Wilson Inlet 6

Report to the Community

Government of Western Australia

WATER AND RIVERS COMMISSION JUNE 2002

Managing the bar and the Inlet

Figure 1: Aerial photo of Wilson Inlet ocean entrance, looking toward the north-east. S. Neville

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One of the major topics in the Wilson Inlet management debate has been the artificial breaching of the sand bar that builds across the mouth of the Inlet. This, the sixth in the series of reports to the community on Wilson Inlet, summarises our understanding of coastal processes, the dynamics of the sandbar, and the hydrodynamics in Wilson Inlet.

There have been a number of previous studies into aspects of the Wilson Inlet ocean entrance and the flushing of the Inlet. Using the information gained from a review of these studies independent coastal engineers MP Rogers & Associates, produced a synthesis of the main features of the hydrodynamics and coastal processes relevant to the ocean entrance of Wilson Inlet. The full list of reviewed documents is provided at the end of this report. Using this synthesis, independent hydraulic modelling and the scientific understanding from the NEMP program, a number of possible management options for the Wilson Inlet ocean entrance were examined.

Introduction

Wilson Inlet lies on the south coast of Western Australia. The Inlet has a surface area of 48 km^2, is 14 km long from east to west, and is about 4 km wide. The Inlet has an average depth of 1.8 m below mean sea level*, and a maximum depth of a little over 3 m below mean sea level. The deeper part of the Inlet is partially divided into eastern and western basins by Pelican Point. The volume at 0 m AHD is about 90 GL†, the volume at 1 m above AHD is about 130 GL. The Inlet has five main tributaries and a catchment of 2300 km^2. The average

* Mean sea level is roughly 0 m AHD (Australian Height Datum).
† Note 1 GL = 1000 ML, 1 ML = 1000 kL, 1 kL = 1000 litres.

