



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

## 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

#### CONTENTS

<i>Water quality in the Swan is monitored regularly</i> .....	2
<i>Nitrogen and phosphorus are the nutrients of primary interest</i> .....	2
<i>The Swan estuary is eutrophic</i> .....	2
<i>Water quality varies across the estuary and through time</i> .....	3
<i>Winter nutrient dynamics</i> .....	4
<i>Spring nutrient dynamics</i> .....	6
<i>Summer nutrient dynamics</i> .....	8
<i>Autumn nutrient dynamics</i> .....	10
<i>Symbol glossary</i> .....	11
<i>Conclusion</i> .....	11
<i>Glossary</i> .....	12
<i>Acknowledgments</i> ....	12
<i>For more information</i> .....	12





**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.

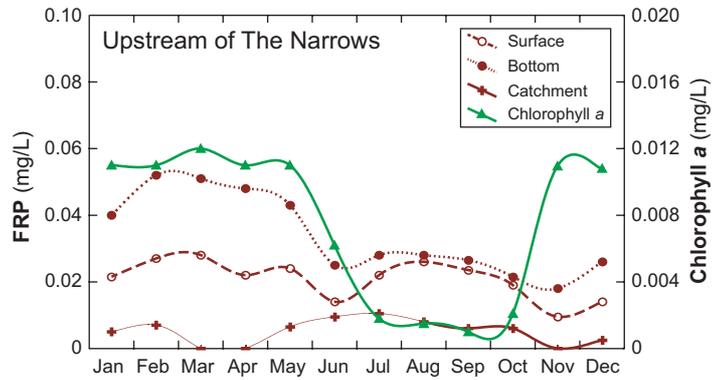
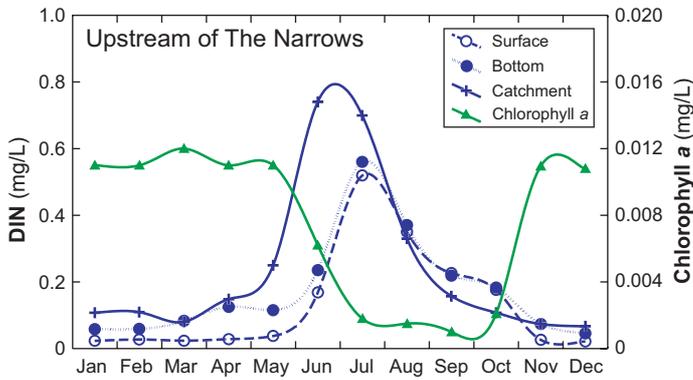
Nitrogen and phosphorus are present in a number of forms (see *River Science 4: The Nitrogen and Phosphorus Cycles*, for a general overview of how these nutrients are transformed and transported in the environment). This document focuses on the soluble fractions of nitrogen and phosphorus, which can 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 ( $\text{PO}_4$ ). Reported DIP values include a certain amount of  $\text{PO}_4$  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

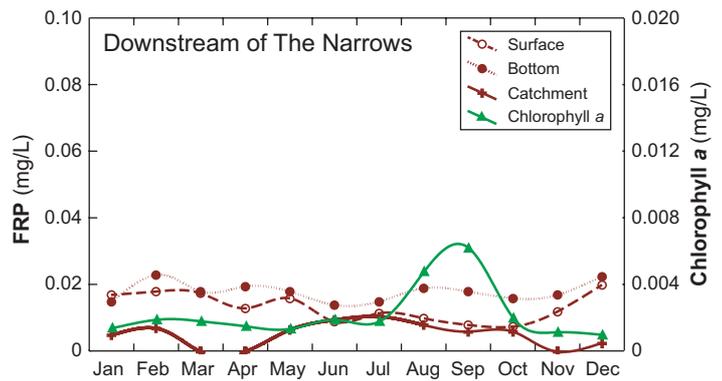
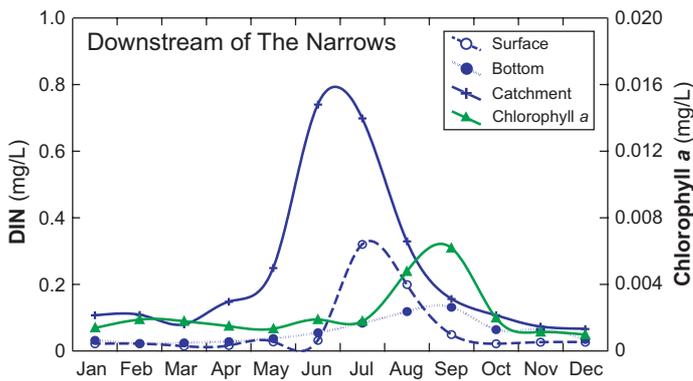
The Swan estuary is **eutrophic** and becomes more eutrophic with distance upstream. This is generally accepted to be a result of substantial clearing of the catchment and discharges from urban, industrial and agricultural land uses (see *River Science 5 and 6* for more information). These activities 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.

