Department of Water
Government of Western Australia

Stokes Inlet Condition Statement

August 2007

Department of Water

Estuarine condition report

August 2007

SOUTHCOAST NATURAL RESOURCE MANAGEMENT INC.

Australian Government

Government of Western Australia

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Subject of cover photograph
Aerial view of Stokes Inlet

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Executive summary

The South Coast Region Strategy for Natural Resource Management (NRM) identified the need to assess the current condition of Stokes Inlet and identify major gaps of baseline information that exist with regard to understanding estuarine processes.

This estuarine condition statement provides an overview of the information available on the physical and biological character of Stokes Inlet, the rivers feeding the system and catchment land use. It provides recommendations to assist the decision making process for management.

Current information on the Stokes Inlet shows the system to be under stress, suffering symptoms of eutrophication (nutrient enrichment); and stratification and deoxygenation. Specific areas in the Inlet that are a concern are the deeper areas of the inlet basin (below 5 m water depth). There is also concern for sediment infilling and the increased frequency that the sandbar opens and if these factors threaten the integrity of the Inlet.

Conditions of concern for the Inlet highlighted in this document include: high nutrient concentrations in the Inlet, in particular autochthonous (from within the Inlet) sources released from the organic rich sediments; sedimentation rates and the occurrence of toxic algae and phytoplankton blooms.

A number of shortfalls in environmental data for the Inlet have been identified in this document. These include further water quality monitoring data; and survey and process based information of water quality, sediment quality and sedimentation rates, plant and animal communities and the social values of the local community. Efforts to gather this information have been implemented, and as the information becomes available the condition of Stokes Inlet can be more adequately defined.

Management targets aimed at reducing or eliminating the conditions of concern focus on water quality parameters such as Total Nitrogen (TN) and Total Phosphorus (TP), determining the denitrification efficiency of the estuarine sediments, increasing the coverage and depth limit of seagrass, decreasing the biomass of macroalgae, and maintaining the biodiversity of fringing vegetation communities. However while target objectives have been identified, more information is required in most cases to set critical target values.

Given the nature of an estuary many of the management actions need to be addressed in the catchment.

Approximately 60 % of the Stokes Inlet catchment (Young and Lort River catchments) has been cleared for agriculture, which include: cropping (wheat, barley, canola, lupins, oats and other pulses) and livestock (cattle and sheep) enterprises.

Progressive clearing of the catchment and changes in land use have altered the quality of river flow in the catchment of Stokes Inlet. Conditions of concern in the catchment include contributions of nutrients, salt and sediments to the river flow which reaches the Inlet.

Management actions for the catchment should include education initiatives to land users that highlight better land use practises that can reduce impacts to their local waterways, revegetation of areas along waterways and restrictions of groundwater abstraction in the catchment.

Recommendations made in this document focus on baseline, temporal and process based data collection to further our understanding of one of the less well known estuaries on the South Coast. Management actions that have been identified target current impacts and pressures on the catchment, and on the Inlet as a resource in the region, and aim to assist in the decision making process for managers.

The production of this document was made possible by funding from South Coast NRM Inc and the welcomed support of the Stokes Inlet Steering Group.

1 Introduction

An estuarine condition statement is designed to provide managers and the community with information on the status of the estuary and its catchment. The status is based on an overview of the information available on the physical and biological character of the estuary, the rivers feeding the system and catchment land use. Recommendations are then made to assist in the decision making process for management.

This report describes the Stokes Inlet Estuarine System from the catchment to the estuary. The catchment of Stokes Inlet includes the watersheds of the Young and Lort Rivers which flow into the Inlet. The combined catchment for these rivers (the Stokes Inlet catchment) is 4575 km^2 and extends 100km inland from the coast. The greater part of the catchment lies in the Shire of Esperance, however the Lort River catchment extends into the Shire of Dundas and the Young River catchment reaches into the Shire of Ravensthorpe. A total sixty percent of the catchment has been cleared, and supports a range of agricultural and pastoral activities.

The Stokes Inlet itself is considered to have high social and environmental value. Bird-watching, camping, fishing, walking and canoeing are popular activities to those visiting the Inlet. There is currently no long term record of the physiochemical conditions in Stokes Inlet. The Department of Water (Albany), recognising this, has recently included Stokes Inlet in the quarterly estuary monitoring program funded by the South Coast NRM (formally SCRIPT). A review of this data is presented in this document.

Linking the catchment to the Inlet; the status of the catchment is discussed and the implications of these issues are related to their impact on the estuary. Nutrient pollution, salinisation and sedimentation are issues of concern. Many of the south coast estuaries are under similar pressures as a result of catchment land use and clearing.

The inclusion of Stokes Inlet into the estuary monitoring program will improve our understanding of estuarine processes taking place in Stokes Inlet. Other information gaps for future scientific research form part of the recommendations made to management.

A conceptual model of Stokes Inlet is included to illustrate our current understanding and highlight areas where research is required.

2 Study area

Stokes Inlet is situated approximately 80 km to the west of Esperance and lies within the Stokes Inlet National Park (Figure 1). It is one of the largest estuaries in the region being 10 km long and 2 km wide: an area of approximately 14 km^2. The Inlets elongate shape extends to the northeast where it meets its tributaries, the Young River to the West and the Lort River to the East. The Inlet typically only opens every couple of years to oceanic exchange, discharging into Southern Ocean. The catchment of Stokes Inlet includes the catchments of the Young and the Lort Rivers (Figure 1).

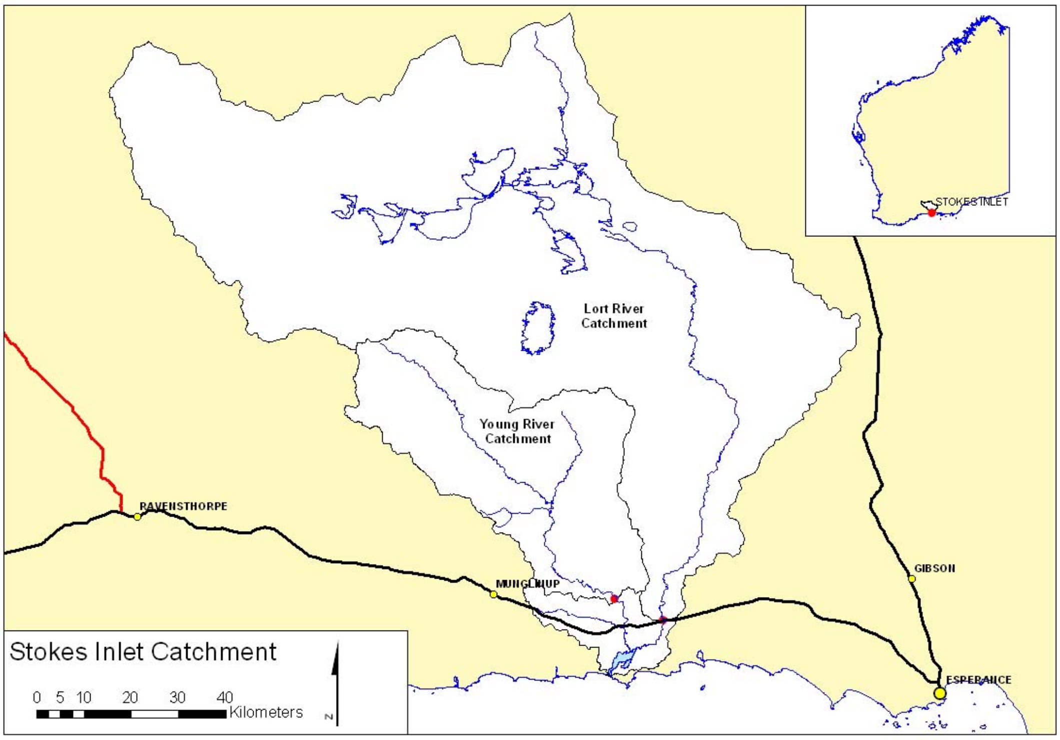


Figure 1 Stokes Inlet Catchment – made up of the Young and Lort Catchments combined.

Provided in this document is a synthesis of the findings of technical reviews and the monitoring programs undertaken in the Stokes Inlet and surrounding catchment.

The primary technical reviews that describe conditions in Stokes Inlet and the Lort and Young River catchments include:

Hodgkin, E. P. & Clarke, R. 1989. An inventory of information on the estuaries and coastal lagoons of south Western Australia: Estuaries of the Shire of Esperance: Stokes Inlet and other estuaries of the Shire of Esperance 40 p.

Bowyer, J. 2001. Lort and Young Rivers Catchment: Catchment Appraisal 2001. Department of Agriculture. Resource Management Technical Report 231. 58 pp.

Hoeksema, S.D., Chuwen, B.M., Hesp, S.A., Hall, N.G., Potter, I.C. 2006b. Impact of environmental changes on the fish faunas of Western Australian south-coast estuaries. Murdoch, Centre for Fish and Fisheries Research, Murdoch University.

Brearley, A. 2006. Swanland: Estuaries and coastal lagoons of south-western Australia. UWA Press. *pp* 485-491*.*

Geoscience Australia 2007. Preliminary report on Stokes Inlet. (Unpublished).

For the purpose of describing the condition of the Stokes Inlet this document focuses primarily on the estuarine reaches of the lower catchment. This includes the Stokes Inlet and its tributaries; the Young River and Lort River.

The condition of the general catchment is described in Chapter 4 for the purpose of providing a backdrop to the Stokes Inlet and to highlight issues that may affect the Inlet. This description includes an overview of the hydrogeology, climate, surface drainage, land use practices, past and present in the Young and Lort River catchments.

3 Environmental condition of the catchment

3.1 Introduction

The Stokes Inlet Catchment (which includes the catchments of the Young and Lort River catchments) extends approximately 100km inland to an area of internal drainage and salt lakes. The combined catchment areas cover approximately 4,500 km^2 (Brearley, 2006). The upper portions of these catchments were cleared for agriculture in the 1970's and 1980's increasing the delivery of sediments into the estuary: anecdotal evidence has suggested that half a metre of sediment has accumulated in the Inlet over the past 30 years (CALM NatureBase web site).

Current monitoring activities in the catchment include:

- Rainfall (Bureau of Meterology, BoM): there have been 7 sites which have recorded rainfall since 1973. Four of these remain active, three ceased recording in 1999.
- Stream gauging: there are 5 stream gauging sites in the stokes inlet catchment which record level data. All of the sites have been rated (calibrated to determine flow rates). Four gauging stations are located on the Young River and one on the Lort River. The first of the gauging stations on the Young River was established in 1971, the remaining stations were established in 1974. For the purpose of this document the data recorded from the closest gauging station on the Young River together with the data from the Lort River gauging station was used to calculate flow to the Inlet.
- Stream sampling : There are 8 stream sampling sites which are used to monitor water quality of the Lort and Young Rivers. Data collected includes physical (e.g. salinity and temperature) and chemical (namely nutrient) variables. The earliest data was collected from one site in 1996. Data has since then only been collected from 2006 and as a result does not provide much of an historical account of catchment condition.

Projects that monitor catchment water quality of the Lort and Young Rivers and will in the future contribute to the information available include:

- Eastern catchment monitoring (SC-C-EASTCATCH from 2006) – physical and chemical water quality monitoring
- Young and Lort River Catchment Monitoring (SC-C-ESDC from 2006) – physical and chemical water quality monitoring.

3.2 Hydrology and climate

The south coast experiences a Mediterranean climate with cool, wet winters and warm to hot, dry summers. Stokes Inlet lies in one of the lowest rainfall regions, receiving on average about 550 mm rainfall per year, decreasing inland to an average of 350 mm. This trend is reflected in different rainfall averages of the two catchments, the Young catchment situated to the southwest receives an annual rainfall of 549 mm and the Lort River situated northeast has an annual average of 350 mm. Average monthly discharge into the Inlet is 0.5 Gigalitres (Figure 2). Despite rain primarily falling in winter, heavy summer rain events are generally responsible for heavy flow events.

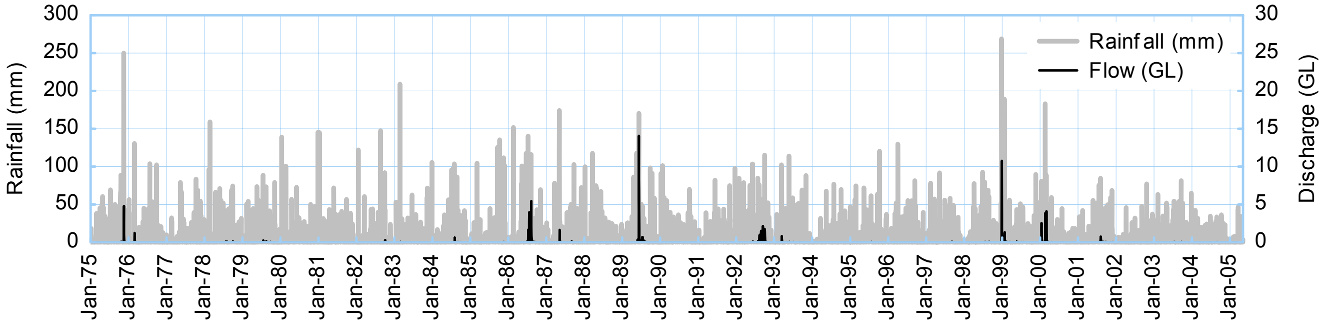


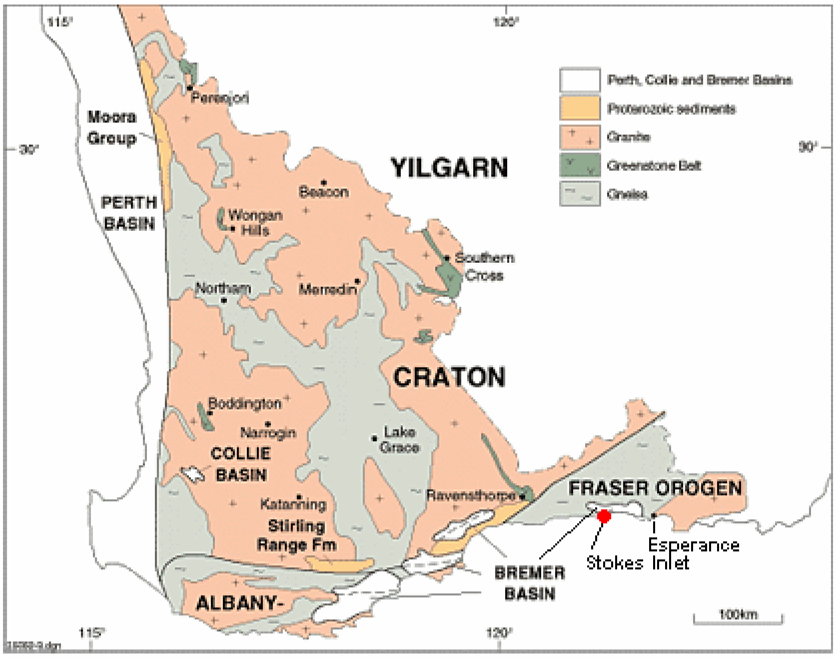
Figure 2 Daily rainfall and discharge into Stokes Inlet between 1975 and 2005

3.3 Groundwater

Stokes Inlet lies within the Albany-Fraser Fractured Rock Province (Figure 3). The crystalline bedrock consists of gneiss and migmatite, outcropping as partially buried hills, and is covered discontinuously by Eocene sediments of the Bremer Basin, and by Quaternary dunes and alluvium near the coast (Johnson, 1998). Bremer Basin sediments assigned to the Plantagenet Group consist of carbonaceous sands and siltstones with fine grained sand. The Inlet itself lies within the Quaternary coastal dune system, which may be underlain in places by Eocene sediments.