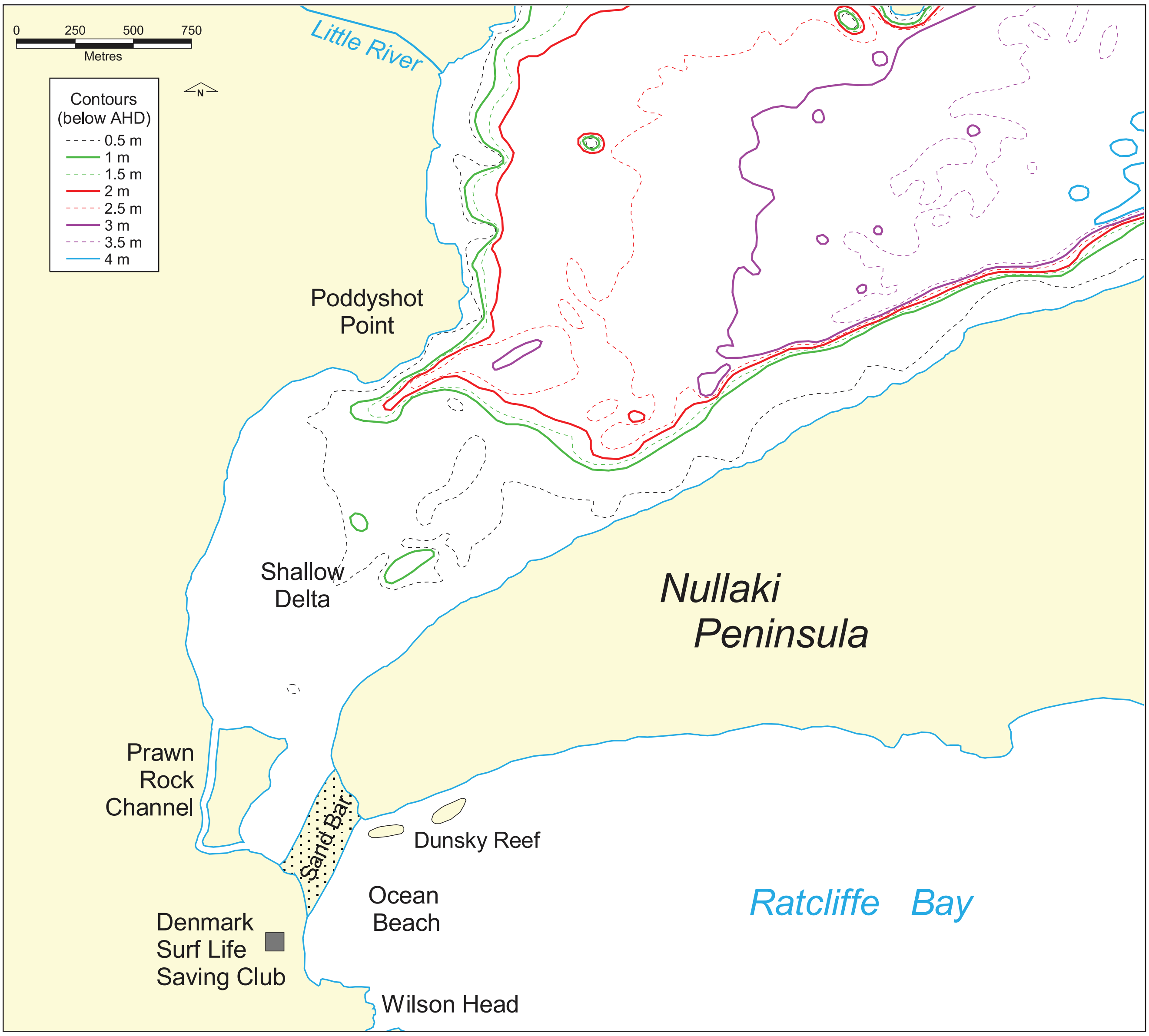

Figure 2: Major features at the mouth of Wilson Inlet.

annual river discharge to the Inlet has been estimated to be 200 GL per year. The Inlet opens to the ocean at the western end of Ratcliffe Bay, east of Wilson Head.

The swell on the south coast is predominantly south-westerly throughout the year. Winds are from the south-west, south, south-east and east in summer, and are from west and north-westerly directions in winter. Wilson Head provides significant protection from the predominant swell waves and from south-westerly sea-breeze and storm waves. The eastern end of Ratcliffe Bay, out of the lee of Wilson Head, is more exposed to the south-west and receives more wave energy than the western end. The headland provides no protection from south-easterly sea-breeze waves for any part of the bay.

The mouth of the Inlet is completely blocked by a sand bar for half of the year (usually about February to July). The bar is about 150 m wide between Inlet and ocean and has a length of 500 m in a north-east to south-west direction. To the west of the mouth are limestone cliffs while to the east of the mouth lies the coastal dunes of the Nullaki Peninsula. The tip of the Nullaki Peninsula appears to be growing westward as the sands at the eastern end of the bar are stabilised by vegetation.

The sand bar is a dynamic feature that is naturally built and eroded as the balance between processes depositing and scouring sand in the mouth of the Inlet changes over the year. The highly seasonal flows of rivers to the Inlet (approximately 80% of the river flow occurs from July to October) and the small tidal range on the south coast result in limited scouring capacity through the mouth of the Inlet for most of the year. On the other hand, despite the shelter of Wilson Head, the relatively intense wave climate on the south coast results in deposition of sand in the mouth of the Inlet by wave generated currents. The bar builds to about 1.8 m above AHD and is composed of medium to coarse grained marine sands.