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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

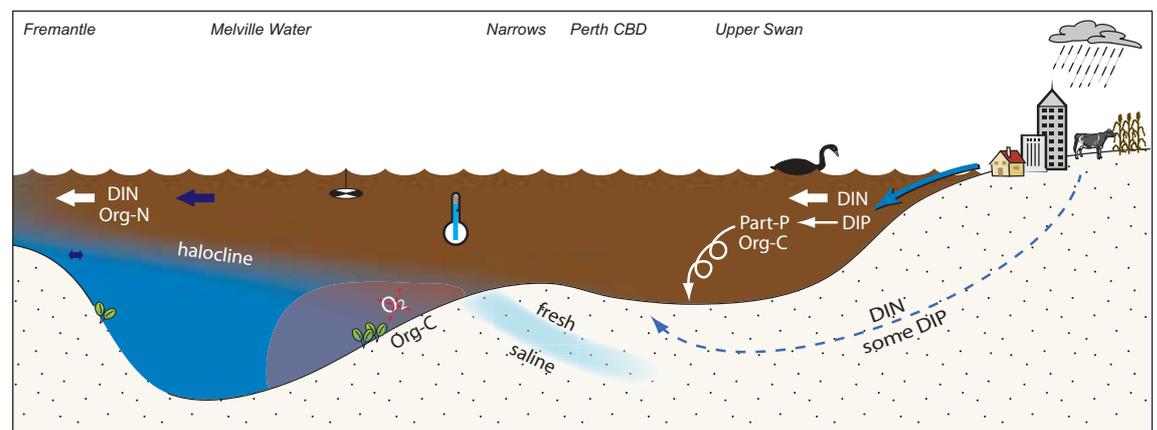
- Catchment flows deliver abundant, bioavailable nitrogen to the upper and lower Swan estuary
- Dissolved phosphorus entering from Ellen Brook adheres to particles delivered from the Avon and deposits in the upper Swan
- A nutrient- and tannin-rich freshwater plume extends over saline bottom waters in 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.

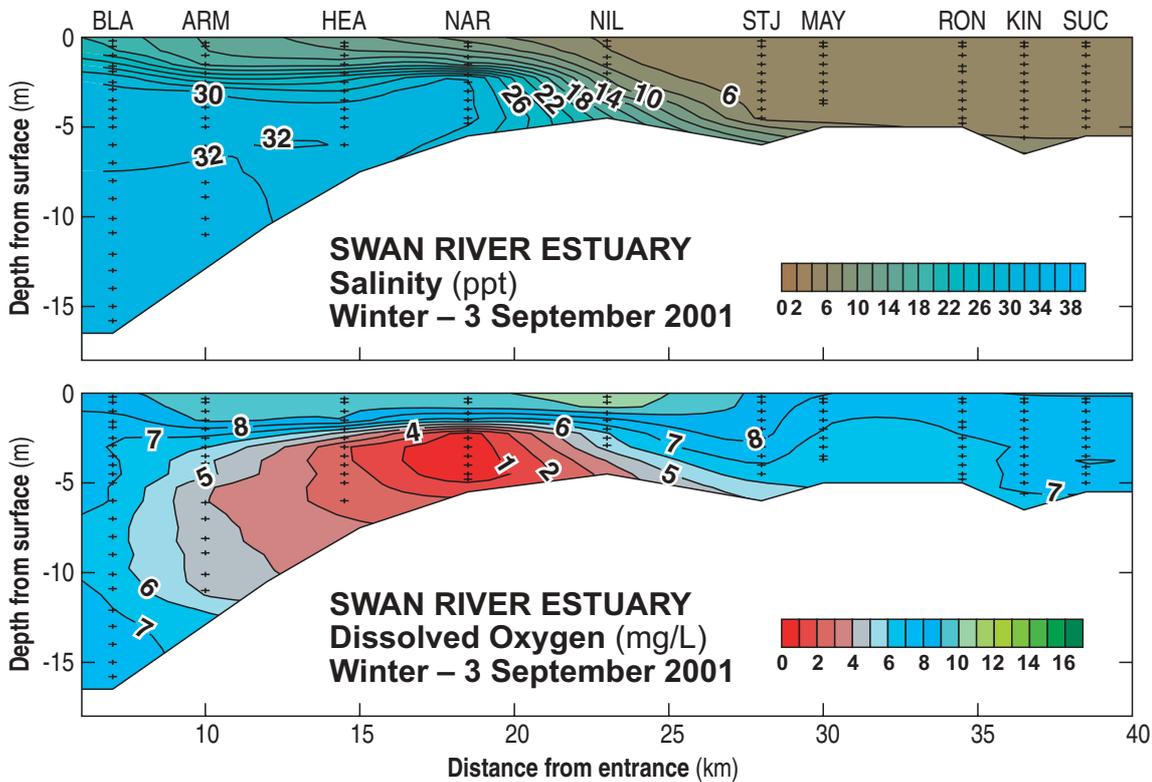
In response to winter rainfall, hundreds of small streams in the vast Swan-Avon catchment begin to flow (figure 6). These funnel fresh water to larger tributaries and ultimately to the estuary. Fresh water moving downstream forces the brackish water remaining from the previous summer out of the upper 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



