River Science 8
The science behind the Swan-Canning Cleanup Program
Issue 8, October 2002

Aerial view over Kings Park looking towards The Narrows and Perth Water with the Darling Range in the background

CONTENTS

Seasonal Nutrient Dynamics in the Swan Estuary, 1995–2000

The estuary is a dynamic environment

Part river, part sea … Australian estuaries are unique environments where seasonal but unpredictable freshwater flows from river catchments meet the regular ebb and flood of the ocean tide. Influenced by these two different forces, estuaries are ever changing. Throughout the year the organisms that live there experience extremes in their physical and chemical environment – from fresh to salty, warm to cold, light to dark.

The Perth region has a Mediterranean climate. Most rain falls in winter – some 60% of the annual average falling between June and August – while summers are hot and dry. The seasonal climate leads to distinct seasonal cycles within the Swan estuary: of salinity, light, temperature and water circulation. The plants and animals that live in the estuary cope with these changes in different ways. Some can tolerate extremes in their environment. Others (e.g. black bream, dolphins) migrate upstream and downstream to maintain favourable conditions. Some, such as the seagrass, *Halophila ovalis*, grow actively while

Swan-Canning Cleanup Program

Figure 1: *Water quality sampling at Maylands Jetty (photo D. Tracey)*

conditions are favourable but die back when they are not.

The distribution and abundance of phytoplankton in the estuary is closely linked to seasonal patterns of water quality. Throughout the year, different groups of phytoplankton increase and decline in abundance in a relatively predictable series of blooms. This is a natural part of the ecosystem. However, an increased supply of nutrients and organic material to the estuary due to human activities (eutrophication) has led to aberrations in the natural cycle, such as regular summer blooms of nuisance species in the upper Swan and Canning Rivers. These blooms have affected recreational use of the estuaries and can present a health risk when toxic species are involved.

Water quality in the Swan is monitored regularly

Water quality in the Swan-Canning estuary has been monitored regularly since the commencement of the Swan-Canning Cleanup Program (SCCP) in 1994 (figure 1). The monitoring program includes weekly sampling of physical and chemical attributes, nutrient concentrations, and phytoplankton composition and abundance (details are given in *River Science 1: Water quality monitoring is a vital part of the SCCP Action Plan*). This edition of *River Science* presents results from the monitoring program to illustrate the seasonal patterns in water quality in the Swan estuary. Results for the Canning will be presented in *River Science 9*.

Nitrogen and phosphorus are the nutrients of primary interest

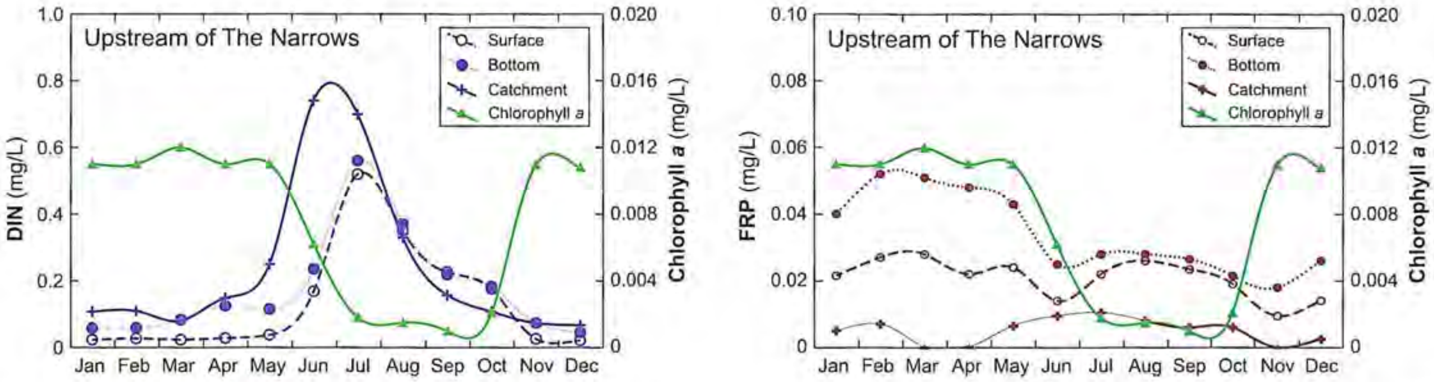
In recent decades both nitrogen and phosphorus have increased in estuaries and coastal waters worldwide. Most of this increase is a result of human activities such as the widespread application of fertilisers. Nitrogen and phosphorus are the nutrients most commonly responsible for nuisance phytoplankton blooms and other eutrophication-related problems.

Nitrogen and phosphorus are present in a number of forms (see *River Science 4: The Nitrogen and Phosphorus Cycles*, for a general overview of how these nutrients are transformed and transported in the environment). This document focuses on the soluble fractions of nitrogen and phosphorus, which can be utilised for phytoplankton growth. These are dissolved inorganic nitrogen (DIN) – composed of ammonium, nitrate and nitrite – and dissolved inorganic phosphorus (DIP), comprised of soluble orthophosphate (PO_4). Reported DIP values include a certain amount of PO_4 loosely bound to very small sediment particles, and for this reason DIP is more accurately reported by the technical term *filterable reactive phosphorus* (FRP).