Brackish groundwater derived from local rainfall recharge on the dunes, and from runoff on areas of exposed crystalline bedrock, forms a thin low-salinity lens close to sea level in the dunes, and most likely discharges around the margins of the Inlet.

In the Lort and Young River catchments, a regional groundwater system occurs in the weathered crystalline bedrock and overlying Plantagenet Group sediments, but may be discontinuous in elevated areas or in areas of unweathered fractured rock. The depth to groundwater is generally less than 5 m below ground surface in valleys and can be as deep as 30 m along topographical divides. Groundwater salinity increases from the coast inland where it may increase from 50-4,000 mS/m in the coastal sand plains to 6,500 mS/m in the northern parts of the catchments (Bowyer, 2001). In particular, groundwater is hypersaline in the upper catchment of the Lort River where there are salt lakes. With generally high groundwater salinities in the Lort and Young Catchment, only small areas have groundwater suitable for stock.



*(adapted from source: http://www.fish.wa.gov.au/docs/pub/AquaGroundWater)

Figure 3 Geological map of the Southwest Agricultural Region showing the Bremer Basin and the location of Stokes Inlet

Groundwater monitoring conducted by the Department of Agriculture found that groundwater levels are rising in the Young and Lort Catchments at rates between 0.05 and 0.30 m per year. In some of these bores groundwater salinity is greater than the salinity of seawater of 5300mS/m. The discharge of saline groundwater to the Young and Lort Rivers is likely to be increasing both in quantity and salinity. Water-logging has also been highlighted as a land degradation issue in the perched aquifer systems in shallow sands near Cascade approximately 45 km north of the Stokes Inlet.

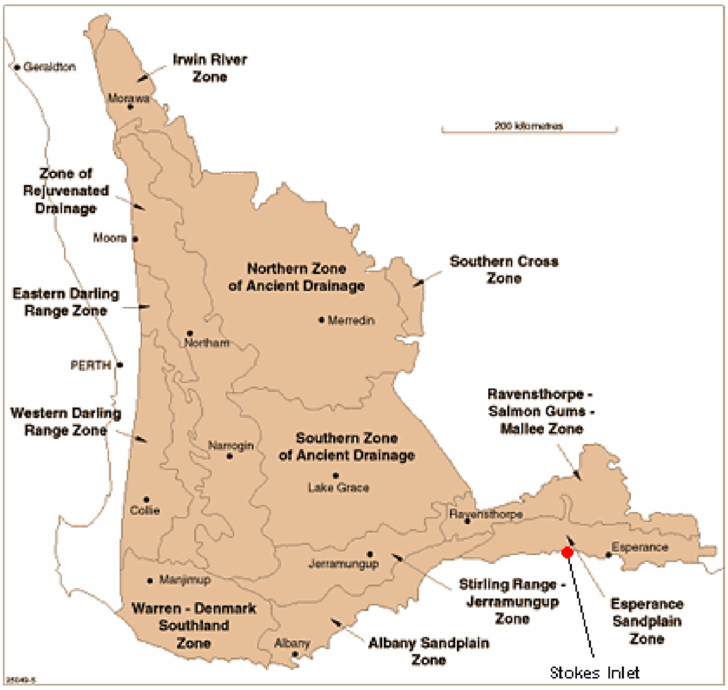
A number of wetlands exist in the Lort River Catchment. These wetlands are fed by springs and are regionally significant.

3.4 Surface drainage

The loss of riparian vegetation from areas in the catchment cleared for agriculture has reduced surface drainage and therefore increased the delivery of sediment, nutrients and salt to the river systems (Olsen & Skitmore 1991). The salinity of water entering the estuary from the Lort River is approximately 1,090 mS/m (or 6.54 ‰, saline) and from the Young River, 2,910 mS/m (or 17 ‰, saline) (Bowyer, 2001; Department of Fisheries web site 2007). In 1989 and 1997 1.4 % of agriculture land was reported to be severely salt affected due to the removal of deep rooted perennial vegetation (Bowyer, 2001). Nutrient data for the catchment is limited to single readings for both rivers and indicate slightly elevated concentrations in the Young River (1.5 mg/L)) and the Lort River (0.83 mg/L).

3.5 Catchment vegetation

The catchment of the Young and the Lort Rivers fall into two of thirteen eco-zones described for the south coast of Western Australia. The first is the Esperance Sandplain West, bounded by the Lort River to the east and Culham Inlet to the West. The second is the Esperance Sandplain East which covers the part of the Lort River catchment to the East of the Lort River. The vegetation of these eco-zones is dominated by Kwongan heathlands, Banksia and Mallee shrublands (McQuoid 2004). The banksia, *Banksia speciosa,* and the ashy hakea, *Hakea cinerea* are particularly exclusive flora to these eco-zones.



*(adapted from source: http://www.fish.wa.gov.au/docs/pub/AquaGroundWater)

Figure 4 Soil-landscape zones in the Southwest Agricultural Region showing the Esperance Sandplain Zone and the location of Stokes Inlet.

3.6 Settlement and land use

The mid 1800's saw the start of pastoral activities in the catchment of Stokes Inlet with a pastoral lease granted to Charles and William Dempster in 1863. Ten years later, a second land lease saw the establishment of the first homestead by the Moirs. The homestead was located near the eastern shore of the Inlet and grazed sheep in the natural bush which was occasionally burnt for feed (Brearley 2006). The homestead eventually succumbed to fire and the remains now exist in a small reserve for the Preservation of Historical Buildings in the Stokes National Park. Land in the catchment has been gradually released for farming activities since the 1950's.

The Stokes Inlet is significant in terms of Aboriginal history and culture. It is known as Walidj Benwenerup to the local Nyoongar people which means "the place where the eagle came to scratch (the cliff) and die". Traditionally like most West Australian estuaries the Inlet and tributaries were associated with indigenous settlement and food gathering. The following dreaming story provided by Esperance elder, Tommy Bullen in 1984 highlights the historical significance of Stokes Inlet to the traditional owners.

"Once everyone was camped way up the Young River. But then, the eagle chased everyone away from the freshwater to keep it for himself. Because he was so greedy, the water eventually all dried up. In the meantime, the eyes of the crow people had all turned white because they'd had to drink salt water. So there was a big fight. The crows speared the eagle and killed him. His wife, the mallee hen, brought his body, downstream and buried him. This hill on the east side of Stokes Inlet that is his grave. Looks like a mallee hens nest all scraped up into a mound" (Museum of Western Australia website 2006).

Consequently, the hill on the eastern side of Stokes Inlet known as Walitch Benwenerup is a sacred area and registered as an aboriginal heritage site.

While there is some documentation relating to the significance of Stokes Inlet to the traditional owners, further detailed information could be gathered in terms of specific activities and other important sites relating to the men and women of the local Nyoongar community.

Today, 60 percent of the catchment has been cleared and supports a wide range of agricultural and pastoral activities. Crops include wheat, barley, canola, lupins, oats and other pulses. Beef cattle along with sheep meat and wool are the livestock enterprises (Bowyer, 2001). Farmland occupies 281,241 hectares of the Young and Lort Catchments which is 56% of the combined catchment areas (Bowyer 2001).

The lower reaches of the Young and Lort Rivers are both in narrow river and foreshore river reserves. The Inlet itself provides recreational value for bird watching, camping, fishing, canoeing and four-wheel-driving. The emergence of tourism as a major industry has increased pressure for the Inlet to be closed to all forms of netting (Brearley 2006).

3.7 Environmental conditions of concern

Progressive clearing and changes in land use in the catchment have changed the characteristics and quality of river flow in the catchment of Stokes Inlet. Table 1 provides a summary of the present environmental conditions of concern in the catchment of Stokes Inlet.

Table 1 A list of environmental conditions of concern for the Young and Lort River catchments that drain into Stokes Inlet.

Conditions of concern	Example
• **Nutrient loading**	Agricultural and pastoral activities are likely to contribute to nutrient input from catchment to the estuary. Data is limited, but does indicate elevated total nitrogen concentrations particularly in the Young River. Management actions should aim at reducing nutrient inputs from the wetter sub-catchments, namely the Young River.
• **Salt loading**	Salinities of the Young and Lort Rivers range from 6 to 17 ‰ (almost half the salinity of seawater (35 ‰). Management actions should aim to revegetate areas along waterways to reduce the affects of salinisation.
• **Sediment loading**	Vegetation loss has increased surface drainage. The loss of vegetation along streams also promotes erosion. Management actions should aim to revegetate areas along waterways to reduce sediment loss.
• **Fringing vegetation**	Visible stretches of the Lort and Young below the highway are choked with vegetation. These areas promote sediment trapping.
• **Climate change**	Climate change (drying climate and changing rainfall patterns) broadly impacts a number of conditions described for the catchment that are affected by a reduction in river flow volumes. Management actions will require that flow to the Lort and Young Rivers is maintained to preserve the ecology of the riverine pools. An example would be restrictions on groundwater abstraction.

4 Environmental condition of Stokes Inlet

4.1 Introduction

The Stokes Inlet is located adjacent to the 10,667 ha Stokes National Park approximately 80 km west of Esperance. The mouth of the Inlet is situated in the middle of a bay with no headland protection and is bordered by beaches and sand dunes overlaying limestone. As such, wave action and dune mobilisation has created a high sand bar at the mouth of the estuary that breaks for approximately two weeks every few years. As a consequence of long closure periods, water levels and salinity in the Inlet alter with river flow and evaporation (Hodgkin and Clarke 1989, Brearley 2006).

The Stokes Inlet is 14 km^2 and one of the largest estuaries in the region. Set in a valley the estuary is relatively deep (10m in the lower basin); however sediment accumulation in the Inlet over the past 6,000 years has formed large deltas in the upper estuary resulting in water depths less than 2m deep.

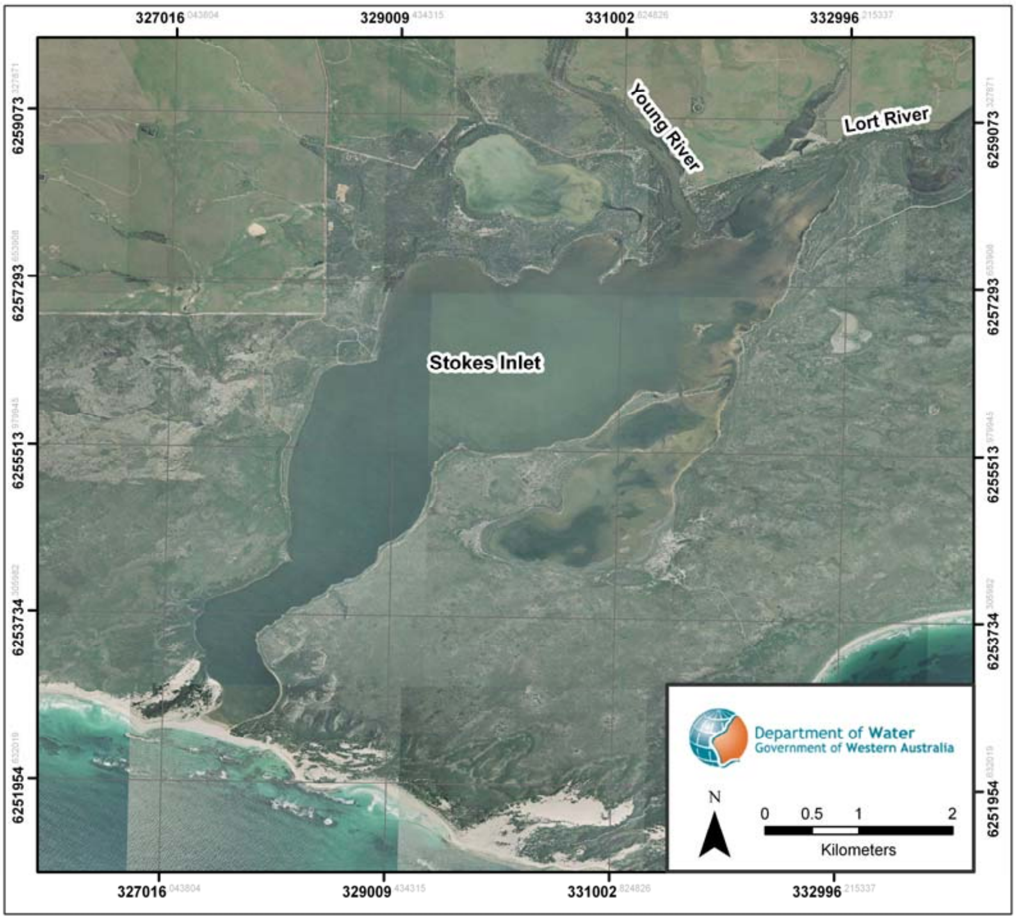


Figure 5 A photo mosaic of Stokes Inlet and its tributaries, the Young and the Lort Rivers.

The Young and Lort Rivers are the major tributaries that flow into Stokes Inlet. The Young River is coarsely aligned in a northwest/southeast direction while the Lort River is roughly aligned in a northeast/southwest direction. The Young River, 120 km long and the Lort River, 100 km long are the two main tributaries that flow into the upper reaches of the Inlet. The rivers are estuarine for a few kilometres upstream; however, with low water levels during dry periods, the rivers become isolated from the Inlet by the alluvial delta system (CALM NatureBase web site).

Current monitoring activities in the Inlet include:

- Water quality monitoring: There are 5 sites established to monitor water quality in Stokes Inlet. Water quality data is limited to only a few sampling events with physical variables measured at four sites and nutrient data collected at two sites.

Projects that monitor Inlet water quality of Stokes Inlet and will in the future contribute to the information available include:

- Stokes Inlet water Quality (SC-E-SCRISTO) - physical and chemical water quality monitoring.

4.2 Hydrology

Water depths up to 10m make the hydrology of Stokes Inlet unique compared with other estuaries along the South Coast. Water depth has a significant effect on the condition of the water quality in the estuary because of the affinity of deep estuarine waters to stratify. Water temperatures generally follow a seasonal cycle. Salinities rarely dilute below that of seawater (Hodgkin 1989). Stratification can be quite abrupt particularly after heavy flows or flooding, but the duration of the stratified condition is generally brief because of wind mixing, even in the deeper waters. Flooding can also cause sediments to accumulate in the Inlet: having a significant effect on the physical character of the Inlet.

4.3 Mouth Status

The entrance channel to Stokes Inlet generally remains closed to the ocean by a sandbar approximately 200 m long and 1.5-2 m above sea level. Prior to land clearing in the catchment, the bar had remained closed for 30 years (Hodgkins & Clark 1989). Bar breaks are now more frequent, every two to seven years (Figure 6), but they are generally brief (less than 6 weeks) and tend to happen in spring following wet winters and after heavy rainfall events that occur in spring and summer (Figure 2 & 7). Records indicate that a flood event discharging at least 10 GL into the Inlet is required to break the bar naturally (Figure 7).