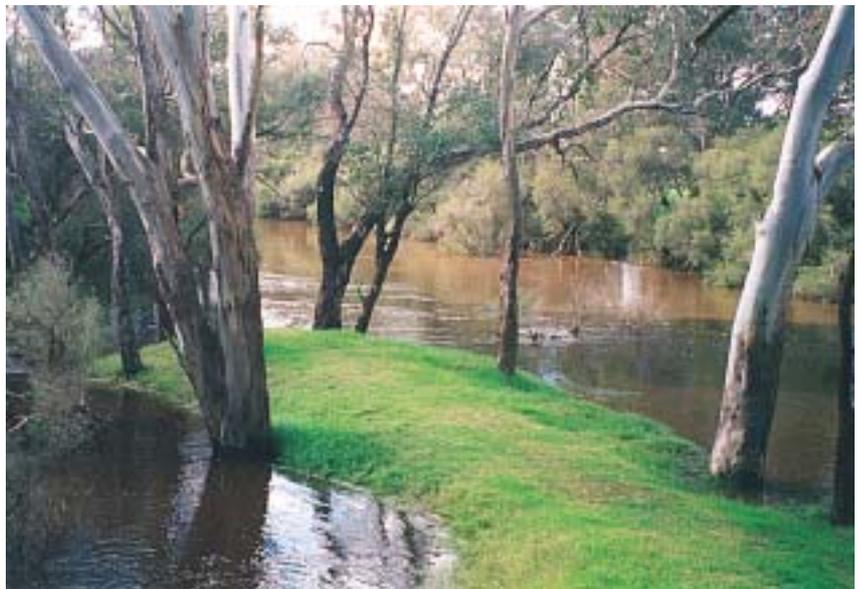
**Figure 7:** Conceptual model of nutrient processes in the Swan Estuary during the winter high flow period. Refer to the Symbol Glossary at the end of this document for an explanation of the symbols used.



**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](http://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,

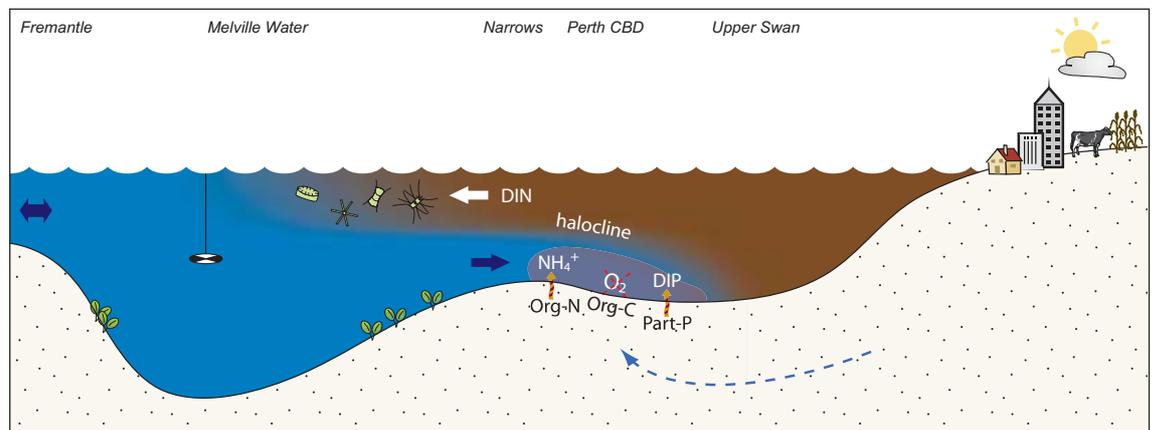
caused by gilvins and tannins from native vegetation. This limits the amount of light that can penetrate the water column. **Secchi depth** measurements are at their minima, 1 m or less throughout the estuary. Short day lengths, and water temperatures of around 14°C greatly slow phytoplankton growth processes. Most phytoplankton are flushed from the estuary before they can reach bloom proportions.