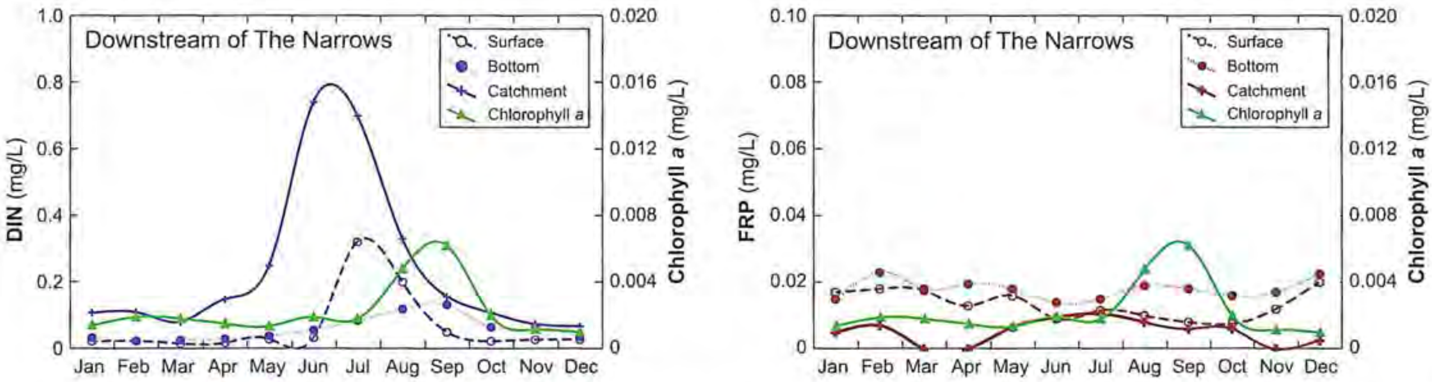
The Swan estuary is eutrophic

The Swan estuary is eutrophic and becomes more eutrophic with distance upstream. This is generally accepted to be a result of substantial clearing of the catchment and discharges from urban, industrial and agricultural land uses (see *River Science 5 and 6* for more information). These activities have increased the quantity of nutrients and organic matter entering watercourses in the Swan catchment. At the same time clearing and draining of natural wetland and riparian areas has affected the natural removal of nutrients within the catchment. As a result nutrients have accumulated in the estuary sediments and high concentrations of nutrients occur periodically in the water column.

Note that all technical terms highlighted in blue are defined in the glossary.



Figures 2 (DIN) and 3 (FRP): Monthly median concentrations of dissolved inorganic nitrogen and phosphorus, and chlorophyll a (1995-2000) in the upper reaches of the estuary and in the catchment (Avon River only). Note the high dissolved phosphate levels in bottom waters, and high phytoplankton levels (chlorophyll a) over late spring, summer and autumn.



Figures 4 (DIN) and 5 (FRP): Monthly median concentrations of dissolved inorganic nitrogen and phosphorus, and chlorophyll a (1995-2000) in the lower reaches of the estuary and catchment (Avon River only). Note the winter peaks of DIN in catchment inflows and surface waters in the lower estuary, and the chlorophyll a peak representing spring phytoplankton blooms.

Water quality varies across the estuary and through time

Water quality varies considerably across the estuary and through time. Salinity varies from almost fresh to almost as salty as seawater. A layer of lighter fresh water often 'floats' on top of more saline (and therefore heavier) bottom waters – this is known as *stratification*. When the water column is stratified, little mixing occurs across the halocline that separates the fresh from the salty layer. As a result water quality is often quite different in surface and bottom waters.

The clarity of the water varies within the estuary and throughout the year. Reduced light penetration is mainly associated with the inflow of dark tannin-stained and turbid water from the catchment in winter. However it can also be caused by high levels of phytoplankton or organic detritus in the water, particularly during summer.

Nutrient delivery and distribution are primarily determined by freshwater inflows from winter rainfall and the tidal movement of salt water into the estuary. There are distinct differences in hydrodynamics and nutrient dynamics between upper and lower reaches of the estuary (up- and downstream of The Narrows) – hence the following discussion relates to these two areas, upper and lower. The greatest variation occurs on a seasonal timescale.

Annual patterns of nutrient concentrations, expressed as monthly medians, for the period 1995-2000 are shown in figures 2-5. The following discussion of seasonal nutrient dynamics relates to these figures.

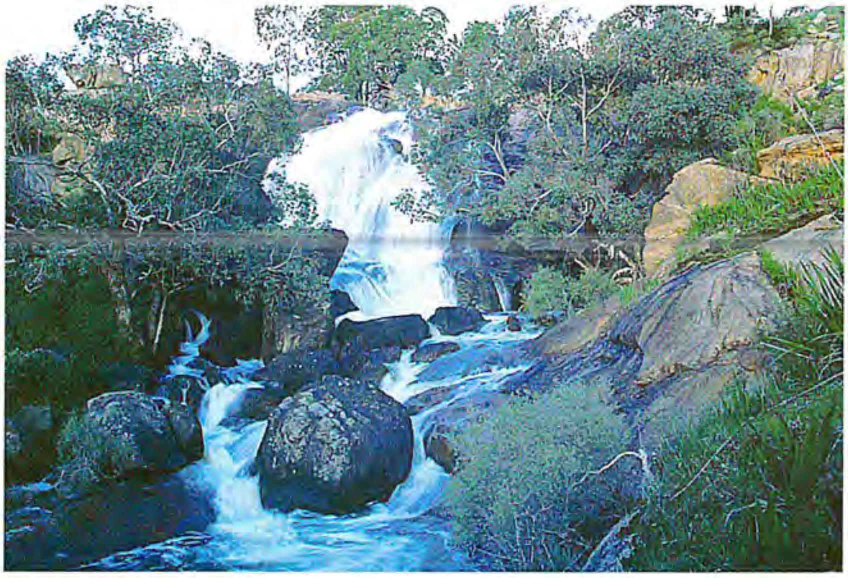


Figure 6: Winter flow in Jane Brook, National Park Falls, John Forrest National Park (photo D. Tracey)

Winter nutrient dynamics

Key Points

- Catchment flows deliver abundant, bioavailable nitrogen to the upper and lower Swan estuary
- Dissolved phosphorus entering from Ellen Brook adheres to particles delivered from the Avon and deposits in the upper Swan
- A nutrient- and tannin-rich freshwater plume extends over saline bottom waters in the lower Swan estuary
- Physical conditions prevent phytoplankton blooms in winter (low light, low temperatures, short day lengths, short residence times) – as a result, dissolved and organic nitrogen is exported to the ocean.