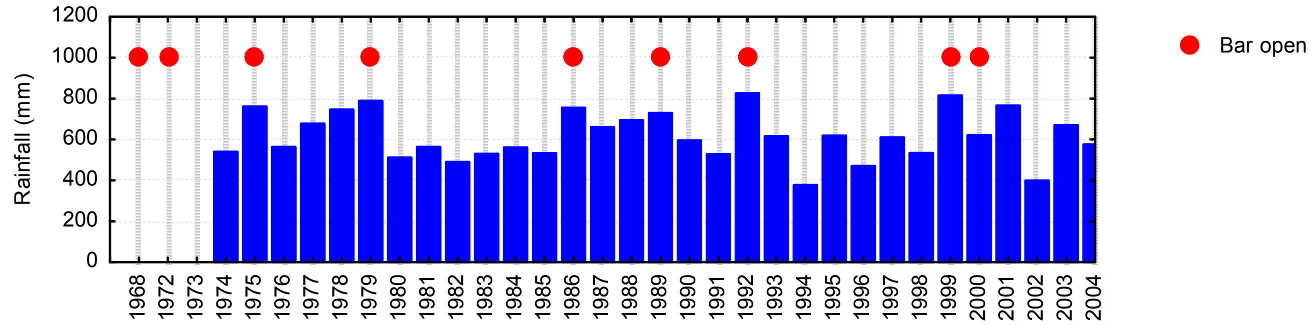


Figure 6 Historical record of the mouth status of Stokes Inlet relative to total annual rainfall.

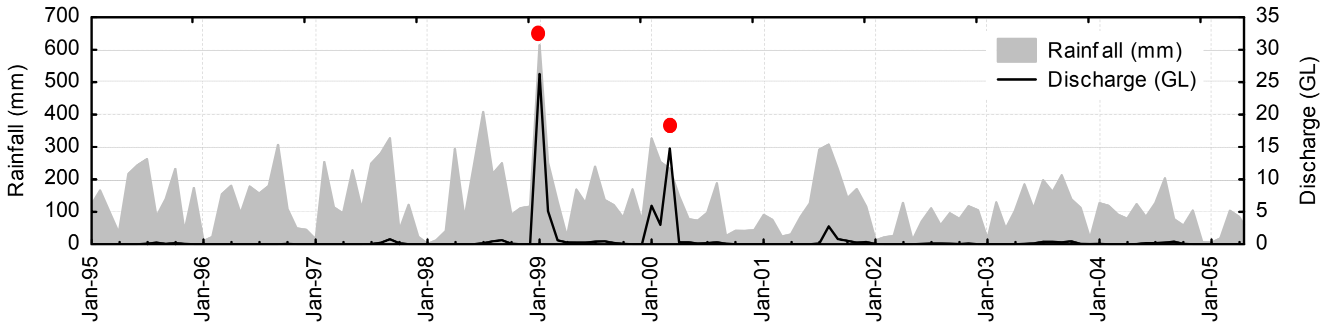


Figure 7 The rainfall and flow data for the Stokes Inlet catchment (1995 – 2005). The red dots indicate flow events that resulted in the Inlet sandbar to break.

4.4 Water quality

Water quality data in estuaries are compared against the low-risk guideline trigger values in the '*The Australian and New Zealand Guidelines for Fresh and Marine Water Quality*' (ANZECC & ARMCANZ, 2000) to assess the risk of adverse effects on aquatic ecosystems. The guidelines refer to a median value of replicate samples from a test site, preferably collected over a period of two years. Median values require at least 5 observations. In this study, water quality data is only available from four sampling events, February 1999 and the first year of quarterly monitoring data started in February 2006. Where comparisons have been made to guidelines it should be noted that an average based on three or fewer observations per site has been used.

The parameters considered in the monitoring program include temperature, salinity, dissolved oxygen, pH, secchi depth and dissolved and total nutrients. The sites for data collection are shown in Figure 8.

4.4.1 Physical characteristics

Stokes Inlet is isolated from oceanic exchange for years at a time and so salinities in the Inlet while closed are coupled to inflow from the catchment and evaporation. Salinities in the Inlet are commonly hypersaline, ranging between 33 ‰ to greater than 49 ‰ in surface waters, and 34 ‰ to greater than 70 ‰ in bottom waters (Appendix 1). Surface salinities can drop to as low as 4 ‰ in the event of flooding, but can rise shortly after (two weeks) mixing with deeper saline waters as a result of wind action (Hodgkin and Clarke 1989). The deeper sites closest to the mouth (ST001 and ST002) show the greatest stratification compared to the shallower sites further away from the mouth (ST003 and ST004) (Figure 9).

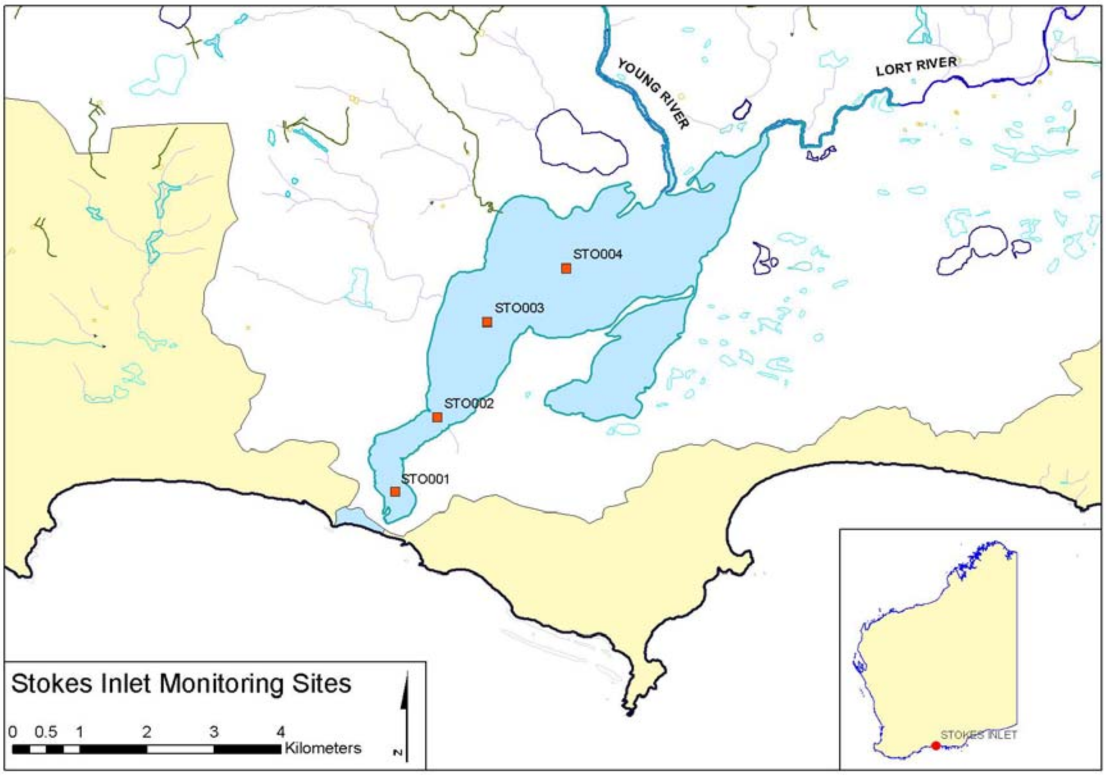
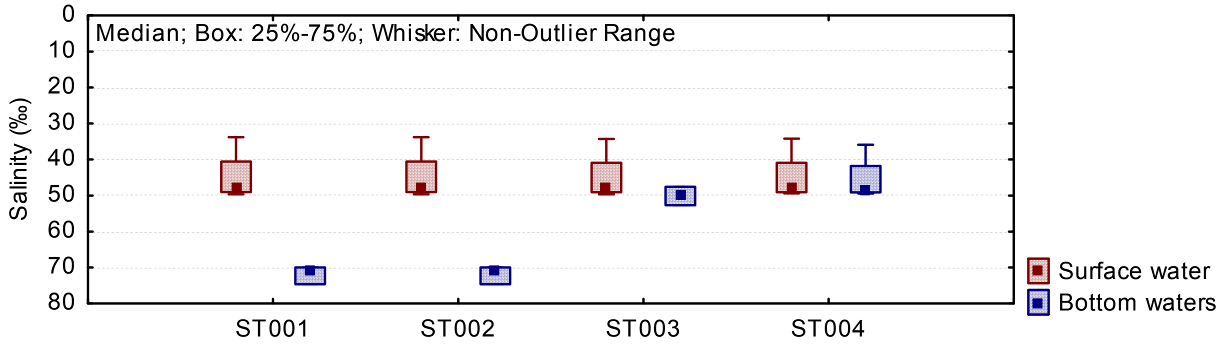


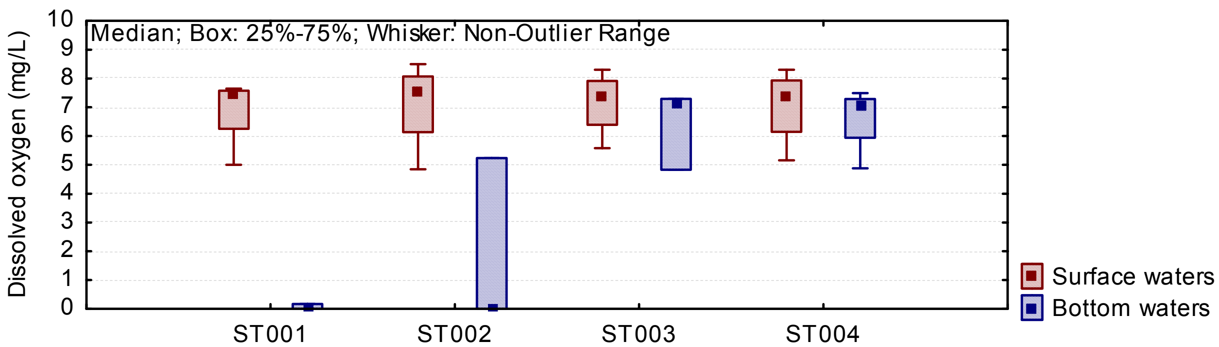
Figure 8 Stokes Inlet and water quality sampling sites



*The sites are ordered by distance from mouth, site ST001 being closest to the mouth and ST004 the site further away from the mouth.

Figure 9 Average surface (red) and bottom (blue) water salinities recorded at the four water quality sites in Stokes Inlet (Feb 1999; Feb, May and August 2006).

Oxygen concentrations are generally between 5 and 8 mg.L^{-1} in the surface waters, while bottom waters are anoxic (0mg.L^{-1}) to oxygenated (7 mg.L^{-1}) (Figure 10). As with salinity, the deeper sites (ST001 and ST002) are stratified and bottom waters are anoxic. Oxygen conditions in the water column improve further up the estuary (ST003 and ST004) where waters would be more readily mixed by prevailing winds.



* The sites are ordered by distance from mouth, site ST001 being closest to the mouth and ST004 the site further away from the mouth.

Figure 10 Average surface (red) and bottom (blue) water oxygen concentrations recorded at the water quality sites in Stokes Inlet (Feb 1999; Feb, May and August 2006)

Stratification of surface and bottom waters is not unusual given the water depth in the Inlet, and oxygen depletion in the bottom waters is typical when there are these strong salinity differences between surface and bottom waters. These same conditions were reported on in the late 1970's (Hodgkin and Clarke 1989) and based on current data appear to have changed little.

Temperatures of the water column follow a typical temporal cycle and are generally uniform to a depth of 5.5 m after which temperatures drop by three to five degrees Celsius. This is likely to be a result of poor water circulation and poor light (heat) penetration to the deeper waters; secchi depths have been less than a meter. The pH of the water column ranges from 7.5 to 8.6.

4.4.2 Nutrients

Based on the data available Stokes Inlet (Appendix 2) could be described as eutrophic (nutrient enriched). Nutrient concentrations recorded in the Inlet are high and higher than the concentrations recorded in the 1970's (Table 2). In the 1970's Hodgkin and Clark (1989) described the Inlet in a state of minor enrichment. Since that time median concentrations of total nitrogen have doubled and total phosphorus has tripled.

Table 2 Comparisons of nutrient concentrations recorded in Stokes Inlet in 1974/5 and in 2006.

Nutrients	1974/75	2006		ANZECC guideline values
		S	B	
TN (mg.L-1)	0.99	2.4	2.6	0.75
NH4 (mg.L-1)	0.02	0.06	0.07	0.004
NOx (mg.L-1)				0.045
TP (mg.L-1)	0.03	0.09	0.09	0.03
FRP (mg.L-1)	0.01	0.015	0.015	0.005

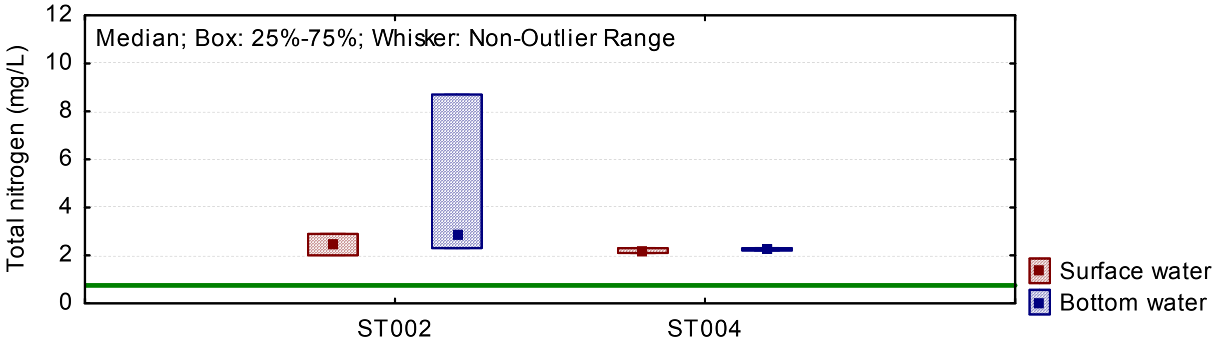
*the median concentrations were calculated from between 4 and 6 data points each and should be considered carefully.

Nitrogen inputs from river flow (the catchment) are high. Total nitrogen (TN) exceeded guidelines (ANZECC 2000) at all sites by 2 to11 times the recommended concentrations (Figure 11). Phosphorus inputs from the catchment appear to be less of a concern: total phosphorous TP only exceeded guidelines at STO002 (Figure 14). This being one of the lower sites in the estuary (Figure 8) indicates that there may be an autochthonous (within the Inlet) source of nutrients or a more localised drainage issue rather than an input from the Young and the Lort Rivers.

There is indication that sediments are an important source of nutrients to the Inlet. Bottom water ammonia (NH_3-N) concentrations (Figure 12) at STO002 were over 100 times the recommended guideline value of 0.04mg/L and concentrations of filterable reactive phosphorous (FRP) (Figure 15) were 56 times the recommended concentrations. ST002 is the deepest site for which nutrient data had been collected and is typically anoxic. Anoxic conditions promote the release of ammonia and FRP from sediments by reducing denitrification and by promoting decomposition of organic material by bacteria in the sediments.