Year	Position	Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec	Opened	Closed	Duration
1955	300		15 June 55	???	???
1956	340		10 June 56	???	???
1957	300		8 August 57	???	???
1958	340		7 August 58	28 December 58	143
1959	350		6 October 59	5 January 60	91
1960	400		12 July 60	24 December 60	165
1961	400		4 July 61	15 January 62	195
1962	360		1 August 62	9 January 63	161
1963	160		4 July 63	???	???
1964	200		22 July 64	???	???
1965	200		24 August 65	???	???
1966	200		27 July 66	14 January 67	171
1967	200		17 July 67	10 April 68	268
1968	200		31 July 68	12 February 69	196
1969	440		1 September 69	22 December 69	112
1970	440		2 August 70	27 February 71	209
1971	50		16 July 71	4 March 72	232
1972	100		10 August 72	15 December 72	127
1973	100		13 August 73	14 February 74	185
1974	100		5 August 74	1 December 74	118
1975	100		30 July 75	1 February 76	186
1976	100		6 July 76	10 February 77	219
1977	100		7 August 77	6 February 78	183
1978	100		30 June 78	2 March 79	245
1979	100		16 July 79	1 February 80	200
1980	100		1 August 80	24 January 81	176
1981	300		3 July 81	8 March 82	248
1982	100		21 July 82	9 September 82	50
1983	100		13 September 83	26 January 84	135
1984	80		5 August	10 April 85	248
1985	80		13 August	19 February 86	190
1986	300		28 August	27 February 87	183
1987	100		13 October 87	18 December 87	66
1988	100		14 June 88	14 May 89	334
1989	100		14 July 89	23 February 90	224
1990	450		17 July 90	10 February 91	208
1991	450		22 July 91	15 March 92	237
1992	100		3 August 92	2 April 93	242
1993	100		3 July 93	2 February 94	214
1994	100		16 July 94	3 February 95	202
1995	100		19 August 95	26 February 96	191
1996	100		5 August 96	23 February 97	202
1997	100		18 August 97	19 January 98	154
1998	50		7 August 98	23 May 99	289
1999	100		30 June 99	6 March 00	250
2000	100		21 July 00	30 November 00	132
2001	100		3 October 01	15 February 02	130

Figure 3: Tabulated data and graph of history of bar openings (on the graph grey indicates bar closed, blue indicates bar open and white indicates unknown, opening position is metres from the cliff on the western side and duration open is in days).

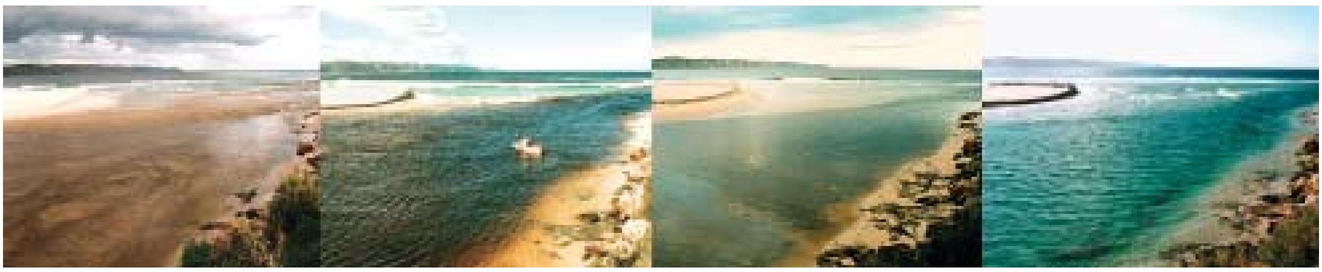

Figure 4: This series of photos, shot 1 day, 2 days, 8 days and 10 days after the 1997 bar opening, illustrates the initial turbid outflow from the Inlet as sand is carried from the delta, the strong outflow of darkly tannin stained catchment derived water, the weak outflow of estuarine waters once the Inlet has drained to mean sea level and finally the inflow of marine water on a rising tide. N. Boughton

Behind the sand bar is a large, shallow, flood tide delta that extends from the mouth back about 2 km into the Inlet. Like the bar, the flood tide delta consists of marine sands that have been washed by waves and blown by winds back into the Inlet over hundreds of years. Flows following bar opening have scoured several channels though this delta. These channels are unstable and fill or scour according to the pattern of flow when the bar is open. The channels at the back of the delta, closer to Poddy Point, are older while those at the front, closer to the bar, are more active and dynamic in their alignment.

The Wilson Inlet sand bar has been artificially opened each winter since the 1920s to limit flooding of low lying lands adjacent to the Inlet. Once the Inlet water level reaches 1.01 m above AHD, the bar is breached by cutting a channel through it with an excavator. This breach water level was originally derived from a point on the old railway bridge that was later determined to be 1.01 m above AHD.

Some effort is made to time the breaching with the lowest water level on the ocean side (so as to maximise the difference between Inlet and ocean water levels and consequently maximise the flow velocities and scour). However circumstances do not always make this possible.

Note that a breach of 200 m or less from the limestone cliffs west of the bar is called a 'western opening' and a breach 300 m or more from the limestone cliffs west of the bar is called an 'eastern opening'.