In response to winter rainfall, hundreds of small streams in the vast Swan-Avon catchment begin to flow (figure 6). These funnel fresh water to larger tributaries and ultimately to the estuary. Fresh water moving downstream forces the brackish water remaining from the previous summer out of the upper estuary, and most winters the Swan is flushed fresh above the Perth CBD. As it continues downstream into the lower estuary, the fresh water tends to float on the saltier water already there, forming a distinct surface layer. This layer can reach a depth of 5 metres in very wet years. The winter of 2001 was an example of a dry year in which the estuary was not flushed fresh (figure 8).

As water moves down through the catchment it picks up nutrients from agricultural and other land uses that have accumulated since the previous spring. High concentrations of nitrate are present in the Avon River, which contributes about 60% of the freshwater inflow to the Swan. As can be seen in figure 2, DIN (mostly nitrate) concentrations usually peak around June or July in the Avon River, and about a month later in the upper estuary. The nitrate-rich Avon waters are diluted somewhat by water from other tributary streams such as the Helena River, Ellen and Susannah Brooks.

As it moves downstream, nitrate-rich water spreads across the surface of the lower estuary. There is little movement of nitrate into bottom waters because the strong stratification prevents mixing of fresh and saline water. The slow seepage of groundwater (which has high concentrations of dissolved

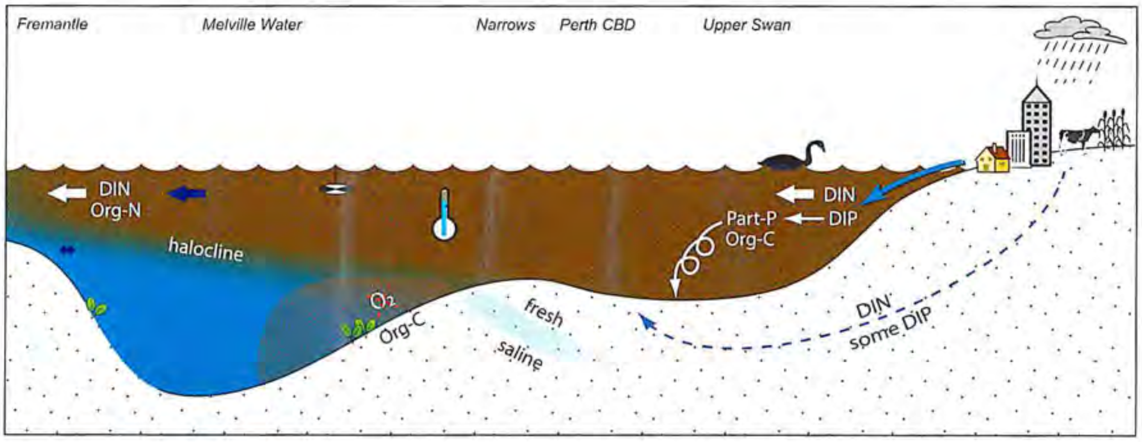


Figure 7: Conceptual model of nutrient processes in the Swan Estuary during the winter high flow period. Refer to the Symbol Glossary at the end of this document for an explanation of the symbols used.

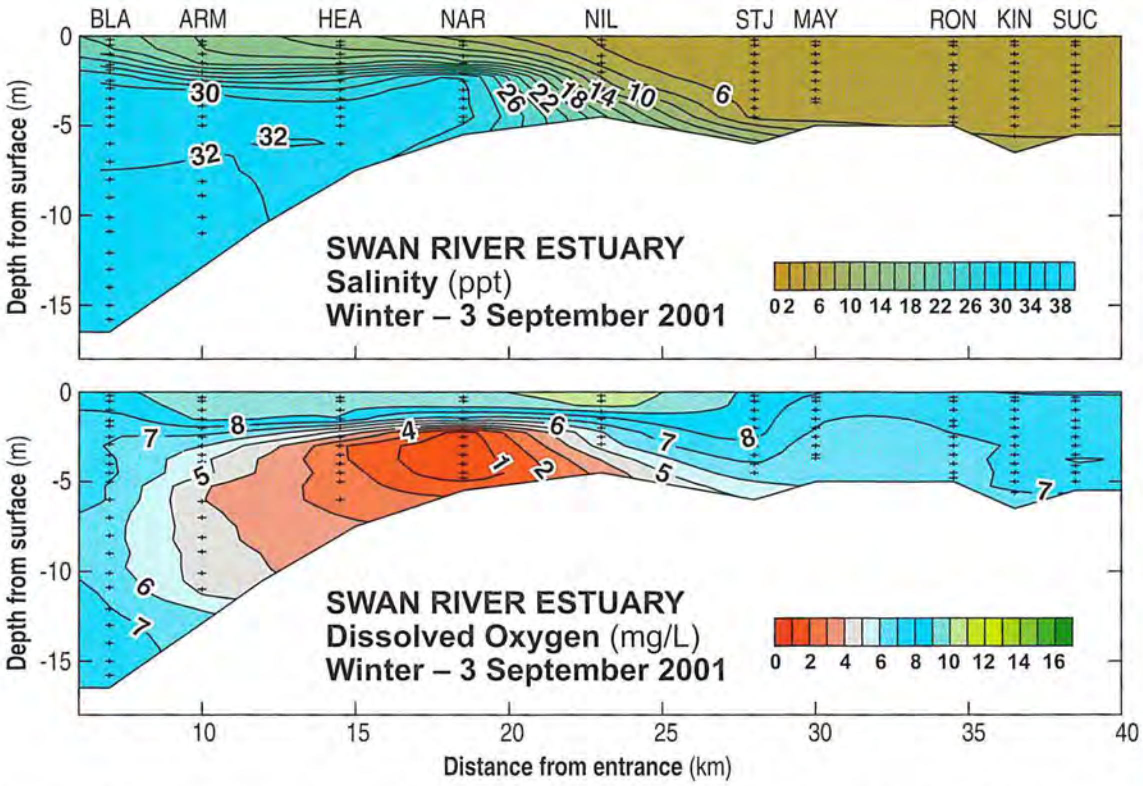


***Figure 8**: Typical longitudinal profiles of salinity (top) and dissolved oxygen (bottom) in the Swan Estuary during a dry winter (2001). In wet years, fresh water extends much further downstream*

nutrients) into the estuary may be responsible for a slight increase in bottom water DIN concentrations during this time.