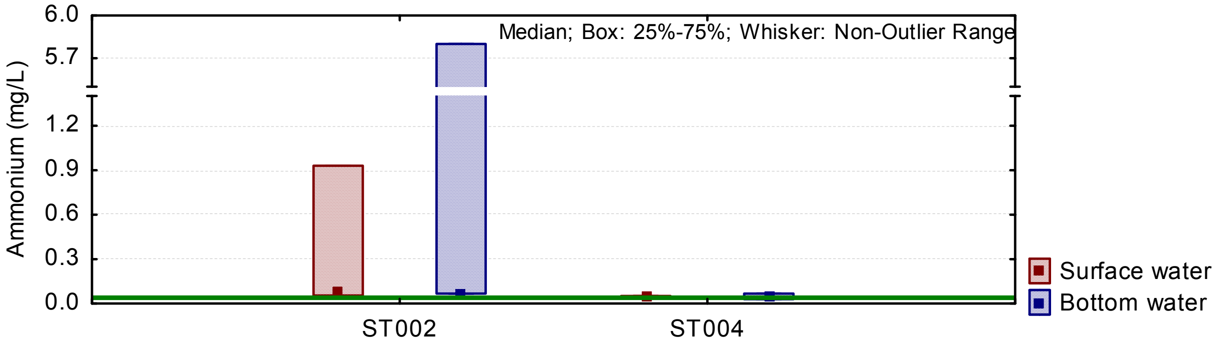
Little is known of the nutrient sources in catchment and the contribution of those nutrients when the rivers flow into the Inlet. While there is some indication of sediment nutrient recycling (also see Sediments) of bioavailable ammonia and filterable reactive phosphorus: how much is being recycled within the Inlet is unknown.

Initiation of the longer term water quality monitoring program for Stokes Inlet will improve knowledge of the chemical and physical characteristics and seasonal dynamics within the estuary. This will help guide management plans and actions for the catchment and the Inlet.



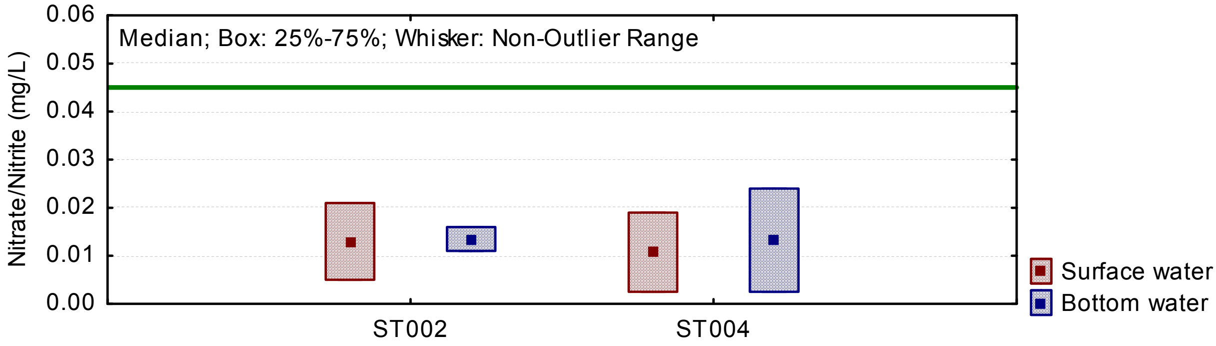
*The green line represents the recommended guideline for total nitrogen concentrations in estuaries on the south west of Western Australia (ANZECC 2000)

Figure 11 Median total nitrogen concentrations for surface (red) and bottom (blue) waters at ST002 and ST004 in Stokes Inlet (Feb, May and August 2006).



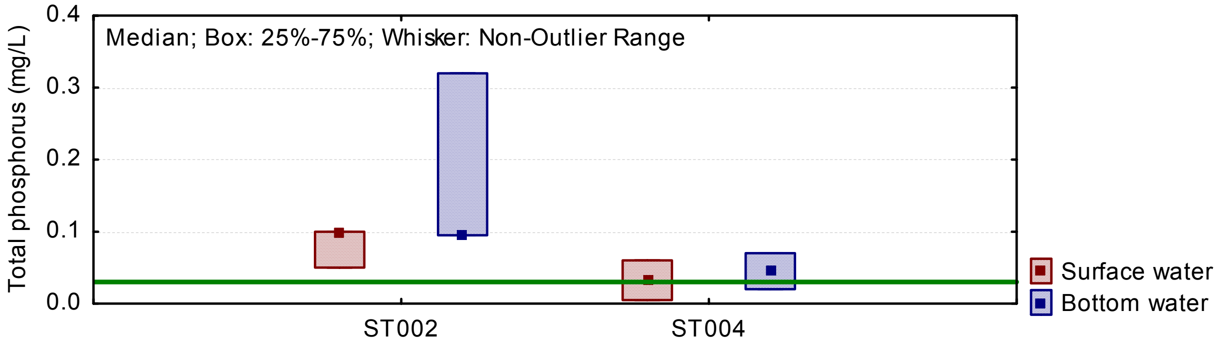
*The green line represents the recommended guideline for ammonium concentrations in estuaries on the south west of Western Australia (ANZECC 2000)

Figure 12 Median ammonium concentrations for surface (red) and bottom (blue) waters at ST002 and ST004 in Stokes Inlet (Feb, May and August 2006).



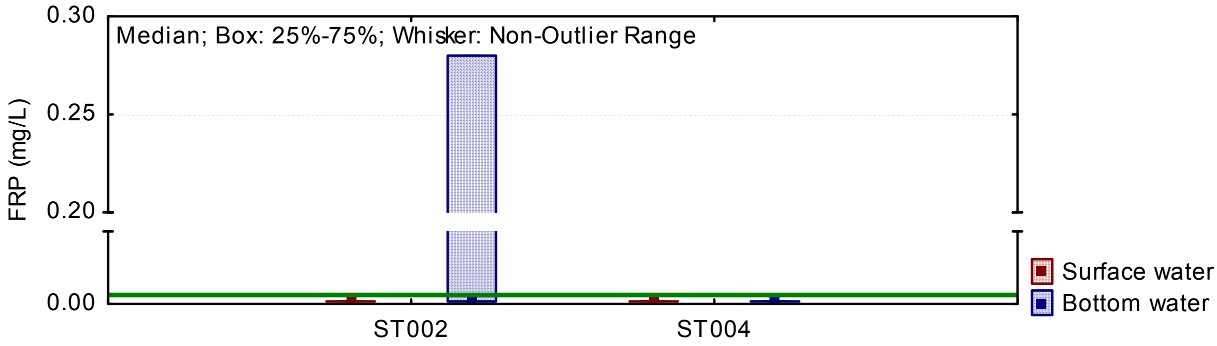
*The green line represents the recommended guideline for nitrate / nitrite concentrations in estuaries on the south west of Western Australia (ANZECC 2000)

Figure 13 Median nitrate / nitrite concentrations for surface (red) and bottom (blue) waters at ST002 and ST004 in Stokes Inlet (Feb, May and August 2006).



*The green line represents the recommended guideline for total phosphorus concentrations in estuaries on the south west of Western Australia (ANZECC 2000)

Figure 14 Median total phosphorus concentrations for surface (red) and bottom (blue) waters at ST002 and ST004 in Stokes Inlet (Feb, May and August 2006).



*The green line represents the recommended guideline for FRP concentrations in estuaries on the south west of Western Australia (ANZECC 2000)

Figure 15 Median filterable reactive phosphate (FRP/soluble reactive phosphorus/ orthophosphate) concentrations for surface (red) and bottom (blue) waters at ST002 and ST004 in Stokes Inlet (Feb, May and August 2006).

4.4.3 Comparison with other estuaries

The limited data collected for Stokes Inlet make comparisons to other estuaries difficult. Nevertheless the following figures have been put together using all the available data collected by the Department of Water (the then Department of Environment, Water and Rivers Commission) to provide a rough comparison of the nutrient conditions of estuaries on the south-west and south coast of Western Australia. The median values have been calculated for total and dissolved fractions of nitrogen and phosphorus (Figure 16, 17 & 18).

Based on the few samples taken in Stokes Inlet, nutrient concentrations in the Inlet are comparable to the water quality of Inlets to the East of Albany, namely Cheyne Inlet, St Marys Inlet and Beaufort Inlet; and the highly eutrophic Torbay Inlet and Lake Powell to the West of Albany. In particular, median total nitrogen, ammonia and total phosphorus concentrations exceed recommended guidelines.

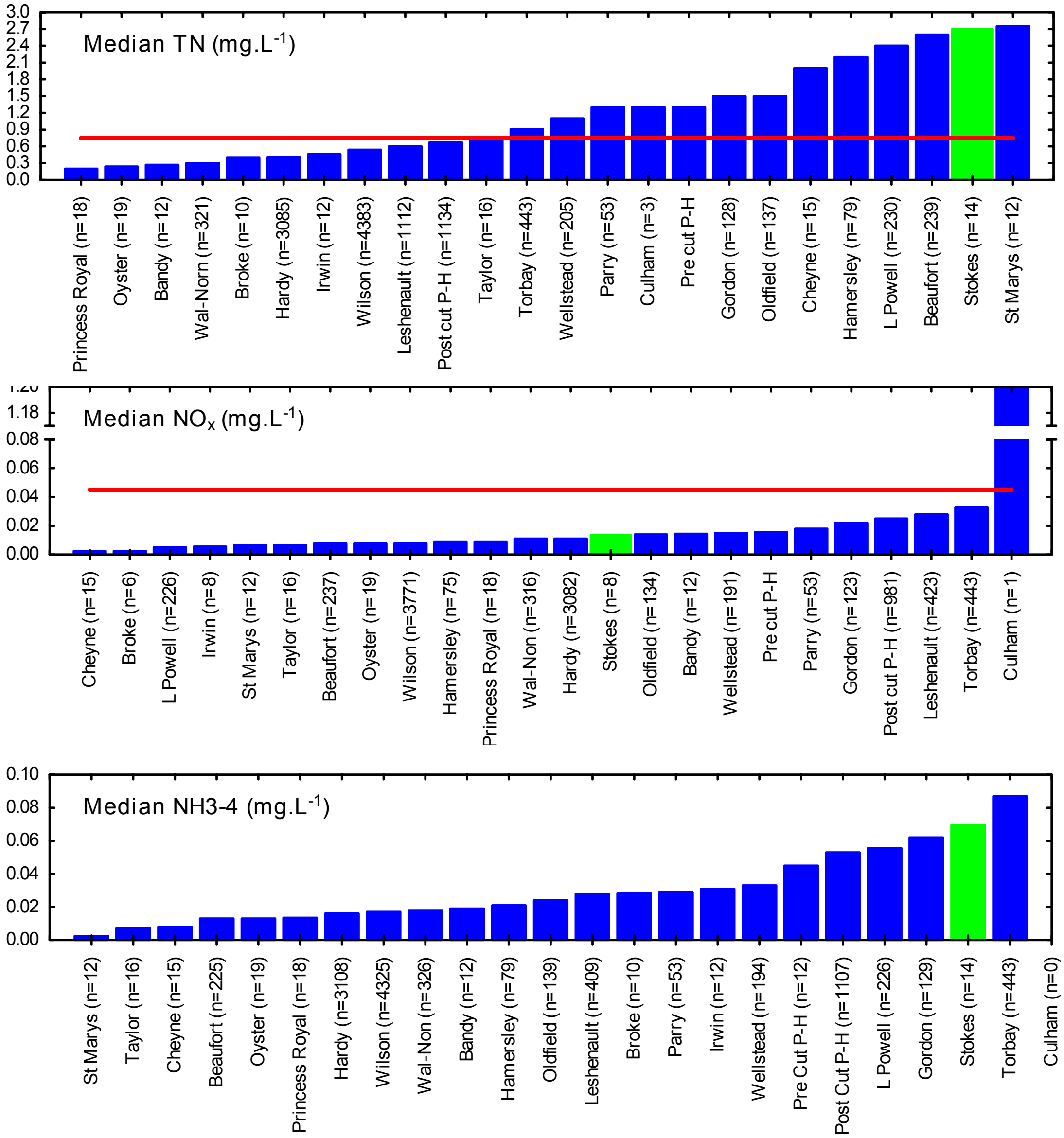


Figure 16 Comparison of total nitrogen (TN), total oxidised nitrogen (NOx) and ammonia (NH3-N) concentrations in stokes Inlet compared to other estuaries on the south west coast of Western Australia. This data represents the median value of all data points for all Inlets between 1997 and 2006, except for the 'Pre-cut P-H' which represents the data for Peel- Harvey between 1980 and 1993prior to the Dawesville Cut. The red line represents the ANZECC guideline (ANZECC 2000).

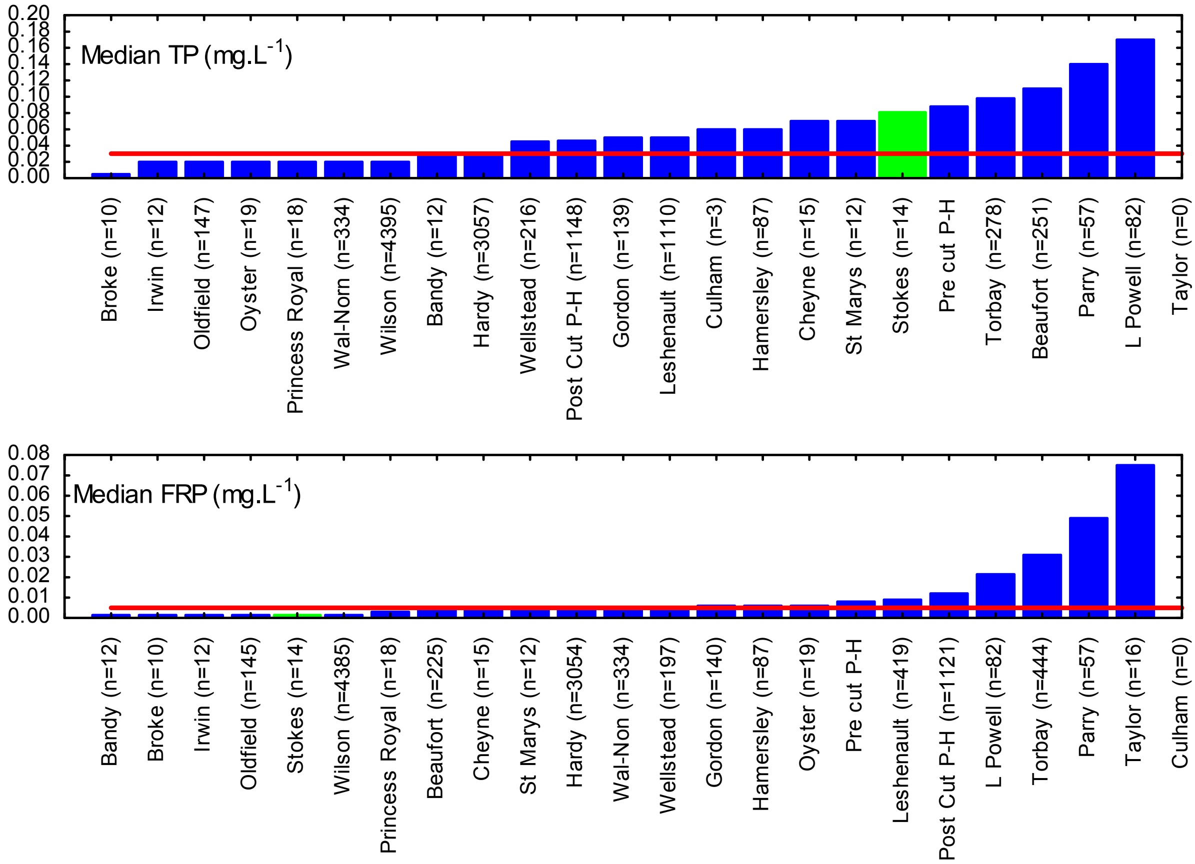


Figure 17 Comparison of total phosphorus (TP) and filterable reactive phosphorus (FRP) concentrations in Stokes Inlet compared to other estuaries on the south west coast of Western Australia. This data represents the median value of all data points for all Inlets between 1997 and 2006, except for the 'Pre-cut P-H' which represents the data for Peel- Harvey between 1980 and 1993prior to the Dawesville Cut. The red line represents the ANZECC guideline (ANZECC 2000).