## Spring nutrient dynamics

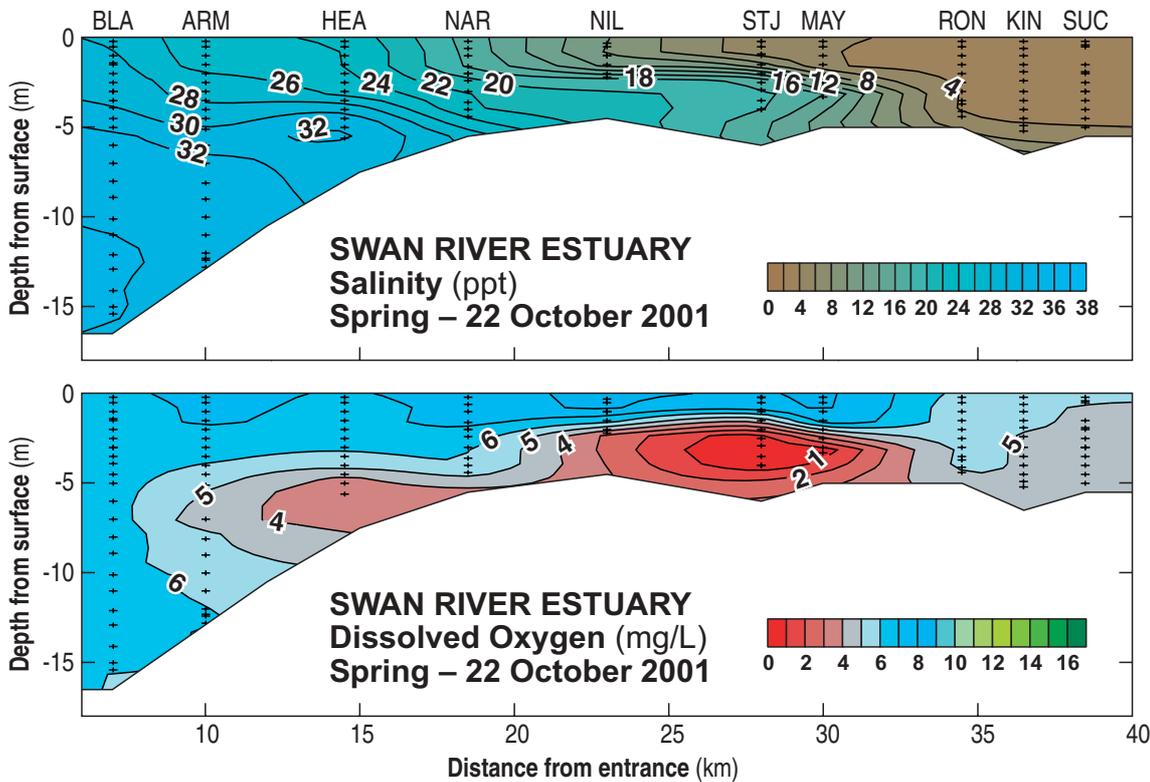
### Key Points

- 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 12:** Typical longitudinal profiles of salinity (top) and dissolved oxygen (bottom) in the Swan Estuary during spring, showing the salt wedge moving into the upper Swan

is the time of greatest phytoplankton growth in the lower estuary. In the upper Swan, largely harmless spring blooms dominated by green algae (chlorophytes) lead to an increase in chlorophyll *a* concentration in around October or November (figure 10).

Growing phytoplankton take up nutrients from the water, leading to declining concentrations of dissolved nutrients (DIN and DIP). Continued groundwater movement often leads to bottom water DIN concentrations exceeding those at the surface by late spring (figure 4).

Although catchment nutrient inputs largely cease during this time, phytoplankton activity continues with a series of blooms (phytoplankton succession is discussed in *River Science* 3). As phytoplankton bloom and die they fall to the bottom where they are broken down by bacteria and other organisms. This releases bioavailable nutrients back into the water column, stimulating further phytoplankton activity. The spring blooms in the lower estuary, usually dominated by harmless marine phytoplankton, are considered a natural part of the ecosystem.

A marked change in **hydrodynamics** occurs in spring when rainfall and catchment runoff have largely ceased. Tidal action pushes heavy saline water upstream along the bottom of the estuary underneath the lighter freshwater layer (figure 12). This 'salt wedge' continues to intrude upstream over the next few months. Oxygen consumption by bacteria and other organisms that metabolise organic carbon leads to low-oxygen conditions below the **halocline** at the front of the salt wedge. Low-oxygen conditions in bottom waters can result in the release of bioavailable nutrients (ammonium and soluble phosphate) from the sediments.