Unlike nitrate, soluble phosphate (DIP) concentrations do not tend to peak during winter in either the upper or lower estuary. Inflowing water from Ellen Brook has high DIP concentrations, but is diluted by the larger volume Avon flows. In addition, DIP tends to bind to suspended particles from the turbid Avon water (figure 9), making it unavailable for phytoplankton growth. Much of this *particulate phosphorus* settles to the bottom in the upper estuary, where it is important for the formation of summer phytoplankton blooms.

***Figure 9**: The confluence of Ellen Brook (tannin coloured water in the foreground) with the more turbid Avon River (photo B. Degens)*

Every week, longitudinal vertical profiles of salinity, dissolved oxygen and temperature are published on the Swan River Trust website: <www.wrc.wa.gov.au/srt/riverscience/profiles.html>. These images show the relative influence of tidal exchange and freshwater inflows and the effect on the oxygen status of estuary waters (see figures 8, 12, 14 and 17).

Figure 10: A spring bloom of chlorophyte algae in the upper Swan Estuary at Success Hill (photo WRC Phytoplankton Ecology Unit)

Despite the abundance of bioavailable nitrogen in the water column, winter is a time of little phytoplankton growth in the estuary. In fact, chlorophyll *a* concentrations in the upper estuary fall away to their minimum values over winter, while those in the lower estuary remain low until the commencement of spring blooms in around August (figures 2-5). Nutrient budgeting has shown that much of the nitrogen delivered to the estuary from the catchment in winter is flushed out to the Indian Ocean during this time.

The reason phytoplankton are unable to respond to nutrient enrichment over winter is that physical conditions in the estuary greatly restrict their growth. In effect the water is moving too fast and is too dark for phytoplankton to bloom. Freshwater flows stain the surface waters of the estuary a dark tea colour, caused by gilvins and tannins from native vegetation. This limits the amount of light that can penetrate the water column. Secchi depth measurements are at their minima, 1 m or less throughout the estuary. Short day lengths, and water temperatures of around 14°C greatly slow phytoplankton growth processes. Most phytoplankton are flushed from the estuary before they can reach bloom proportions.

Spring nutrient dynamics

Key Points

- More favourable physical conditions, combined with high nutrient (especially nitrate) levels fuel spring phytoplankton blooms in the estuary
- Soluble nutrients are converted to organic forms (as phytoplankton biomass), which build up in the sediments as phytoplankton bloom and die
- As freshwater flow ceases, a tidal salt wedge forms and begins to move upstream, transporting low-oxygen water up the estuary.

In early spring, conditions in the lower estuary become favourable for phytoplankton growth. Day length and water temperatures increase, and mixing with marine waters leads to increased light penetration (median Secchi depths increase to around 3 metres). Freshwater flows decline, which means that water is not flushed from the estuary as quickly. This gives phytoplankton time to reach bloom proportions before they are flushed out to sea. Spring

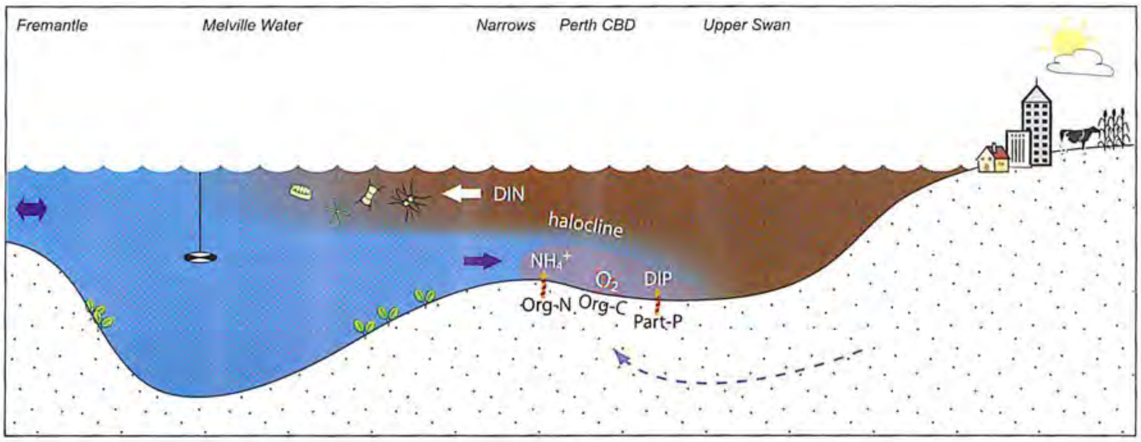


Figure 11: Conceptual model of nutrient processes in the Swan Estuary during spring. Refer to the Symbol Glossary at the end of this document for an explanation of the symbols used.