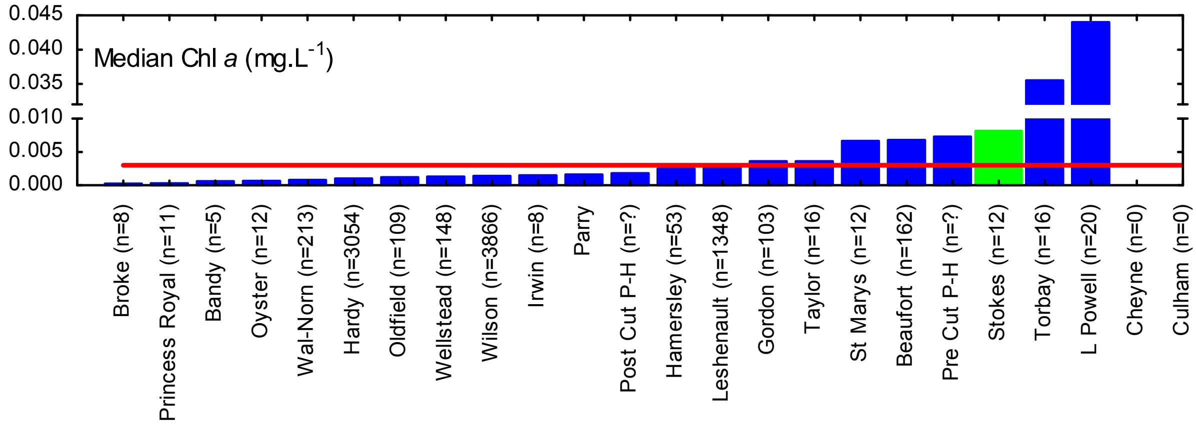


Figure 18 Comparison of chlorophyll a (Chl a) concentrations in Stokes Inlet compared to other estuaries on the south west coast of Western Australia. This data represents the median value of all data points for all Inlets between 1997 and 2006, except for the 'Pre-cut P-H' which represents the data for Peel- Harvey between 1980 and 1993 prior to the Dawesville Cut. The red line represents the ANZECC guideline (ANZECC 2000).

Chlorophyll *a* concentrations in Stokes Inlet are comparable with the highly disturbed Torbay Inlet and Lake Powell (Figure 18). The high chlorophyll *a* concentrations may reflect the availability of nutrients such as the inorganic oxidised nitrogen (NOx), ammonia (NH_3-N) and filterable reactive phosphorus (FRP). Both NOx and NH_3-N exceed recommended guidelines. Chl *a* concentrations may also reflect the availability of organic nitrogen (e.g. urea). This is supported by the fact that the proportion of NOx and NH_3-N is less than 3 % of total nitrogen. At present the dissolved organic fraction of nitrogen is not measured.

4.5 Sediments

A preliminary survey (March 2006) found sediments shallower than about 2 m to be very coarse and compacted (Geoscience Australia 2007). Similar observations were made by Hodgkin and Clarke (1989). These shallow coarse sediments predominantly make up the sand delta where the Young and the Lort Rivers enter into the Inlet. Coarser particles settle out of the water column first. Sediment compaction may be explained by exposure and drying of the sediments when the water level drops in the summer months.

Deeper sediments were very fine ('muddy'), dark grey to deep black in colour. Shell fragments were found particularly in lower parts of the cores (Geoscience Australia 2007). The shells are principally of the marine cockle species *Katelysia*. These shells have been dated to 4000+ years old and show the estuary to have been permanently open to ocean exchange in that time (Hodgkin and Clarke 1989).

Organic matter concentrations were typically of estuarine sediments. Stable isotopic composition of organic carbon and nitrogen suggested that the organic matter in surface sediments is largely formed within the estuary. In the March 2006 study, a deep green, flocculent layer was found on top of sediment cores suggesting recent deposition of organic rich material, possibly from a summer phytoplankton bloom.

Comparing the types of organic material contributing to the sediment organic fraction in Stokes Inlet to other estuaries; phytoplankton sources contribute most to sediment organics in Stokes Inlet and Beaufort Inlet. In contrast aquatic macrophytes contribute most to the sediment organics in Wellstead Estuary and Gordon Inlet (Figure 1919).

The site closest to the river mouth contained the largest fraction of catchment-derived organic matter (Geoscience Australia 2007).

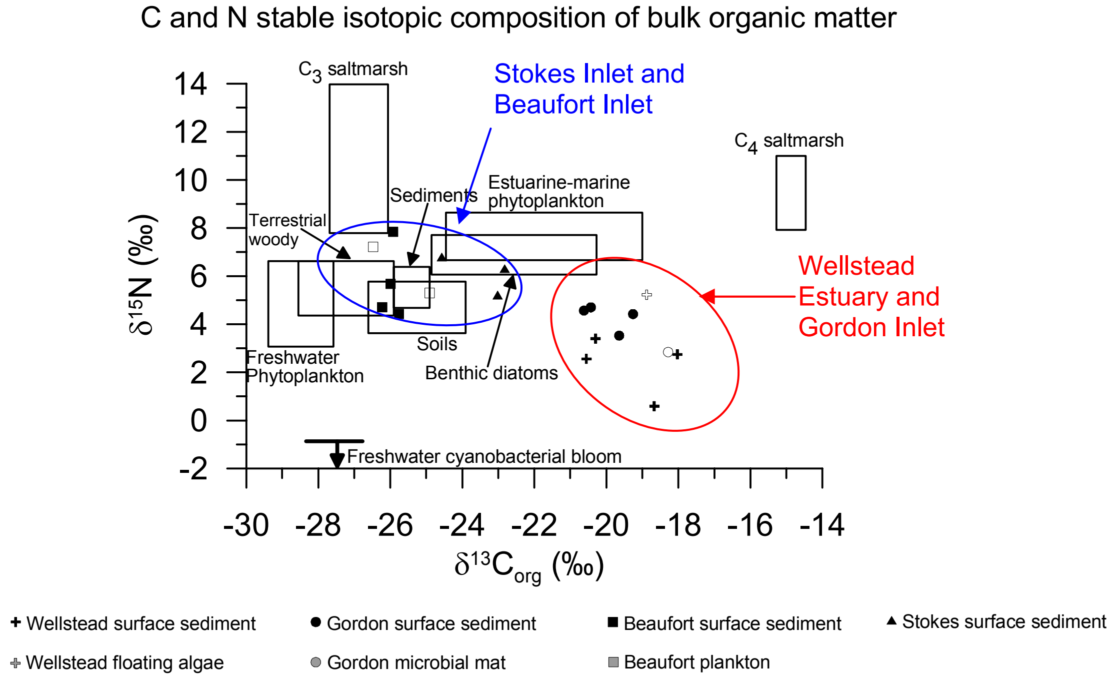


Figure 19 Cross plot of organic carbon and nitrogen stable isotopic composition in surface sediments. The rectangles indicate end members of organic matter sources according to Cloern et al. 2002 (Geoscience Australia 2007). The blue and red circles highlight the estuaries grouped by phytoplankton derived organic matter (blue) and aquatic macrophyte derived organic matter (red).

4.5.1 Sediment pore waters

Preliminary data from three sediment core profiles shows salinity at the sediment surface to resemble bottom water salinities. In contrast bottom pore waters show higher salinity concentrations. This may suggest that the bottom sediment water of

Stokes Inlet is relatively old and extensive evaporation has led to the high salt content.

Pore water nutrients indicate that sediments in the shallow waters (< 5 m water depth) retain and transform bioavailable nutrients, while deeper sediments (> 5 m water depth) provide significant input of nutrients to the Inlet. This was supported by higher nutrient concentrations in the upper part of the sediment profile in the shallower waters, compared to higher nutrient concentrations in the bottom of the sediments profile in the deeper waters (Geoscience Australia 2007).

These differences are likely to be driven by the oxygen concentrations. Anoxic conditions in the deeper waters facilitate nutrient release (see Water quality).

4.6 Estuarine Vegetation

4.6.1 Fringing vegetation

Stokes Inlet is surrounded by *Melaleuca cuticularis* (Saltwater Paperbarks) (Figure 20) and Samphire habitats alternating with sedges along the waters edge or in low sandy beach ridges (Hodgkin & Clark 1989). The width of the paperbark stands alter with the shoreline topography. On the steeper south-eastern shores stands shrink to a few trees or a single live or dead tree. *Sarcocornia quinqueflora* (Beaded Grasswort) is common on the north–western shores and eastern mud flats and is associated with other salt tolerant plants including *Suaeda australis* (Samphire), *Samolus repens (Creeping brookweed)*, *Carpobrotus sp*. and *Lomandra sp*. On slightly higher ground lies the rush vegetation: *Isolepis nodosa (Club Rush)*, *Euphorbia paralias* or *Juncus kraussii* (Shore Rush) and *Baumea juncea* (Bare twigrush) (Table 3).

No other known surveys of riparian vegetation have been undertaken since the late 1980's.

Figure 20 Melaleuca cuticularis (Saltwater Paperbarks) that surround Stokes Inlet (Photo 8/08/06 by Mieke Bourne)

Table 3 A list of common fringing vegetation and dune vegetation species surrounding Stokes Inlet (Hodgkin and Clark 1989).

Fringing plants	Common Name	Scientific name
	Saltwater paperbark	*Melaleuca cuticularis*
	Samphire	*Sarcocornia quinqueflora*
	Samphire	*Suaeda australis*
	Samphire	*Halosarcia*
	Salt tolerant	*Samolus repens*
	Salt tolerant	*Carpobrotus sp.*
	Salt tolerant	*Lomandra sp.*
	Salt tolerant	*Juncus kraussii*
Dune vegetation		**Scientific name**
Colonisers		*Spinifex hirsutus*
		Isolepis nodosa
		Carpobrotus sp.
		Arctotheca populifolia
		Ammophila arenaria
		Euphorbia paralias
First Dune		*Scaevola crassifolia*
		Acacia eglandulosa
		Cakile maritima
		Pimelea ferruginea
		Lepidosperma gladiatum
		Olearia axillaris
		Angianthus cunninghamii
Established Dunes		*Spyridium globulosum*
		Leucopogon parviflorus
		Templetonia retusa
		Acacia rostellifera
		Rhagodia baccata
		Guichenotia ledifolia

4.6.2 Aquatic vegetation

Aquatic vegetation in Stokes Inlet was last described by Hodgkin and Clarke (1989) in the 1970s at which time the Inlet was dominated by salt tolerant species such as the stonewart *Lamprothamnium papulosum,* the small green alga *Polyphysa peniculus* which occupies the shallows, and the macrophyte *Ruppia megacarpa*. *Ruppia* dominated the shallow areas on the eastern side of the Inlet (Hodgkin and Clarke 1989).

No recent studies on the aquatic vegetation have been conducted in Stokes Inlet. Water depth and accessibility in and around the Inlet add to the challenge of surveying the aquatic flora.

4.6.3 Phytoplankton

Assessing phytoplankton communities includes samples for biomass (Chlorophyll *a* concentrations) and community composition (cell counts of phytoplankton groups).

Chl *a* concentrations in Stokes Inlet (STO002 and ST004) have been higher than the recommended trigger value (0.003mg/L) on all but the May sampling occasions in

2006 (Figure 21). In August 2006, concentrations at ST002 were high enough to cause a visible discoloration in the water (Figure 22).

Chlorophyll *a* (Chl *a*) concentrations measured in surface and bottom waters can also be used to assess the impact of a nutrient disturbance to water column productivity (see Water Quality).

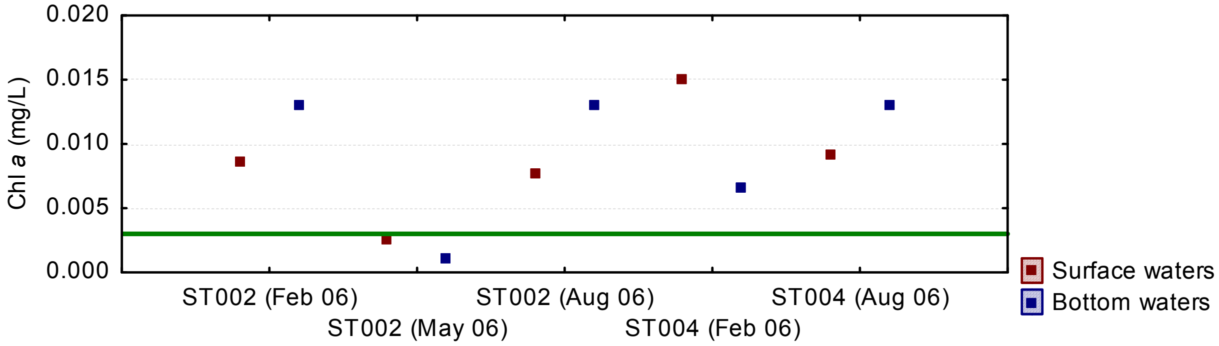


Figure 21 Chlorophyll a concentrations (mg/L) at STO002 and ST004 in the Stokes Inlet

Figure 22 Visible green discolouration of water at Stokes Inlet (Photo 8/08/06 by Mieke Bourne)

Phytoplankton samples taken in Stokes Inlet were dominated by miscellaneous phytoplankton cells (unidentified cells), Dinophytes, Cryptophytes and planktonic diatoms (Figure 23,