Sailing is a popular pastime on the Swan during summer (copyright 2001, Suzi Wild, Photographer)

## Summer nutrient dynamics

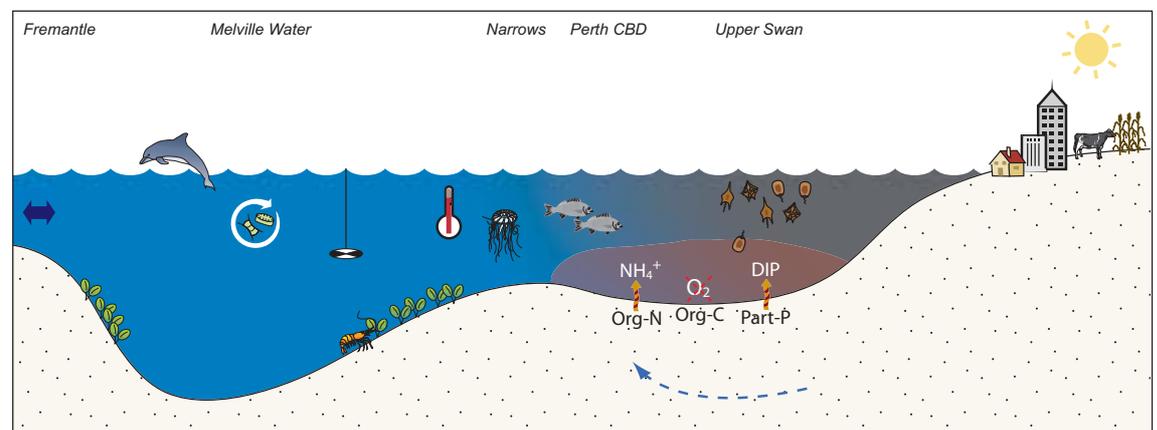
### Key Points

- The salt wedge moves further upstream, transporting oxygen-depleted bottom waters to the upper Swan; here, salt water mixes with residual fresh water in the upper Swan to create a brackish environment
- Sediment DIP release and increasing ammonium concentrations in bottom waters (related to the low-oxygen conditions) contribute to summer dinoflagellate blooms in the upper estuary
- Mixing with low nutrient oceanic water limits summer phytoplankton blooms in the lower estuary.

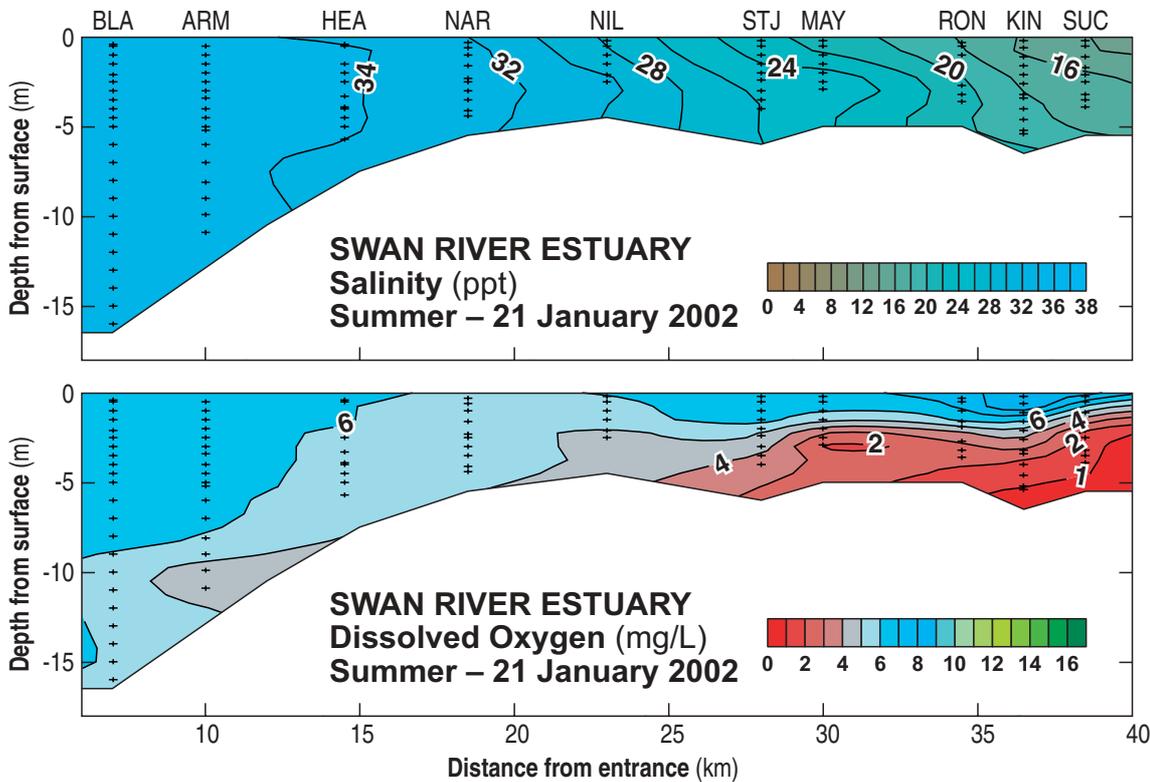
Physical conditions during summer are ideal for phytoplankton growth. Water temperatures increase to around 25°C, days are longer, light intensity is high and oceanic exchange further increases water clarity. Summer is indeed a productive time for phytoplankton in the upper estuary, particularly for nuisance species (figure 15). Chlorophyll *a* concentrations peak in summer and remain high until the onset of late autumn rains. In contrast, phytoplankton in the lower estuary – though not inactive – rarely reach bloom proportions.