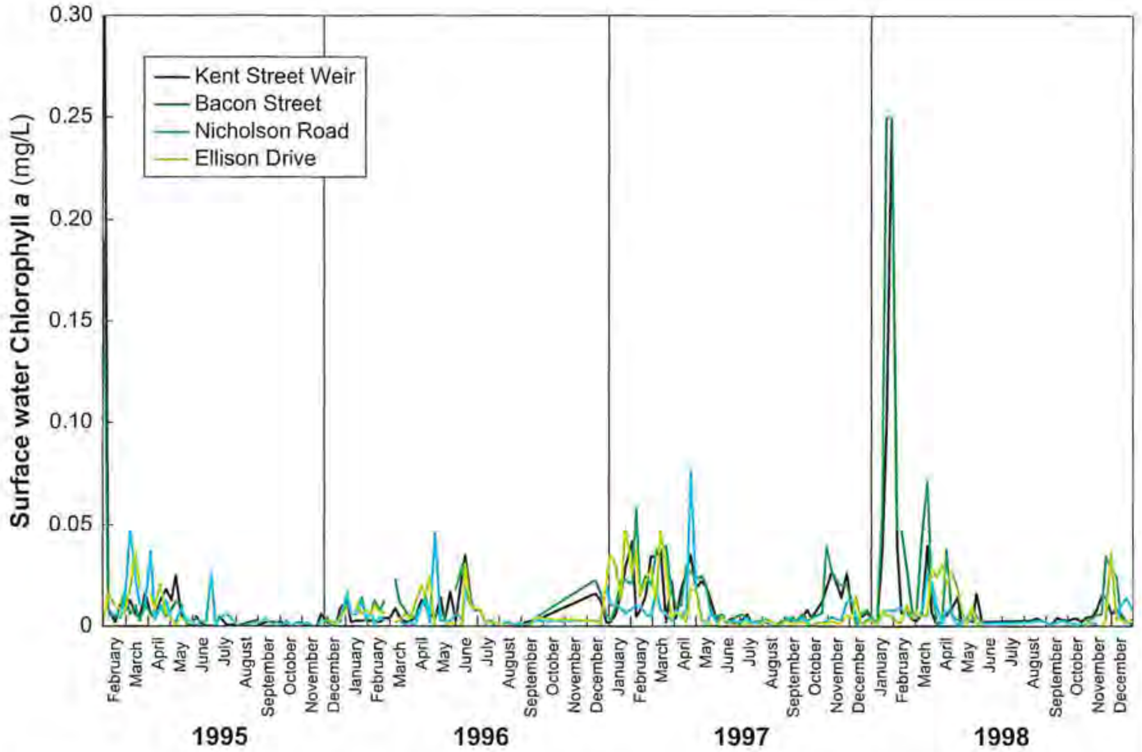


Figure 6: *Weekly phytoplankton abundance (chlorophyll a) at sampling sites in the upper Canning, 1995-98. (NB chlorophyll a values for Jan '95 at Kent Street Weir (0.4) and Nicholson Road Bridge (0.32) exceeded the maximum scale of this graph)*

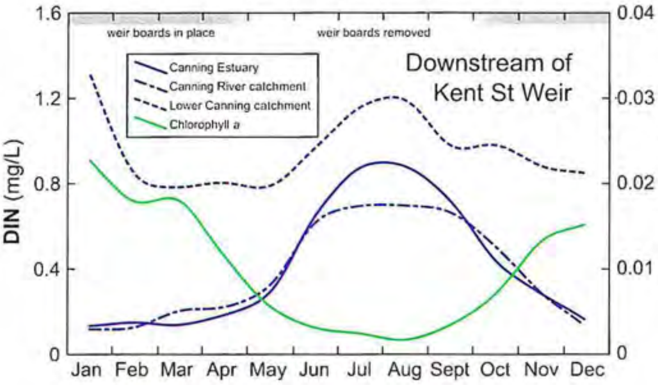
an increasing ratio of dissolved phosphorus to nitrogen over this period. This encourages the growth of certain cyanobacteria (blue-green algae) which are able to supplement their nitrogen supply by 'fixing' atmospheric nitrogen.

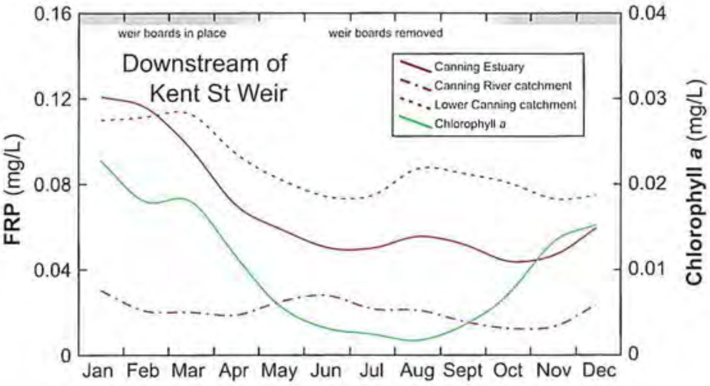
Chlorophyll *a* concentration (which measures the density of phytoplankton cells in the water) shows a distinct seasonal pattern in the upper Canning – with relatively high median values over summer and autumn and low values over winter. Phytoplankton growth in winter is limited by low light levels, low temperatures and short day lengths, and as a result most phytoplankton are flushed from the system before they can reach bloom proportions. When the weir boards are put in place, the lack of flow along with increasing temperatures and increased light penetration makes the upper Canning conducive to phytoplankton growth. Indeed, median chlorophyll *a* values in the upper Canning are at their highest over summer. It is interesting to note that values are higher in bottom waters than surface waters for much of this time. Unlike in the upper Swan where phytoplankton (e.g. dinoflagellates) are thought to migrate to bottom waters to access nutrients it is unlikely that the much smaller cyanobacteria in the upper Canning could do this. The higher bottom water values may result from physical conditions (intense light at the water surface, lack of mixing) that favour heavier phytoplankton which remain buoyant deeper in the water column.

Phytoplankton populations are highly dynamic, and when conditions are favourable they are capable of explosive growth. From about November to May, phytoplankton proliferate and crash repeatedly, resulting in a series of peaks in chlorophyll *a* concentration (figure 6). Occasional very high chlorophyll *a* values (e.g. Jan 1995, Jan-Feb 1998) are associated with major bloom events. Of most concern in the upper Canning is the occurrence of blooms of toxic, nitrogen-fixing cyanobacteria, such as the large *Anabaena* bloom in January 1998 (figure 12).