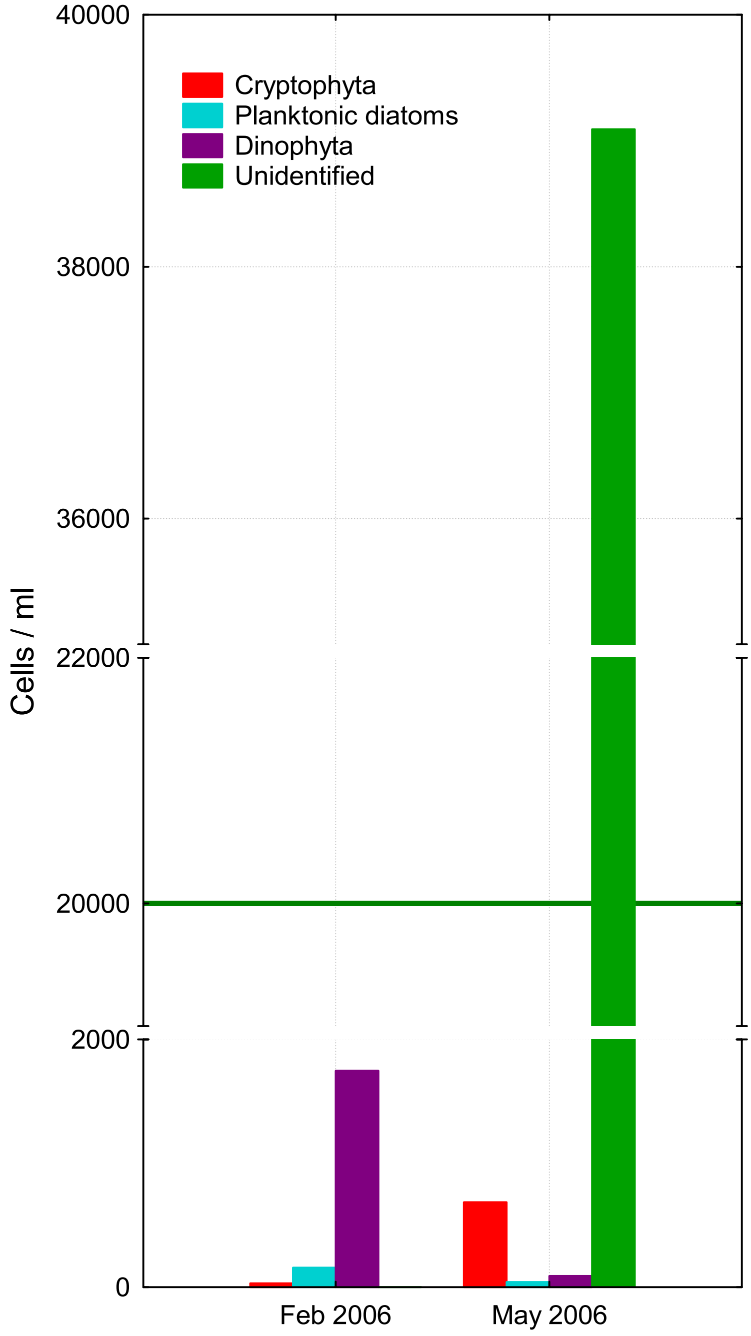


Figure 23 Phytoplankton assemblages in Feb 2006 and May 2006 recorded in Stokes Inlet (sites STO002, ST004, ST005).

High cell numbers, although in this case unidentified phytoplankton cells, in Stokes Inlet is some indication that the Inlet is at risk of phytoplankton blooms, particularly given nutrient availability. The risk of harmful algal blooms is also a consideration given the occurrence of potentially toxic species: the dinoflagallate species, *Karlodinium micrum* and *Prorocentrum rhathymum.* These species are characteristically associated with diarrhetic shellfish poisoning (DSP) and neurotoxic shellfish poisoning (NSP) (Table 4). *Heterosigma akashiwo* has also been recorded in the Inlet which is toxic to fish (Table 4).

Further investigations are required in regards to seasonal trends in phytoplankton assemblages along with nutrient and salinity dynamics.

Table 4 Phytoplankton species and their characteristics recorded in Stokes Inlet in 2006.

Group/Genera	**Species**	**Characteristics**
Benthic Diatom	*Nitzschia*	
Benthic Diatom	*Entomoneis*	Often associated with anoxic conditions OR during storm events
Dinoflagellate (Marine)	*Scrippsiella*	May cause red tides when in high densities. Forms cysts that lay dormant in the sediment until conditions are ideal for growth
Dinoflagellate	*Katodinium*	Very small
Dinoflagellate	*Karlodinium micrum*	Potential toxicity to fish, Neuro toxic shellfish poisoning (NSP)
Dinoflagellate	*Heterocapsa*	Prefers Brackish to Marine conditions
Dinoflagellate	*Karlodinium micrum*	Potential toxicity to fish Neuro toxic shellfish poisoning (NSP)
Dinoflagellate	*Prorocentrum rhathymum (formerly mexicanum)*	Diarrhetic shellfish poisoning (DSP)
Cryptophyte	*Chroomonas*	Can form red tides when in high densities
Cryptophytes	*Plagioselmis*	Prefers Brackish to Marine conditions
Raphidophyte	*Heterosigma akashiwo*	Toxic to fish, can influence grazing activity of coastal zooplankton, prefers marine conditions
Passive Pico phytoplankton	*NA*	<3 micron in size

4.7 Invertebrates

Bottom fauna are predominantly estuarine species tolerant of a wide range of salinities. On occasion large numbers of salt lake snails, *Coxiella* are also present. Few marine species survive for extended periods in Stokes Inlet. Marine species may be introduced into the Inlet when the sandbar breaks: species recorded in the Inlet have included juvenile prawns (*Penaeus latisulcatus*), mussels (*Mytilus edulis*) and blue manner crab (*Portunus pelagicus*).

Oxygen concentrations also present difficult conditions for bottom fauna. The bristle worm (polychaete) *Capitella capitata* has been recorded in high numbers in the Inlet. *Capitella* is a species common to disturbed or low oxygen sediment conditions.

Common bottom fauna collected from Stokes Inlet are listed in Table 55. Changes in the composition of the bottom fauna since 1989 are unknown and would require investigation.

Table 5 Bottom fauna recorded in stokes Inlet (Hodgkin and Clark 1989)

Phyla	Family	Species
Polychaeta	Spionidae	*Prionospio sp.*
	Capitellidae	*Capitella capitata*
		Ficopomatus enigmatica
Mollusca - Gastropoda	Hydrobiidae	*Hydrobia buccanoides*
	Hydrococcidae	*Hydrococcus brazeiri*
	Atylidae	*Liloa brevis*
	Amphibolidae	*Salinator fragilis*
	Nassariidae	*Nassarius burchardi*
		Coxiella sp.
Mollusca - Bivalvia	Mytilidae	*Mytilus edulis planulatus*
	Leptonidae	*Arthricia semen*
	Cardidae	*Fulvia tenuicosta*
	Mactridae	*Spisula trigonella*
	Sanguinolariidae	*Sanguinolaria biradiata*
	Veneridae	*Katelysia scalarina*
	Tellinidae	*Tellina deltoidalis*
Crustacea	Mysidacea	*Mysid sp.*
	Amphipoda	*Melita sp.*
	Isopoda	*Sphaeroma sp.*
	Decapoda	*Penaeus latisulcatus*
		Ovalipes australiensis
		Leptograpsodes octodentatus
		Palaemonetes australis
Insecta	Trichoptera larvae	
	Chironomidae	*Pontomyia cottoni*

4.8 Fish

The most recent survey conducted between 2002 and 2004 recorded just twelve species of fish in Stokes Inlet (Table 6) (Hoeksema *et al*. 2006a and b). Although numbers were still high, species composition compared poorly to the 31 species recorded in studies published between 1974 and 1982 (Hodgkin and Clark 1989). The composition of fish in the estuary depends largely on the time and duration that the sandbar remains open, and the salinity and oxygen conditions of the water column. Bar opening events were recorded in 1972, 1973, 1975, 1979, 1989, 1992, 1999 and 2000 (Figure 6).

The most dominant species in the nearshore shallow reaches of the Inlet were *Atherinosoma elongata* (Hardyhead), *Pseudogobius olorum* (Swan River Goby) and *Acanthopagrus butcheri* (Black Bream). These collectively represented 99.8% of the total number of fish caught (Hoeksema *et al.* 2006).

Acanthopagrus butcheri (Black Bream) represented 97.8% of the total number of fish caught in the shallow nearshore and deeper waters of Stokes Inlet.

Table 6 Stokes Inlet Fish Fauna, in order of abundance, the life cycle guild (LC), percentage contributions (%) to the total of fish species caught by seasonal seine and gill netting between summer 2002 and spring 2004 collectively in the nearshore, shallow and off-shore waters of Stokes Inlet. Presence specifically in basin and major tributary of Stokes Inlet are also noted (adapted from Hoeksema et al. 2006)

Netting type	Species	Stokes Inlet		Basin	Tributary
		LC	%		
Seine netting	*Atherinosoma elongata*	E	79.2	Yes	Yes
	Pseudogobius olorum	E	15.7	Yes	Yes
	Acanthopagrus butcheri	E	5	Yes	Yes
	Favonigobius lateralis	E & M	<0.1	Yes	-
	Engraulis australis	E & M	<0.1	Yes	Yes
	Galaxias maculatus	F	<0.1	-	Yes
	Aldrichetta forsteri	O	<0.1	yes	-
	Number of species			**6**	**5**
Gill netting	*Acanthopagrus butcheri*	E	97.8	Yes	Yes
	Aldrichetta forsteri	O	0.7	Yes	-
	Engraulis australis	E	0.6	Yes	Yes
	Mugil cephalus	E & M	0.3	Yes	-
	Arripis georgianus	O	0.3	Yes	-
	Cnidoglanis macrocephalus	O	0.1	Yes	Yes
	Platycephalus speculator	E & M	0.1	Yes	-
	Rhabdosargus sarba	E & M	0.1	Yes	-
	Number of species			**8**	**3**

Stokes Inlet is a popular location for recreational and commercial fishing. The fishery is covered by the South Coast Estuarine Fishery Management Plan 2005, all of the 25 licensed commercial fishermen are permitted to fish Stokes Inlet and its tributaries (to the South Coast Hwy), but only 3 or 4 generally do. There is community and recreational interest in closing the Inlet to commercial fishers (Pearn and Cappelutti 1999). The principal targets are the Black Bream and Sea Mullet (*Mugil cephalus*). Sea mullet made up only 0.3 % of the catch between 2002 and 2004. Differences in life cycle strategies are the most likely explanation. Black Bream are an estuarine species that breed in the estuary. Sea mullet rely on the marine environment to complete their breeding cycle (Hoeksema *et al.* 2006): there presence in the estuary would be depending on the timing and duration of sand bar breaks of the estuary mouth.

The absence of freshwater species records in the tributary or the basin may be an indication of the saline waters coming from the catchment.

Three mass mortalities have been recorded in Stokes Inlet; in 1932, 1938 and 1983 (Hodgkin and Clark 1989). These, like those recorded in Gordon Inlet, Beaufort and Culham Inlet have been attributed to the effects of high salinities and temperatures, and deoxygenation.

4.9 Current management

The Department of Water (previously the Water and Rivers Commission) has recently included Stokes Inlet into the south Coast NRM (formerly SCRIPT) funded water quality monitoring program for south coast estuaries: current data exists only for two sampling events in 1999 and 2006. The combination of characteristics considered, include salinity, dissolved oxygen, pH, turbidity, nutrient concentrations and phytoplankton biomass (Chl *a*) and community structure (species).

Stokes Inlet is currently vested as Unallocated Crown Land (UCL) and is surrounded by Stokes National Park (managed by the Department of Environment and Conservation (DEC)) which extends to the low water mark of the Inlet and includes some of the estuarine reaches of the Young and Lort Rivers. The Department of Fisheries manages all fish resources in the Inlet and the Department of Planning and Infrastructure manages activities carried out on the waterbody such as boat use. The Department of Water takes the lead on waterways issues and has received funding from South Coast NRM to prepare a management plan for the Inlet. This Condition Statement will provide recommendations to be included in the plan. The management planing process provides an opportunity for integrated management including government agencies, organisations and the local community.

A number of reports have suggested that the Inlet be included within the formal reserve system as such this may be a possibility in the future.

4.10 Conceptual models

Collating the available information conceptual diagrams of Stokes Inlet are provided to illustrate the current understanding of the Inlet and to highlight areas where information is insufficient. These shortfalls in information are elaborated later in the document (see 'Shortfalls in environmental information').

Figure 24 illustrates the normally closed bar situation of stokes inlet. Three factors are highlighted by this model:

- The lack of baseline data of the biological communities in the Inlet limits the use of biological indicators of change in the condition of the Inlet and the processes that drive the system.

- There is no long term data set that can identify the temporal processes in physical and chemical water quality in the Inlet.
- The lack of water quality data of the Young and Lort Rivers as they flow into the Inlet leaves a gap in our understanding of how catchment activities influence conditions in the inlet.

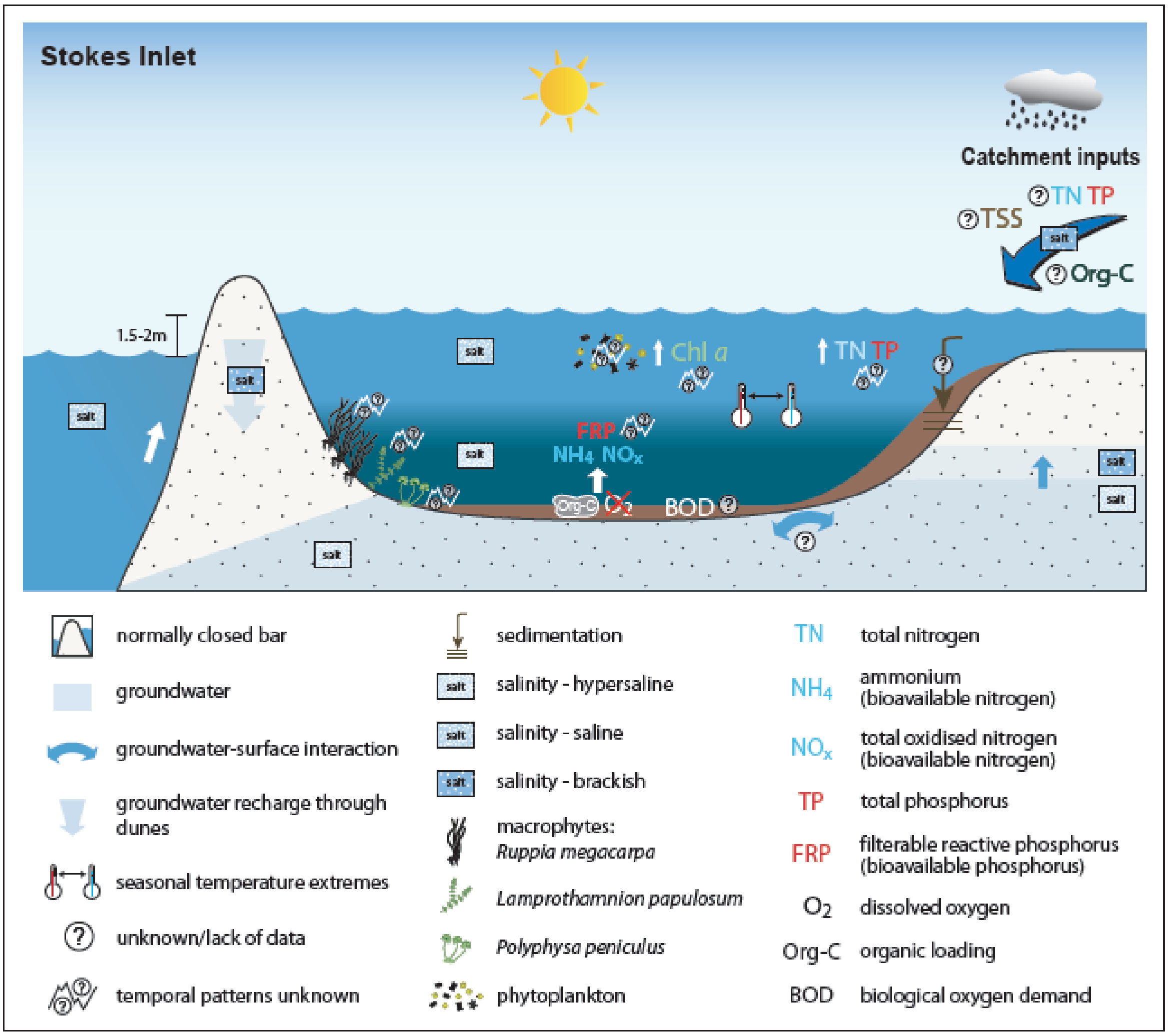


Figure 24 Conceptual model summarising the current understanding of the condition of the Stokes Inlet during its usual 'closed' state

Figure 25 illustrates Stokes Inlet when it is open to oceanic exchange. This is a short lived state of the estuary, however information of how oceanic exchange can influence the biological communities and the physical conditions in the estuary are an important consideration, yet poorly understood.