By summer, freshwater flows are usually restricted to a few random rainfall events (which can be locally important as they cause urban drains to discharge into the estuary). During early summer, tidal movement pushes the salt wedge further upstream, transporting **hypoxic** bottom waters to the upper estuary. Tidal exchange is not strong enough to replace fresh water in the upper estuary completely with the saline, low-oxygen water from the lower estuary. Instead the tongue of the salt wedge mixes with residual fresh water to create a brackish environment. The strong stratification evident in spring breaks down, but weak stratification appears to be sustained over summer, restricting vertical transport of nutrients and maintaining low-oxygen conditions in bottom waters (figure 14).

In the upper estuary, **anoxic** conditions in bottom waters (and possibly groundwater **efflux**) result in the release of ammonium and phosphate into the water column (*River Science 4: The Nitrogen and Phosphorus Cycles* explains the processes involved). Stratification tends to trap these nutrients below the halocline, leading to a build-up of ammonium and



**Figure 13:** Conceptual model of nutrient processes in the Swan Estuary during the summer low flow period. Refer to the Symbol Glossary at the end of this document for an explanation of the symbols used.

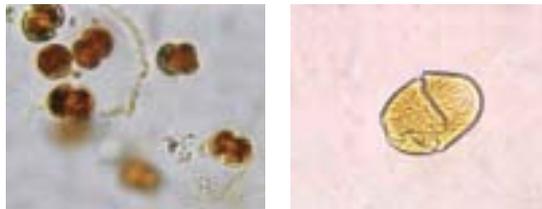


**Figure 14:** Typical longitudinal profiles of salinity (top) and dissolved oxygen (bottom) in the Swan Estuary during summer

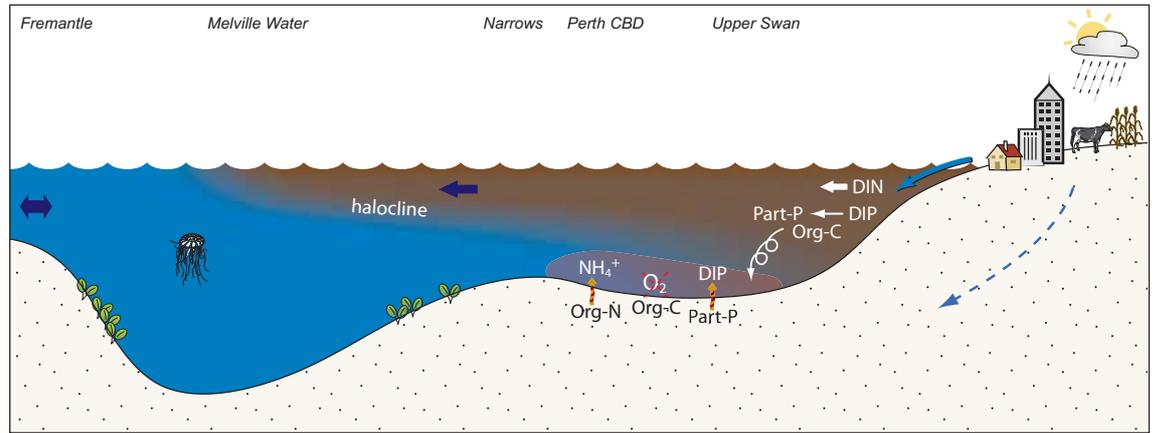
phosphate in bottom waters. As a result, summer phytoplankton blooms in the upper estuary are often dominated by species, such as dinoflagellates, that are able to migrate up and down in the water column to access both nutrients and light (figure 15).