The growth of macrophytes (such as *Potamogeton* and *Azolla*) appears to be an important factor controlling phytoplankton abundance. Actively growing macrophytes may limit phytoplankton growth, both by shading the surface of the water and competing with phytoplankton for nutrients. Dense macrophyte growth can tie up large amounts of nutrients, from both the water and sediments. The downside is that death of macrophytes (especially *Potamogeton*, which often dies back in late summer) may provide a nutrient source for phytoplankton as they decay. Large phytoplankton blooms have on occasion followed the natural collapse or manual removal of dense macrophyte growth.

Figure 7: *aerial view of the lower Canning, looking over the Shelley (bottom) and Riverton (top) bridges towards the Canning River Regional Park wetlands (photo D. Tracey)*





***Figures 8 (DIN) and 9 (FRP)**: Median concentrations of dissolved inorganic nitrogen and phosphorus, and chlorophyll a (1995-1998) in the Lower Canning. DIN and FRP concentrations are also given for the upper (Canning River) and lower (Mills St Main Drain and Bannister Creek) catchment. Note the winter peak of DIN in both the upper catchment and estuary, and the high summer levels of FRP and chlorophyll a. Samples are integrated across the depth of the water column in these shallow sites.*

Lower Canning

From 1995-98, water quality data from the shallow sites in the lower Canning was integrated across the entire depth of the water column; therefore there is no separation here into surface and bottom waters.

The lower Canning also experiences a seasonal trend of DIN concentration, with a winter peak corresponding to catchment inflows (figure 8). Again, most of this nitrogen is flushed from the lower Canning to Melville Water by freshwater flow. Concentrations decline in spring and remain low over summer, suggesting that a combination of phytoplankton growth and denitrification removes DIN from the system over this time.

Dissolved phosphate concentrations peak in summer, which is likely to be driven by sediment release rather than catchment inflow. When the Kent Street Weir is closed, freshwater input to the lower Canning is minimal. From around September to November there is often some flow over the weir boards from the upper Canning. A number of small urban catchments (mainly the Mills Street Main Drain and Bannister Creek) also discharge directly into the lower Canning throughout the year. However, though DIP concentrations in urban drains are high (figure 9), the volumes discharged are insufficient to explain the high DIP concentrations in the lower estuary.

As in the upper Swan and Canning estuaries (but distinct from the lower Swan), phytoplankton density in the lower Canning is highest throughout summer and autumn when physical conditions are optimal for growth. Median chlorophyll *a* values are actually slightly higher than in the upper Canning. Factors likely to favour phytoplankton growth in the lower Canning could include the shallowness of the sites, and lack of competition from macrophytes. High salinity prevents the sort of toxic blue-green blooms evident in the upper Canning. Phytoplankton dynamics in the lower Canning are more similar to those of the upper Swan. The spring-summer-autumn blooms involve several groups of phytoplankton in a succession related to changes in salinity and sediment nutrient release.

Summary of nutrient dynamics in the Canning

1. Nutrient dynamics with the weir open (late autumn to spring)

The weir boards are usually removed from the Kent Street Weir in response to early winter rainfall. If rainfall continues then the upper Canning is likely to be flushed fresh throughout the water column. However, if rainfall is inconsistent after the boards are removed, the salt wedge can move upstream of the weir into the normally freshwater section of the river. The extent of the surface layer of fresh water into the lower Canning also depends on flow. When the weir boards are removed the Canning behaves as a typical 'salt wedge' estuary, with distinct salinity stratification of the water column. Stratification in the Canning is often associated with low-oxygen conditions at the sediment surface, and anoxic water can be transported up or down the estuary with the movement of the salt wedge.

The freshwater layer in the Canning is high in DIN (mostly nitrate) washed down from rural and urban catchment areas. While the weir is open, most of this nitrogen is flushed from the Canning into Melville Water. Adsorption of phosphate to suspended particles and inflow of particulate phosphorus leads to deposition of phosphorus-rich particles in the upper and lower Canning over winter and spring.

Phytoplankton and macrophyte growth is minimal during winter. Physical conditions (high flow, low temperature and short day length) do not encourage plant growth. In addition, the inflowing water is relatively turbid in winter, which restricts light availability to aquatic plants, including phytoplankton. Some macrophytes die back over winter; others are perennial but grow little or are killed off by salinity if the salt wedge moves up into the riverine section of the Canning.

Spring is characterised by a strong decrease in flow, with a concomitant decrease in DIN delivery from runoff. A combination of denitrification and uptake by phytoplankton and macrophytes leads to a decrease in N:P ratio, driven mainly by a strong decline in nitrate concentration in the water column. The decreasing N:P ratio increases the likelihood of toxic cyanobacteria blooms in the upper Canning; however short residence times and low light levels prevent the development of significant blooms while the weir is open.

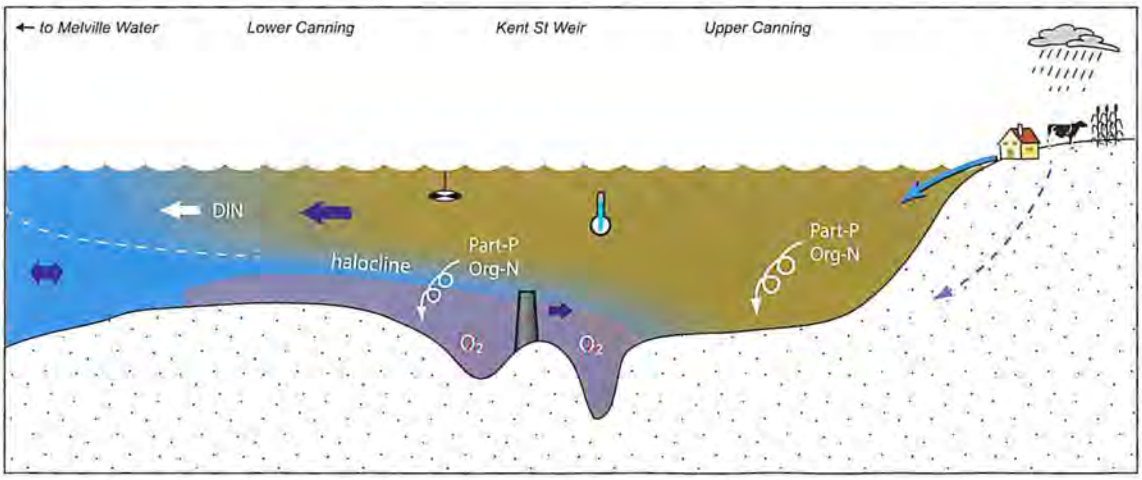


Figure 10: conceptual model of the Canning River with the Kent Street Weir boards removed, during the winter flow period. Refer to the Symbol Glossary for an explanation of the symbols used