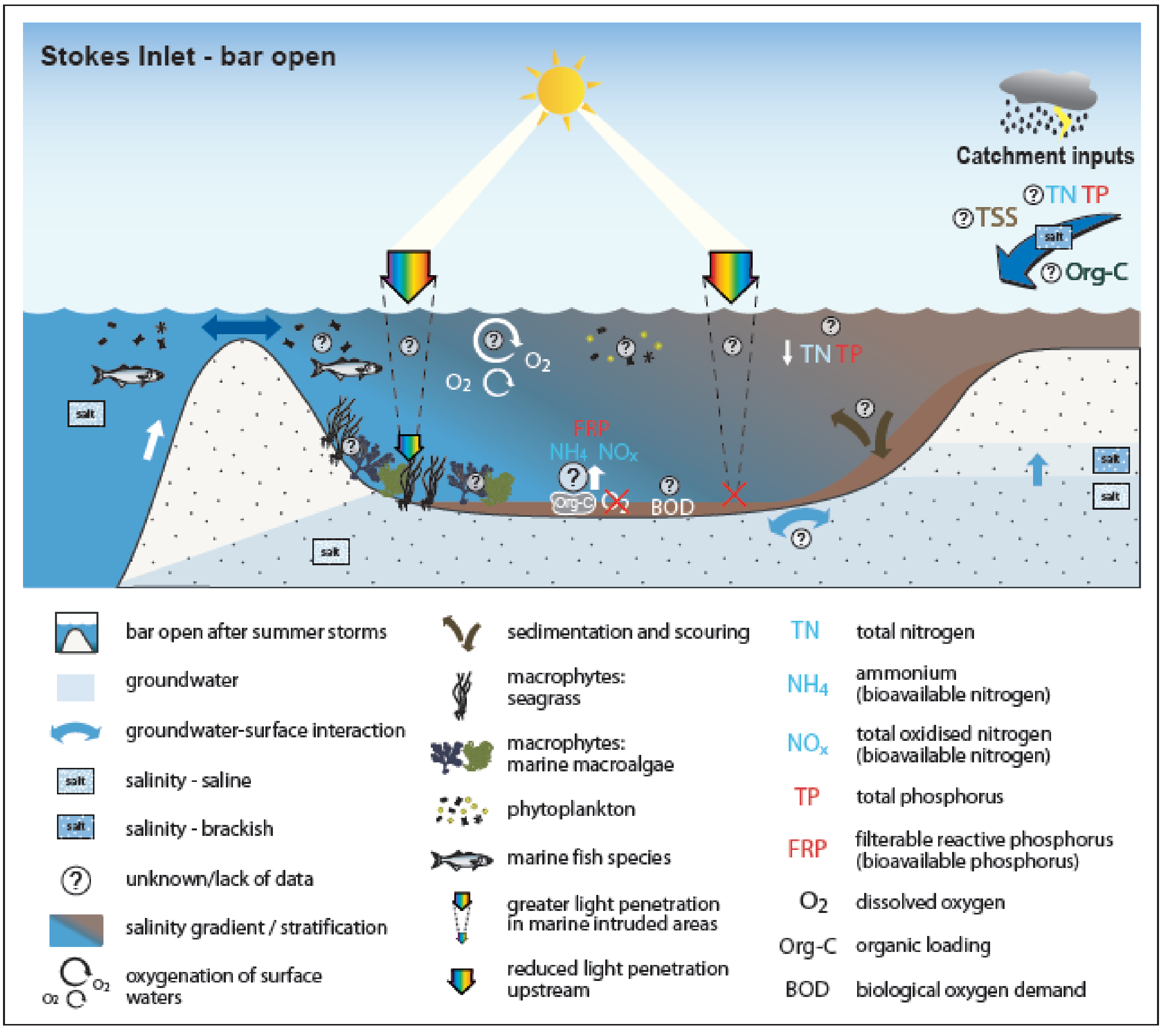


Figure 25 Conceptual model summarising the current understanding of the condition of the Stokes Inlet during its usual 'closed' state

4.11 Environmental conditions of concern in Stokes Inlet

Environmental conditions of concern for Stokes inlet include poor water quality associated with high nutrient concentrations, localized and intense stratification and deoxygenation, and the occurrence of harmful algal species. The potential for phytoplankton blooms and sediment infilling of the Inlet are also a concern.

A summary of the present environmental conditions of the Stokes Inlet has been summarized by region in Table 7.

Table 7 A summary of environmental conditions of concern in the Stokes Inlet.

Condition	Example
Strong salinity stratification and **deoxygenation**	Salinities of the surface and bottom waters can vary by up to 20 ‰ in the deeper basin (> 5 m water depth) Bottom waters are frequently anoxic in the deeper basin.
High nutrient concentrations	Since the 1970s median concentrations of total nitrogen have doubled and total phosphorus has tripled.
Harmful algal species	Harmful algal species namely *Gymnodinium complex* have been found to occur in the Inlet.
Phytoplankton blooms	Phytoplankton blooms are infrequent, but a concern given the nutrient concentrations available for primary production.
Sedimentation rates	Sediment deltas that extend into the Inlet appear to be increasing.
Climate change	Climate change (drying climate and changing rainfall patterns) may result in a reduction in river flow to the Inlet and / or a change in the frequency of flood events to the region. Reduced flow may result in drop in Inlet water levels which would be accompanied by changes in water quality such as increased salinities and poor oxygen conditions. Summer bar opening events may become more frequent. Depending on duration this could have dramatic effects on the biological and physical conditions of the Inlet.

4.12 Environmental management issues

With the appearance of environmental conditions of concern in the Stokes Inlet it is crucial that the processes that lead to or continue to yield these conditions be understood. This requires adequate monitoring and scientific investigations to supply data from which management solutions can be drawn.

4.12.1 Current sampling efforts

The Department of Water (Albany) currently coordinate an environmental monitoring program on the Stokes Inlet. This program involves three monthly water quality data collection.

During each sampling run, physical and chemical information is collected. Salinity, dissolved oxygen (mg/L and percent dissolved oxygen), pH, turbidity, temperature are recorded at discrete depths throughout the water column using a Hydrolab (DS5). Water samples from surface and bottom waters are taken and analysed for nutrient concentrations including total nitrogen and total phosphorous as well as nutrient fractions including Ammonia-N, Nox-N and soluble reactive Phosphorous. Water samples are also collected to determine phytoplankton species present (cells/mL) as well as Chlorophyll *a*.

Recently in February 2007 the monitoring program expanded to incorporate a site in the estuarine reaches of both the Young and Lort River systems. Profile readings are recorded and water is collected for nutrient analysis, Total suspended solids (TSS) and Loss of Ignition (LOI).

At all sites field observations are recorded including Seechi depth, cloud cover, wind speed and direction and general observations regarding the status of the bar.

The Department of Water (DoW) has gauging stations on the Lort and Young Rivers. The Lort River site (immediately upstream of the South Coast highway bridge) was established in 1971 and the three sites on the Young River, Neds Corner, Munglinup and Melaleuka which were established in 1971, 1974 and 1974 respectively.

These gauging stations continuously record flow and are manually sampled to test all the water quality parameters every two months (nutrients, temperature, conductivity, pH, turbidity etc). Additionally, for the last two years, the gauging station at Neds Corner has continuously measured temperature and salinity.

Water samples are taken from the Lort and Young Rivers where they cross the South Coast Highway fortnightly, this sampling is recent and commenced in August 2006. The water samples are tested for the standard parameters including nutrients, conductivity, pH and TSS.

4.12.2 Shortfalls in environmental information

Environmental data collected for Stokes Inlet is only recent (2006; and 2 sampling events in 1999) and limiting in providing an understanding of the Inlet against baseline parameters of water quality. Aside from water quality, there is also little ecological data, process based data, or event driven environmental information available. Without this environmental information the development of strategies to minimise or eliminate the conditions of concern identified first the Inlet are not possible. As such, the primary recommendation is to obtain information on some of the intrinsic processes in the Inlet.

The following knowledge gaps have been highlighted:

- **Additional water quality parameters:** While the water quality monitoring program includes analyses of inorganic nutrient concentrations, there is no data to indicate contributions of allocthonous organic nutrients. Other parameters to consider would be total suspended solids (TSS) which could give an indication of the weight of suspended material in the water column: this would be a useful measure of particulate loading from the Young and the Lort Rivers during periods of river flow.

- **Sedimentation:** There is no data that can assist in the management of sedimentation processes in the Inlet. Sediment cores, site differential levelling surveys and / or bathymetric surveys are required to monitor the movement of sediments in the Inlet, in particular sedimentation processes around the flood tidal delta at the meeting of the Inlet and the Young and Lort Rivers.
- **Macrophyte / macroalgal growth**: There is presently no current or routine macrophyte / macroalgal surveys of the Inlet that enable monitoring of the distribution (depth presence / absence) or biomass of species in the Inlet. Submerged aquatic vegetation provides an important habitat to estuarine fauna and is important to the ecology of the Inlet**.** It is also important to monitor the presence and distribution of harmful species.
- **Macrofauna:** There is presently no current or routine macrofauna survey data. Macro-invertebrates are a commonly used indicator of estuarine health. Typically estuarine species complete their life cycle within the estuary and so changes in community structure can provide insight to marked changes in the condition of the sediments and water column and the ecology of the estuary.
- **Fringing vegetation:** At present there are no routine surveys of the health and distribution of fringing vegetation along the estuarine reaches of the system to monitor change in this habitat.
- **Social and environmental values**: An assessment /surveys of the social and environmental values of local communities regarding the Inlet are required to guide management priorities.

Capture of this information is required before the current condition of the Inlet can be adequately defined.

The following knowledge gaps have recently been addressed:

- **The scale of water quality monitoring:** An additional two sites have been included in the regular water quality monitoring program for stokes Inlet. There were previously only no water quality monitoring sites inestuarine reaches of the Lort and Young Rivers. The addition of these sites will help monitor the inputs of nutrients and organics into the Inlet from the catchment. In the event that boat access is not possible, consideration needs to be given to alternative access options and random sampling sites in order to keep a regular record of water quality in the Inlet.
- **The frequency of water quality monitoring:** The frequency of water quality monitoring has also been adjusted to include ‘event monitoring’ to capture high river flow events. The frequency of monitoring these events may still need further consideration e.g. fortnightly monitoring during high flow to capture the time-scale effects of high river flow events into the Inlet.
- **Sediment nutrient exchange**: Benthic chamber experiments were conducted early in 2007 to compliment the sediment cores collected in 2006. These

experiments have furthered our understanding of sediment nutrient exchange between sediments and the water e.g. denitrification efficiency.

- **Social and environmental values**: An assessment /surveys of the social and environmental values of local communities regarding the Inlet has recently been completed. The information will help guide management

Studies in progress include:

- **Fish**: Investigations into a recent fish kill event have been conducted. Eco-toxicological tests are been conducted on Black Bream to investigate the bioaccumulation of heavy metals, pesticides and herbicides. The importance of upstream pools in the Young River are being studied to establish their importance to fish as a refuge during low flow periods.
- **Groundwater monitoring**: A groundwater bore has been sunk near Stokes Inlet. This could assist with investigations on groundwater-estuarine interactions which are poorly understood.

4.13 Determination of targets

4.13.1 Target setting

In a natural resource management program, a target is a numerical measure of a management objective. A management objective may be achieved by identifying the current environmental condition of a water body, and the desired environmental condition of that water body. Targets are then set as benchmarks and milestones between the current and desired conditions. Targets can be used to strengthen the objectives of the resource management program from a broad statement of intent to numerical measures of progress. ‘Compliance’ with a target means that a desirable condition has been attained. Non-compliance with (or breach of) a target indicates that resource quality is inconsistent with the management objective and action needs to be taken to improve the system.

In some circumstances the current and desired conditions may be the same, and the target setting will involve monitoring to ensure current condition does not deteriorate. However, if the current condition is inconsistent with management objectives, targets can be set to monitor for improvement in resource condition through management actions. In developing a target, the current condition, which includes both current state and variation in state over time, of the resource, needs to be quantified through monitoring. Monitoring data are used to set a target level and to assist management to define the management objective.

The recently developed Monitoring and Evaluation Framework II for the National Action Plan for Salinity and Water Quality and the Natural Heritage Trust requires target setting as a basis for determining management actions that can be linked to environmental outcomes. This framework refers to three types of targets, which are relevant on different time-scales:

1. **Aspirational targets** (>50 years), which are vision statements of the overall goals or outcomes of a natural resource management program for the water body.

These are yet to be established for the Stokes Inlet and will be developed based on a social survey. The estuary to date has been managed for the surrounding vegetation complexes and for recreational access, not for estuarine values which in general are poorly understood by the general community. The cross over, however, is when water quality deteriorates to the point that fisheries collapse or when boating and other recreation is affected.

2. **Resource condition targets (RCTs)** (10–20 years) are quantifiable outcome-based targets relating to desired changes in natural resource condition. Resource condition targets must be achievable, measurable and time-bound.

   Insufficient data exist to establish RCTs for the Inlet and which are also dependent on identification of the aspirational targets. The possible indicators, from which targets could be developed based on what we currently know, are indicated in the table below.

3. **Management action targets**, or milestones (0–5 years), which are targets linked to specific actions.

Given the nature of the estuary, many of the management actions will be in the catchment but estuary actions will need to be discussed.

The chosen measures of success are known as indicators, and a target is the chosen value of the indicator that is consistent with the management objective. Indicators need to be readily measurable, scientifically valid for assessing resource quality, and provide relevant information for management decision making. Environmental indicators are often highly variable, and respond to a range of factors in addition to any implemented management actions. For this reason an approach incorporating a well-designed sampling program (when, where, how often, and how you sample), and appropriate data analysis and use of statistical techniques is necessary to set targets and measure against them.

4.13.2 Selecting Indicators for Targets

The first step in developing targets is to select an indicator that is both an indicator of environmental condition and also a measure that can be influenced by management actions. This is clearly not always possible so we will need to select from both categories. The selection of indicators also depends on a clear identification of a problem for which, by common agreement improvement is required.

