for the Bolivar discharge.

Table 7 Bolivar Nutrient Management Options

	Key Issues	Consider Further
Process and Plant Optimisation	Marginal reduction in nutrient discharge	Yes
Upgrade activated sludge plant to BNR in order to increase Nitrogen Removal To 5 mg/L	Technically possible. Significant costs involved.	Yes
Bio-P Removal	Reduction to around 2.5 mg/L. Process is difficult to control. Sludge handling is difficult and costly.	No
Chemical P Removal (with or without filtration)	Possible reduction to between 0.5 and 1 mg/L. Increased sludge production.	Yes
Reverse Osmosis	Extreme costs. Produces concentrate that must be treated further.	No
Temporary Storage	Benefits not yet confirmed. Land may not be available.	Yes
Increase Reuse For Irrigation	Potential for increased removal of nutrients from marine discharge. Limited by demand and storage capacity ASR may not be approved	Yes
Urban Reuse	Insufficient demand in short to medium term.	No

Some of the options that may be applicable were investigated in further detail and indicative costs developed. These are presented in Table 14 below.

Table 8 Bolivar Nutrient Management Options Indicative Costs

Option	Reduction in Nitrogen Discharge Compared To Current Output (%)	Present Value	Unit Costs[4]
Reduce N To 5 mg/L	50	High ($50-100 M)	Extreme (>$10/kg N)
Chemical P Removal	85 (Phosphorus)	High ($50-100 M)	Extreme (>$10/kg P)
Expand Reuse To 75% of Main Flow (ASR)	60	High ($50-100 M)	Extreme (>$10/kg N)
Expand Reuse To 75% of Main Flow (Surface Storage)	60	Extreme (> $100 M)	Extreme (>$10/kg N)
Expand Reuse To 100% of Main Flow (ASR)	85	Extreme (> $100 M)	Extreme (>$10/kg N)
Expand Reuse To 100% of Main Flow (Surface Storage)	85	Extreme (> $100 M)	Extreme (>$10/kg N)

All the options above incur high to extreme costs from a present value calculation. The cost per unit amount of nutrient for all options is extreme. It is not clear from this high level analysis, which options offer the best value with regard to nutrient removal and further work would be required to determine the most cost effective option.

Whilst substantial increase of reuse has been considered in the above exercise with a view to drastically reduce nutrient discharges, it should also be noted that there is potential for marginal increases in reuse using existing infrastructure at relatively small additional costs.

3.4 Conclusions

The following conclusions are drawn:

- A significant reduction in nutrients discharged to the marine environment is technically feasible by modifying the biological treatment process or expanding reuse for irrigation.

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[4] Based on annual operating costs plus capital costs expressed as an annuity divided by the mass of nitrogen removed.

- Both options involve high costs but it is not possible from this high level review to identify which is the more cost effective one and whether any of them provide overall environmental benefits.
  - Expansion of reuse by irrigation would be dependent on the development of cost effective storage (i.e. ASR) and the emergence of sufficient demand for the water.

3.5 Future Strategy

Based on this review of industry practice and ammonia management options the following future strategy is envisaged:

- Continued optimisation of the biological processes to maximise nitrogen removal.
- Continued efforts to maximise reuse with the existing infrastructure.
- Investigate the costs of modifying the biological treatment process or expanding reuse for irrigation to determine the most cost effective route for reducing nitrogen and phosphorus discharges.
- Consider the environmental benefits of managing nutrient levels according to seasonal conditions, e.g., temporary storage, reduction of phosphorus at certain time of the year.

4. ABBREVIATIONS

BOD	Biological oxygen demand
COD	Chemical oxygen demand
ESAPA	European Soda Ash Producers Association
N	Nitrogen
P	Phosphorus
RO	Reverse osmosis
TKN	Total Kjeldahl nitrogen – equivalent to ammonia nitrogen plus organic nitrogen

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