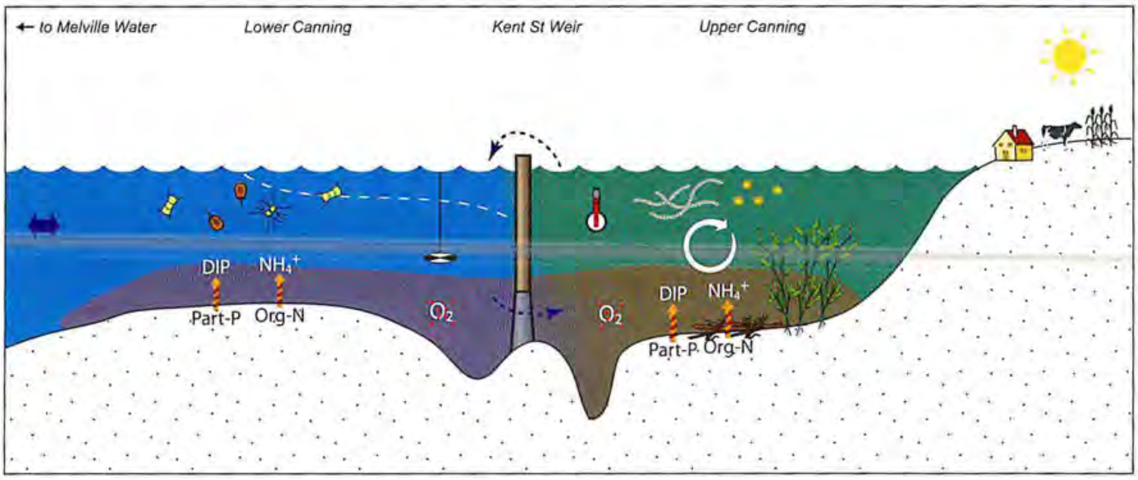


__Figure 11:__ conceptual model of the Canning River with the weir boards in place, during the summer low flow period. Refer to the Symbol Glossary for an explanation of the symbols used

2. Nutrient dynamics with the weir closed (late spring-summer-autumn)

The weir boards are usually put in place around September or October to prevent movement of the salt wedge into the upper Canning. There can still be some movement of both fresh and salt water through or across the weir due to flows, tidal surges and leakage through the weir boards. However, the Canning is basically divided into a brackish to saltwater lower section and a freshwater upper section. In summer the upper Canning becomes a relatively stagnant freshwater pool. While the weir is closed there is rarely substantial mixing of the water column, resulting in strong and persistent differences in surface and bottom water chemistry.

After impoundment, the upper Canning is characterised by thermal stratification, falling oxygen levels in bottom waters, and increasing temperature and water clarity. Anoxic events promote sediment nutrient release, but stratification tends to restrict nutrient movement into surface waters. During late spring and early summer, macrophyte growth is often active but major phytoplankton blooms are uncommon. Nevertheless, phytoplankton activity increases as conditions become more favourable. Nitrogen to phosphorus ratios tend to decrease during this time, increasing the likelihood of nitrogen-fixing cyanobacteria blooms as summer progresses.

__Figure 12:__ This dense bloom of blue-green algae (Anabaena) occurred in January-February 1998 (photo K. McMahon)

Mid to late summer is the greatest risk period for toxic cyanobacteria blooms in the upper Canning. Low N:P ratios promote the growth of nitrogen-fixing cyanobacteria, while the final bloom biomass may be determined by the availability of DIP. During a large bloom, dense growth of phytoplankton reduces water clarity and as a result the bloom growth tends to be restricted to surface waters. (This may also help blue green algae outcompete other species as they have greater buoyancy control). Much of the phosphorus released from the sediments over summer may not become available to phytoplankton due to thermal stratification. During the 1998 bloom for instance (figure 12), although bloom biomass appeared to be limited by surface DIP, the bloom was estimated to have consumed only about 15% of phosphorus efflux from the sediments. At some stage demand for a resource – such as phosphorus or carbon – outstrips availability, leading to the collapse of the bloom.

Curiously, there are rarely repeated big blooms in one summer in the upper Canning – even though physical conditions may be suitable. This 'lag period' following a major bloom is not completely understood, but could be due to phytoplankton cell damage under conditions of intense light and nutrient limitation.

In the lower Canning, summer is a productive time for phytoplankton. When the weir boards are first put in place, upstream movement of anoxic salt

Symbol glossary

	urban catchment		exchange with Melville water		water movement across Kent Street Weir		mixed marine phytoplankton
	rural catchment	Part-P	particulate phosphorus		nutrient flux		chlorophytes
	nutrient movement	Org-N	organic nitrogen		deoxygenation		blue-green algae
	water movement	DIN	dissolved inorganic nitrogen		cold water		
	deposition	DIP	dissolved inorganic phosphorus		warm water		macrophytes (*Potamogeton*)
	groundwater movement	NH_4^+	ammonium		secchi depth		nutrient recycling

water promotes sediment nutrient release. A combination of uptake and denitrification leads to low DIN concentrations over summer, and phytoplankton dynamics are likely to be dominated by rapid cycling of nutrients. The high salinity in the lower Canning prevents the growth of both macrophytes and the cyanobacteria which bloom above the weir. Rather, several groups of mainly marine phytoplankton are common at different times throughout the spring-summer-autumn period.