At the same time, the lower estuary is well flushed with low-nutrient oceanic water, and is well mixed vertically. Bottom waters are well oxygenated – median dissolved oxygen is around 80% at depth – and dissolved nutrient concentrations are low. Nitrogen is lost from the lower estuary through ocean exchange and [denitrification](#).

Continuous phytoplankton activity occurs in the lower estuary over summer, fed mostly by recycling of nutrients from phytoplankton decay, but blooms are rare. Phytoplankton growth in the lower estuary seems to be [nitrogen-limited](#). Phytoplankton are able to respond rapidly to inputs of bioavailable nitrogen e.g. from urban drains (which cause localised blooms) and summer rainfall events. For example, the summer 2000 blue-green algae bloom was caused by a large, unseasonal rainfall event (see *River Science 2* for a detailed analysis of this event).



**Figure 15:** Large numbers of phytoplankton, such as these *dinoflagellates*, can make the water appear brown in summer (photos WRC Phytoplankton Ecology Unit)



**Figure 16:** Conceptual model of nutrient processes in the Swan Estuary during autumn. Refer to the Symbol Glossary at the end of this document for an explanation of the symbols used.

## Autumn nutrient dynamics

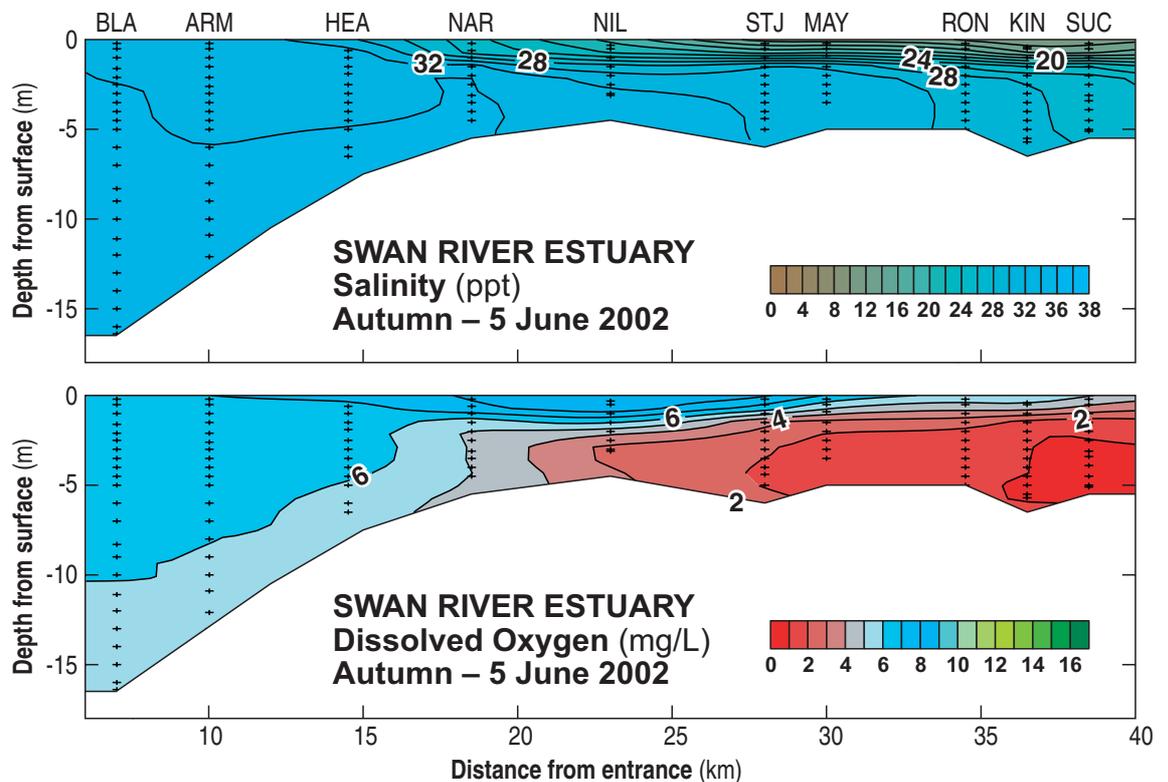
### Key Points

- Transition to winter conditions – sporadic rainfall events make for high variability
- The estuary is mainly marine, warm and nutrient-rich, hypoxic in bottom waters.