History of bar openings

Data on the position, timing, water level and duration of bar openings over the past 50 years are tabulated in Figure 3. The data show significant variability between years. In summary:

Drivers of opening: The length of time that the bar is open correlates well to the annual rainfall and river discharge, shows some correlation to the Inlet water level at the time of opening, and shows no correlation with other factors such as the initial position of the opening.

Opening water level: Despite the intent to open at 1.01 m above AHD the water level at opening has actually varied between 0.71 m above AHD to 1.25 m above AHD; a range of 0.54 m.

Closing water level: The water level in the Inlet at closure has varied between 1.19 m above AHD to 0.75 m below AHD; a range of almost 2 m.

Position of opening: The position of the opening has been as close as 50 m to and as far as 450 m from the cliff on the western side of the bar.

Timing of opening and closing: The bar is normally opened in July or August and closes in about February the following year. However, some openings have been as early as June and others as late as October. Whilst some closures have naturally occurred as early as November and others as late as May.

Duration of opening: The length of time that the bar has remained open has varied from 50 days to 334 days; a range of 284 days, with an average of 191 days.

The ocean side of the sand bar: Coastal processes

The movement of sand at the mouth of Wilson Inlet is one of the most important processes determining bar opening and closure. The major mechanisms for sand transport include the scour of the bar and delta during the breaching of the bar, and the redistribution of sands in the nearshore zone due to wave action.

Scour during bar opening

It is estimated from surveys that most of the scour of sand from the bar and delta occurs in the first few days after opening. This scoured sand is deposited in and behind the surf zone in Ratcliffe Bay where it is later redistributed back onto the beach by wave action, rebuilding the bar and closing the Inlet off from the ocean once more.

The greater the difference in the water levels between Inlet and ocean at the time of opening, the greater the energy available to scour a channel through the bar and delta.

In 1998 approximately 50 000 m^3 of sand was scoured from the bar and delta and deposited in Ratcliffe Bay in the first 5 days after opening; the scour rate was similar in 1997.

The main influences on the volume of scour are the mean sea level at opening, the Inlet level at opening, the sand build up in the delta from previous openings and the river flow following opening.

Channel dimensions after opening

Surveys in 1997 and 1998 indicate that that within a week of opening, the bar channel during a western opening is 50 m to 75 m wide with a depth of 1.5 m to

Figure 5: Initial outflow after bar opening (1997).
N. Boughton

3 m below mean sea level. The throat of the channel through the bar continues to slowly deepen for about 4 to 6 weeks subsequent to opening, after which the bar channel begins to fill from the east. There is limited information concerning the size of the bar channel with an eastern opening. A survey following the 1991 eastern opening indicated that this eastern opening created a bar channel that was slightly deeper and wider than the channels in the western openings that have been surveyed. However, the data is not extensive enough to conclude that eastern openings regularly create deeper and wider channels.

Effect of rip cells

Aerial photographs of both western and eastern openings show that offshore currents called rip cells are commonly set up and there can be four to five rip cells between Wilson Head and Dunsky Reef, located about 700 m from the cliff (Figures 7 to 11). From the photographs it is clear that both western and eastern openings can link to rip cells and that the linkage between rip cells and bar openings reinforces both features.

Effect of waves on sand movement

Waves in Ratcliffe Bay play an extremely important role in sand transport on Ocean Beach. Waves may be generated by the wind conditions in the Bay or by swells. The waves then set up the longshore, onshore and offshore currents that move sand. In general the smaller summer waves tend to push sand from offshore up onto the beaches while storm waves tend to be erosive dragging sand offshore.

Longshore currents move sand back and forth along the beach. It is estimated that the net longshore drift of sand in Ratcliffe Bay is about 2 000 m^3/year in a westerly direction. The gross movement of sand back and forth along the beach is likely to be about 10 000m^3/year. These are small rates of longshore drift, for example the net longshore transport at Dawesville is estimated to be about 80 000 m^3/year and at Mandurah about 100 000m^3/year.

Migration of bar channel

Aerial photographs show that both western and eastern openings can migrate in a westward direction; with western openings doing so much faster. There are two processes at work governing this western migration.