Addressing nutrient problems in the Canning

Reducing the occurrence of toxic phytoplankton blooms in the Canning River is a major goal of the Swan-Canning Cleanup Program. The results from weekly water quality monitoring in the Canning provided the basis for trials of innovative methods aimed at modifying conditions in the river to reduce the occurrence of blooms. The aim of these techniques (oxygenation and sediment remediation using Phoslock™, a modified clay) is to reduce the supply and availability of nutrients to phytoplankton. Information on the development and implementation of these techniques from early trials in 1997-98 to 1999-2000 can be found in *River Science 13-14* and *17-18*.

The implementation of these techniques has coincided with a marked decrease in nutrient concentrations across the Canning (both in treated and control sites), yet summer blooms of cyanobacteria have still occurred. Results have been promising but it is clear that in practice the relationship between deoxygenation, nutrient release and phytoplankton response is not straightforward – for instance it appears that cyanobacteria are very efficient at exploiting even occasional pulses of phosphate availability. Operation of two oxygenation plants, and further Phoslock trials, have continued over the subsequent two summers. Future use beyond 2002-03 depends on the availability of funding. For more information on these remediation techniques contact the Swan River Trust.

Caring for the Canning: A plan to revitalise the Canning, Southern and Wungong rivers, released in August 2002, is a river management plan for the Canning River system, focusing on riparian zone and catchment issues. This report, which is available from the Swan River Trust, outlines actions to address the decline of the Canning River system that will be implemented over the next five years.

Conclusion

The Canning River is a very different ecosystem to the one encountered by early European observers. The seasonal interaction of fresh and salt water has been modified by upstream impoundments, dredging of the Fremantle sill, the development of an urban drainage network, and construction of the Kent Street Weir. Nutrient inputs from the catchment have resulted in advancing eutrophication in the Canning, which in recent years has been manifested by periodic blooms of nuisance and potentially toxic blue-green algae. Although there is no possibility of returning the river to its pristine, pre-settlement condition, hopefully with time it can be restored to a healthier and more resilient system. The Swan-Canning Cleanup Program is making progress towards long-term goals of improving land use practices, and restoring foreshores, drainage lines and streams within the catchment. In conjunction with the short-term remediation techniques mentioned above the expectation is to achieve a healthy and attractive river that is valued by the community.

SWAN RIVER TRUST

GOVERNMENT OF WESTERN AUSTRALIA

Water and Rivers Commission

Glossary

Adsorption – is the process where phosphate binds to the surface of solid particles.

Anoxic – without oxygen.

Bioavailable – refers to nutrients that phytoplankton and other plants can take up directly from the water.

Biomass – the amount of living matter in a unit area or volume of habitat.

Chlorophyll *a* – a green pigment found in all plants and phytoplankton, which is critical in the capture of light energy during photosynthesis. The concentration of chlorophyll *a* in water is commonly used as a measure of phytoplankton abundance.

Cyanobacteria – also known as blue-green algae, are a group of photosynthetic bacteria. Some species produce toxins harmful to people and other flora and fauna.

Denitrification – the conversion of nitrate to gaseous nitrogen (N_2) by bacterial action.

Deoxygenation – the depletion of oxygen.

Dinoflagellates – a group of phytoplankton that have one or more flagella (whip-like structures) with which they can move through the water column; includes several toxic and nuisance species.

Eutrophication – the process of nutrient enrichment, especially due to increased nutrient inputs resulting from human activity.

FRP – filterable reactive phosphorus; this is the correct technical term for the form of dissolved inorganic phosphorus (DIP) measured in standard water quality sampling.

Hydrocarbons – organic compounds containing only carbon and hydrogen, such as grease and oils.

Luxury uptake – (of phosphorus) is uptake and storage by phytoplankton of DIP that is present in excess of growth requirements; this stored phosphate can then be used for continued growth when DIP becomes scarce.

Macrophytes – aquatic plants and algae – including 'waterweeds' – that are large enough to be seen with the naked eye (see *River Science 19* for information on macrophytes in the Canning).

Median – an 'average' value calculated as the middle value in a set of data when all results are arranged from lowest to highest.

Nitrification – chemical transformation of ammonium to nitrate facilitated by bacteria under an oxygen rich environment.

Nitrogen fixation – the conversion of N_2 gas to inorganic nitrogen.

Nutrient limitation – when the availability of a nutrient limits phytoplankton growth or biomass.

Phytoplankton – free floating or weakly mobile photosynthetic organisms, usually single-celled or chain-forming (e.g. diatoms, dinoflagellates, chlorophytes, cyanobacteria).

Phytoplankton bloom – a proliferation of phytoplankton sufficient to discolour the water column (for management purposes blooms are defined by the density of algal cells in the water – if moderate to large algal cells exceed 20 000 cells/mL it is referred to as a bloom; cyanobacteria densities greater than 20 000 cells/mL will lead to closure of the waterway to the public).

Stratification – layering of a water body due to density differences caused by salinity or temperature.

Thermocline – a sharp vertical gradient in water temperature.

Turbid – having a high concentration of suspended particles; murky in appearance.

Acknowledgments

The *River Science* series is an initiative of the Aquatic Science Branch of the Water and Rivers Commission with funding from the Swan-Canning Cleanup Program. This issue was written by Catherine Thomson and Dieter Tracey. Thanks to Malcolm Robb, Bruce Greenop and Dr Tom Rose for editorial comments.

For more information

More detailed publications on water quality in the Swan-Canning Estuary and catchment are available from the Swan River Trust. The complete list of Swan-Canning Cleanup Program publications is available on the internet at <www.wrc.wa.gov.au/srt/publications/>. *River Science* publications can be obtained from the Swan River Trust or downloaded in PDF format through <www.wrc.wa.gov.au/srt/riverscience/publications.html>.

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ISSN 1443-4539
Printed on environmentally friendly paper
October 2002