From what we know about the Stokes Inlet, we have identified eutrophication as an indicator which could possibly increase and which, in extreme could lead to an ecosystem collapse. Therefore measures of algal growth, productivity or symptoms of eutrophication (e.g. low oxygen concentrations) can be recorded for the purpose of setting targets. The most common measure of algal biomass is **Chlorophyll *a***, a standard, easily understood measure for which a numerical target could be set. We currently do not have a sufficient data for Chlorophyll *a* from which to develop a resource condition target.

The most commonly applied symptom measure is **dissolved oxygen**. Most fish kills in the South West of Western Australia have been related to low oxygen events and so this measure also has a resonance with the broader community. Oxygen levels can be described using a simple measure of central tendency such as a mean, or expressed in terms of extent and distribution of hypoxia or anoxia. This is clearly an appropriate indicator for the Stokes Inlet given the observed anoxia.

Phosphorus and **nitrogen** reductions are usually sought to reduce algal growth in the estuary and ameliorate the impacts of such high productivity, but we have little or no data on catchment contributions, so nutrient reduction targets from the catchment cannot be developed any further.

Measures of **algal bloom occurrence** or **density** are a routine measurement of estuarine sampling programs but are difficult to incorporate into a target compliance scheme. More general measures such as reduction in frequency of algal blooms or reduction in occurrence of a target species but without a numerical target are more useable. There are also methodological differences in definitions of what constitutes a bloom that relate to frequency of observation, type of phytoplankton and spatial extent of a bloom

Estuarine algal production is not just related to nutrient delivery from catchments but also **phosphorus and nitrogen internally cycled from sediments** within the estuary and delivered through groundwater. Achievement of algal reduction targets will depend on both nutrient reduction efforts in the catchment, and internal sources of nutrients.

Nutrient values in the estuary are high, so it is tempting to use direct measures of phosphorus or nitrogen such as **total Nitrogen (TN)** and **total Phosphorus (TP)** for the estuarine waters because reductions in catchment delivered Phosphorus, if sufficiently substantial and sustained, will ultimately result in reductions of TP in the estuarine water column. Caution should be applied when developing a numerical target. Concentrations indicative of undisturbed estuaries are provided by ANZECC and ARMCANZ who also advise against the use of those numbers as targets, preferring site specific targets to be developed. The latter can only occur with a good understanding of contributing processes. It is thus too early to establish nutrient targets for the estuary.

4.13.3 Targets for Stokes Inlet

Below are the provided recommendations that will allow resource management indicators and targets to be developed for Stokes Inlet specifically addressing environmental conditions of concern in this condition statement. Overall it is recommended that the resource management plan for the Stokes Inlet comprise of 5 components:

- Water quality
- Sediments
- Sedimentation
- Macrophyes / macroalgae
- Fringing vegetation

Therefore for each of these components, suggested management objectives and resource condition targets have been provided below. It should be noted that for many of the indicators, it is not yet possible to derive numerical targets for the indicators due to lack of data. Where this situation exists and environmental monitoring program that would capture the necessary information has been recommended.

Water quality

The current water quality monitoring program run on the Stokes Inlet includes the measurement of total nitrogen and total phosphorus concentrations, dissolved oxygen concentrations, Chlorophyll *a* and phytoplankton cell density counts. These measurements could be used to derive preliminary numerical targets for indicators relating to nutrient and dissolved oxygen concentrations in the Inlet. Further data is required to adequately define these targets. Measurements of nutrients in the Young and Lort Rivers should also be considered in order to derive targets for the estuarine reaches of these tributaries. These would also act as a target for the reduction of nutrients from the catchments to these waterways.

The recommended water quality management objectives, and resource condition indicators and targets, have been summarised in figure 8. Derivations of the numerical targets that cannot be achieved with the existing monitoring data have been colour-coded red.

Table 8 Possible water quality indicators for Stokes Inlet

Location	Management objective	Resource condition	
		Indicator	**Target**
Stokes Inlet	Reduce spatial extent and frequency of hypoxic/anoxic events	Dissolved oxygen in surface waters	[O_2 mg/L]
	Reduce nutrients feeding phytoplankton blooms in estuarine reaches of the rivers	Nitrogen Phosphorus	[TN] [TP]
	Reduce frequency of potentially toxic phytoplankton blooms (e.g. cyanobacteria and dinoflagellates)	Phytoplankton cell counts; number of recorded blooms; chlorophyll *a*	[Chl *a*]
Young and Lort	Reduce nutrients leaving catchment to estuary	Nitrogen Phosphorus	[TN] [TP]
	Reduce sediment leaving catchment to the estuary. Improve water clarity.	Total suspended solids (TSS) Turbidity	TSS Turbidity (NTU)

Sediments

Sediment data for the Stokes Inlet is limited to three sediment core / pore water nutrient profiles (Geoscience Australia (2006).

Before indicators can be selected and targets derived, the 2006 study should be expanded to include benthic chamber studies. This would help define the denitrification rate/efficiency of the sediments and help quantify the availability of nutrients in the sediment for primary production.

At this time, the suggested sediment quality management objectives, and resource condition indicator and targets have been summarised in figure 9. Derivations of the numerical targets that cannot be achieved with the existing monitoring data have been colour-coded red.

Table 9 Possible sediment quality indicators for Stokes Inlet

Location	**Management objective**	**Resource condition**	
		Indicator	**Target**
Stokes Inlet	Reduce organic content of surface sediments	Organic content of surface sediments	Total organic content (μg/g) in top 2cm (%)
	Increase/maintain sediment denitrifying activity	Summer denitrification rates of sediments	Sediment denitrification rates (mmol $N/m^2/d$)
	Reduction of indicator species (eutrophication / anoxia)	Abundance and distribution	The numbers of *Capitella capitata* per m^2

Sedimentation

There is currently no data available that allows for sedimentation rates to be used as a resource condition.

Before indicators can be selected and targets derived, data describing the current movement of sediment into and around Stokes Inlet need to be collected. This requires a bathymetric survey of the Inlet and the use of differential survey and levelling techniques at fixed sites or along fixed transects.

The suggested sedimentation management objectives, and resource condition indicator and targets have been summarised in figure 10. Derivations of the numerical targets that cannot be achieved with the existing monitoring data have been colour-coded red.

Table 9 Possible sedimentation indicators for Stokes Inlet.

Region	Management objective	Resource condition	
		Indicator	Target
Stokes Inlet	Maintain elevation along a fixed transect	Depth	Elevation along transect (cm)
	Aerial extent of flood tidal delta	Area	Differential levelling / positioning (ha)

Macrophytes / macroalgae

Surveys in the early eighties (Hodgkin and Clarke 1989) provided the last record of the biomass and distribution of macrophytes in Stokes Inlet.

The distribution of macrophytes in the Inlet needs to be reviewed to derive targets for Stokes Inlet. Macrophytes are an important habitat for estuarine fauna and an indication of water quality in the inlet with respect to water clarity. High levels of suspended particulate matter have been argued to limit the growth of macrophytes in Stokes Inlet. Monitoring the presence / absence; percent cover and depth limit of macrophytes in Stokes Inlet together with measure would be a good indicator of water quality (nutrients and levels of suspended solids), habitat biodiversity and estuarine health.

The nuisance green algae, *Cladophora* sp. has been recorded in the Inlet and is potentially an indicator of deteriorating resource condition for the estuarine system and should be monitored.

The recommended macrophyte management objectives, and resource condition indicators and targets have been summarised in figure 11. Derivations of the numerical targets that cannot be achieved with the existing monitoring data have been colour-coded red.

Table 10 Possible aquatic macrophyte indicators for Stokes Inlet.

Location	Management objective	Resource condition	
		Indicator	Target
Stokes Inlet	Increase seagrass distribution in the Inlet	Seagrass presence & density	Aerial coverage, Percent cover
	Increase seagrass depth limit in the Inlet	Seagrass presence	Depth of *Ruppia* (m)

		Resource condition	
	No increase in macroalgal biomass in the Inlet	Macroalgal biomass	g dwt/m2

Fringing vegetation

Other than the original survey of fringing vegetation conducted by Hodgkin and Clark (1989) there is not enough data to provide resource condition targets for fringing vegetation along Stokes Inlet.

An ongoing surveys/monitoring programs of the fringing vegetation is required to identify changes in the fringing vegetation communities in response to environmental conditions. This is relevant to changing water levels as a result of more frequent bar opening events (tidal inundation, scouring / erosion) or increased sediment loads to the inlet (sedimentation) which may cause the alteration or removal of fringing vegetation habitats.

It should be recognised that this management objective may encompass both passive (e.g. introduce and maintain monitoring effort) and active (e.g. restoration of fringing vegetation habitat to ensure ecosystem integrity) management strategies for fringing vegetation communities. For example, revegetating fringing dune habitats may reduce the movement of sediment into the estuary.

The recommended fringing habitat management objectives, and resource condition indicators and targets have been summarised in figure 12. Derivations of the numerical targets that cannot be achieved with the existing monitoring data have been colour-coded red.

Table 11 Possible fringing vegetation indicators for Stokes Inlet.

Location	**Management objective**	**Resource condition**	
		Indicator	**Target**
Stokes Inlet	Maintain spatial extent and distribution of fringing vegetation	Area of fringing vegetation; community composition	Fringing vegetation area (ha) Species diversity & abundance (per m^2)

Appendices

Appendix 1 Water quality data collected in Stokes Inlet

* Surface and bottom salinity, dissolved oxygen (mg/L) and dissolved oxygen (%) concentrations at sampling sites in the Stokes Inlet (February 1999, February 2006 and August 2006. (Note: bottom depth is stated in brackets; ND = No data obtained)

Site	**Date**	**Salinity (ppt)**		**Dissolved Oxygen (mg/L)**		**Dissolved oxygen (%)**	
		Surface	Bottom	Surface	Bottom	Surface	Bottom
STO001	21/02/99	33.8	*ND	7.5	*ND	109.5	*ND
	20/02/06	48.39	74.65 **(8.0)**	5.0	0	78.6	0
	29/05/06	49.67	70.74	7.5	0	100	0
	8/08/06	47.3	>70	7.65	0.17	100.5	2.6
STO002	21/02/99	34.1	34.1 **(6.0)**	8.5	ND	120.7	118.4
	20/02/06	48.49	74.69	4.85	0	76.1	0
	29/05/06	49.4	70.74	7.64	0	101.6	0
	8/08/06	47.8	47.9	7.42	5.24	98	69.1
STO003	21/02/99	34.3	*ND	8.3	*ND	118.1	*ND
	20/02/06	48.53	52.67 **(3.4)**	5.58	4.83	88	77.7
	29/05/06	49.66	49.66	7.2	7.16	95.9	95.3
	8/08/06	47.49	47.56	7.52	7.29	98.4	95.2
STO004	21/02/99	34.2	35.9 **(2.6)**	8.3	7.0	117.1	97
	20/02/06	48.71	48.77	5.16	4.88	80.5	76.3
	29/05/06	49.43	49.47	7.13	7.08	94.5	93.8
	8/08/06	47.64	47.68	7.56	7.49	99.2	97.9
STO005	8/08/06	49.48	49.48 **(0.8)**	7.65	7.65	100.6	100.6

Appendix 2 Nutrient data collected in Stokes Inlet (2006)

* Total nitrogen (TN) and total phosphorus (TP), and nutrient fractions of Ammonia (NH3-N), Total oxidised nitrogen (NOx) and filterable reactive phosphorous (FRP) measured at three sites in the Stokes Inlet (20/02/06. ANZECC/ARMCANZ (2000) guidelines refer to trigger values set for South-west Australian estuaries subject to slight to moderate disturbances.

		TN (mg/L)		**NH3-N (mg/L)**		**NOx (mg/L)**		**FRP (mg/L)**		**TP (mg/L)**	
ANZECC guidelines (2002)		0.75		0.04		0.045		0.005		0.03	
Site	Date	S	B	S	B	S	B	S	B	S	B
STO002	20/02/06	2.5	8.7	0.93	5.8	0.005	0.011	<0.003	0.28	0.05	0.32
	29/05/06	2.9	2.9	0.074	0.071	ND	ND	<0.003	<0.003	0.1	0.095
	8/08/06	2	2.3	0.054	0.068	0.021	0.016	<0.003	<0.003	0.1	0.095
STO004	20/02/06	2.3	2.2	0.038	0.03	<0.005	<0.005	<0.003	<0.003	0.06	0.07
	8/08/06	2.1	2.3	0.052	0.068	0.019	0.024	<0.003	<0.003	<0.01	0.02
STO005	8/08/06	2.9	2.9	0.073	0.08	ND	ND	<0.003	<0.003	0.093	0.092

Glossary

Abstraction	Pumping groundwater from an aquifer.
Allochthonous	Nutrient source supplied from outside the water body
Anoxic(-ia)	Absence of oxygen
Aquifer	A geological formation or group of formations able to receive, store and transmit significant quantities of water.
Autochthonous	Nutrient source supplied from within the water body
Benthic	Organisms living on or in the bottom of a water body
Confined Aquifer	An aquifer that is confined between shale and siltstone beds and therefore contains water under pressure.
Detritus(-al)	Disintegrated or eroded matter
Deoxygenation	Loss of oxygen from the water column
Environmental Water Requirements	Water level that will maintain current ecological values.
Evaporation	The vaporisation of water from a free-water surface above or below ground level, normally measured in millimetres.
Epiphyte	Plant living attached to another plant
Gastropod	Any of various molluscs of the class Gastropoda, such as the snail, slug, cowrie, or limpet, characteristically having a single, usually coiled shell or no shell at all, a ventral muscular foot for locomotion, and eyes and feelers located on a distinct head
Hectare (ha)	10 000 square metres or 2.47 acres.
Hypersalinity	Salinity measurement above seawater salinity (i.e. >35 ppt)
Hyposalinity	Salinity measurement below seawater salinity (i.e. <35 ppt)
Ichthyofauna	The fish of a particular water body
Invertebrate	An animal lacking a backbone or spinal column
Kilolitre (kL)	1000 litres, 1 cubic metre or 220 gallons.

Macroalgae	Aquatic plants commonly known as seaweed
Macrofauna	Invertebrates greater than 2 mm in size
Macrophyte	Aquatic plant
m AHD	Australian Height Datum. Height in metres above Mean Sea Level +0.026m at Fremantle.
Median	The middle value in a distribution of data
Microphytobenthos	Unicellular algae living in or on the sediment column
Micro-tidal	Having a tidal range less than 2m
Pelagic	Organisms living in open water of a water body rather than in waters adjacent to land or inland water
Phytoplankton	Pelagic photosynthetic microorganisms
Pico-plankton	Planktonic organisms passing through a filter of diameter less than 10-12m
Plankton	Organisms living in the pelagic environment
ppt	Unit of measurement for salinity
Primary productivity	Production of carbon through sequestration and utilisation of energy (e.g. sunlight)
Practical Salinity Units (PSU)	Salinity is referred to without units according to the Practical Salinity Scale. On this scale, salinity is defined as a ratio of conductivities and therefore cannot have units. Seawater typically has a salinity in the range of 34–36.
Recharge	The downwards movement of water that is added to the groundwater system.
Riparian	Of, on, or relating to the banks of a natural course of water
Sediment porewater	Water found in between sediment particles within the sediment column
Stratification	Formation of layers of one or more parameters (e.g. salinity) within the water column

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