Autumn in the Swan estuary is a time of transition. The sporadic nature of autumn rainfall events tends

to govern this transition, making generalisations difficult. Before the onset of autumn rains, summer conditions still prevail. Concentrations of inorganic nitrogen (particularly nitrate) are low throughout the estuary. In the upper estuary phosphate and ammonium concentrations are elevated in bottom waters.

Autumn rains mobilise high concentrations of nutrients that have accumulated over summer. The first rainfall events can cause urban drains to discharge into the estuary, delivering small volumes of nutrient-rich water. Further rain can mobilise



**Figure 17:** Typical longitudinal profiles of salinity (top) and dissolved oxygen (bottom) in the Swan Estuary during autumn

## Symbol glossary

 urban catchment	 ocean exchange	 nutrient flux	 phytoplankton (diatoms)
 rural catchment	<b>Part-P</b> particulate phosphorus	 deoxygenation	 phytoplankton (dinoflagellates)
 nutrient movement	<b>Org-N</b> organic nitrogen	 cold water	 nutrient recycling
 water movement	<b>Org-C</b> organic carbon	 warm water	 seagrass ( <i>Halophila</i> )
 deposition	<b>DIN</b> dissolved inorganic nitrogen	 secchi depth	 black bream
 groundwater movement	<b>DIP</b> dissolved inorganic phosphorus	 fresh/saline interface (groundwater)	 jellyfish
	<b>NH<sub>4</sub><sup>+</sup></b> ammonium		

nutrients that have accumulated in the broader catchment. As a result, phytoplankton blooms are unpredictable yet quite common in the upper estuary during autumn. For instance, 1995 and 1997 saw high levels of phytoplankton in the upper estuary, whereas 1996 was characterised by high flows and low phytoplankton concentrations, more typical of winter conditions.

## Conclusion

Estuaries are dynamic environments, marked by continuous and productive activity and change. The natural cycle of phytoplankton growth in the Swan-Canning Estuary contributes to the production of organic matter that supports the estuary food web. The supply of nutrients from the catchment is the source of phytoplankton productivity, and allows abundant fish catches in the estuary. However, the greatly enlarged supply of nutrients which has resulted from human activities in the catchment has not only increased productivity but also increased the occurrence of nuisance and potentially toxic algal blooms. Activities of the Swan-Canning Cleanup Program seek to reduce the overall nutrient supply to the estuary with the intention of reducing the occurrence of these blooms.

The Swan-Canning estuary is dominated by seasonal rather than inter-annual and random climatic influences (unlike many south coast estuaries for instance). This is because the area has relatively reliable winter rainfall and the estuary has a deep, permanently open entrance (albeit artificial) which facilitates year-round tidal exchange. As a result,

despite significant year to year variation, predictable seasonal patterns of nutrient delivery and cycling are evident in the estuary. These in turn influence phytoplankton composition and abundance over seasonal timescales.

Seasonal patterns are of course only part of the story. Inter-annual and random influences are also important as evidenced by the summer 2000 cyanobacteria bloom, which was triggered by a large unseasonal rainfall event. In addition, many of the factors influencing the timing and composition of phytoplankton blooms are subtle and poorly understood. Nevertheless, an understanding of the broad patterns of seasonal nutrient dynamics enables managers to identify the chronic causes of nuisance and toxic phytoplankton blooms in the estuary. This information is critical to reduce the occurrence of such blooms and make the estuary a healthier, safer and more enjoyable place for everyone.

## Glossary

**Anoxic** – without oxygen; cf. **hypoxic**, which refers to low-oxygen conditions.

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

**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.

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

**DIN** – dissolved inorganic nitrogen, comprised of ammonium ( $NH_4^+$ ), nitrate ( $NO_3^-$ ) and nitrite ( $NO_2^-$ ).

**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.

**DIP** – dissolved inorganic phosphorus ( $PO_4$ ).

**Efflux** – something that flows out or forth.

**Eutrophic** – nutrient enriched, 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.

**Halocline** – a sharp vertical gradient in salinity between a relatively fresh water mass and a more saline water mass.

**Hydrodynamics** – the patterns of water movement through the landscape.

**Hypoxic** – low in oxygen.

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

**Nitrogen-limited** – when conditions are suitable for phytoplankton growth and other nutrients are in adequate supply, but insufficient nitrogen is present for growth to occur.

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

**Riparian** – associated with the edge of a watercourse.

**Secchi Depth** – a measure of water clarity, taken as the depth at which a 30 cm disc divided into black and white quadrants disappears from view when lowered into the water.

**Stratification** – separation into distinct vertical layers.

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

## Acknowledgments

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### 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/](http://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](http://www.wrc.wa.gov.au/srt/riverscience/publications.html)>.

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