Firstly the movement of the entrance channel following opening could be caused by stream flow eroding bends; particularly at the back of the bar due to the different angle of the channels through the delta and the bar. As stream flow erodes the outside of the bend the bar will migrate in a south-westerly direction. This process could be particularly strong for western openings, as the channels are more curved than for eastern, causing western openings to realign much faster than eastern through this mechanism.

A second process is the transport of sand along the beach from east to west under the action of south-easterly winds (this is the direction of the net longshore drift described above). This may fill the channel through the bar from the east. As the channel is reduced in cross section by sand from the eastern side, the currents increase and scour the channel on the western side.

Closure of bar channel

Using computer models of sediment transport it was concluded that the onshore transport of sand by summer swell is the dominant mechanism in the closure of the entrance. As the river flow subsides sand is washed into the Inlet from the ocean by waves. From survey work the rate of sand deposition in the bar during the closure of 1998 was estimated to average 300 m^3 of sand infill per day over several months.

Importance of the delta

Hydraulic modelling has shown that the shallow area of the delta immediately behind the bar is the major control on water flow between the ocean and the Inlet. Flow in the channel through the bar itself, for either an east or west opening is controlled by the delta.

The delta channels are dynamic and vary in size depending in a large part upon how much scour has occurred during opening and how much infill has occurred in previous years.

The position and dimensions of the bar channel affect the delta infill, as a wide and deep entrance channel may permit sand to be deposited further into the deltaic area during the closure. Increased infill amounts may take longer to scour out in the next bar opening. Regular changing of the location of the opening could lead to the progressive siltation of channels through the delta and over a number of years reduce the hydraulic capacity of the area.

Repeated openings in the one location could lead to the improvement of the scour channels through the delta and an improvement in the hydraulic capacity of the area. There is some evidence to suggest that this deepening occurred between 1974 and 1980 and between 1994 and 1999.

Width of Ocean Beach

There have been concerns about the effect of the opening on the width of the beach berm in front of the Denmark Surf Life Saving Club. With the current understanding of the coastal processes at the mouth of the Inlet, it is not possible to accurately distinguish between the relative merits of a western or eastern opening in relation to the width of Ocean Beach. East or west opening aside, the Surf Life Saving Club is situated on the coastal vegetation line and consequently, even with the protection of Wilson Head, is at significant risk from storm erosion.

Most beaches experience significant fluctuations caused by the changing balance of coastal processes and their effects on sand transport. Aerial photographs show that the width of Ocean Beach in front of the Surf Life Saving Club can vary substantially. There is generally a 20 m to 30 m beach berm but, for example, the December 1996 photograph shows a 50 m wide berm (Figure 11).

The major driver of the width of Ocean Beach is believed to be the interannual variation in storm activity.

During stormy years there can be significant loss of the beach berm and the vegetated dunes as sand is eroded and deposited offshore. On other southwest WA beaches recession of the vegetated dunes can easily be 10 m to 20 m in severe storms. On the south coast there appears to be a pattern of a few very stormy winters separated by relatively calm winters.

Figure 6: Western opening shortly after breach. The photo shows the location of the surf club building (in left foreground) on the fore-dune vegetation line (1996).
T. Carruthers

This interannual variation in storminess means that in stormy years large amounts of sand can be moved offshore in short periods of time with significant loss of the beach berm, while little erosion may occur in calm years.

The amount of sand feed to Ocean Beach from the bar opening is likely to be related to the vigour of the scouring processes during opening. As noted above, the scouring process is influenced by the Inlet water level at the time of the opening, the size of the flow channels through the delta, as well as the river flow following the opening.

Because there is usually significant wave energy present along the beach, it would be reasonable to expect that the sand deposited in the bay by the opening process could be spread along the beach in the months following the opening. If this is the case, then the position of the opening may not be the dominant influence on the amount of sand feed to Ocean Beach near the Surf Life Saving Club.

The Inlet side of the sand bar: Exchange and stratification

The annual cycle of hydrodynamic events in the Inlet can be broadly divided into four states. These four states are characterised by the nature of the flows into the Inlet; those flows being freshwater flows from the catchment and marine water from the ocean. The four states are:

Closed dry (typically January or February to May or June): Bar is closed so there is no marine water input, catchment is dry so there is little freshwater input.

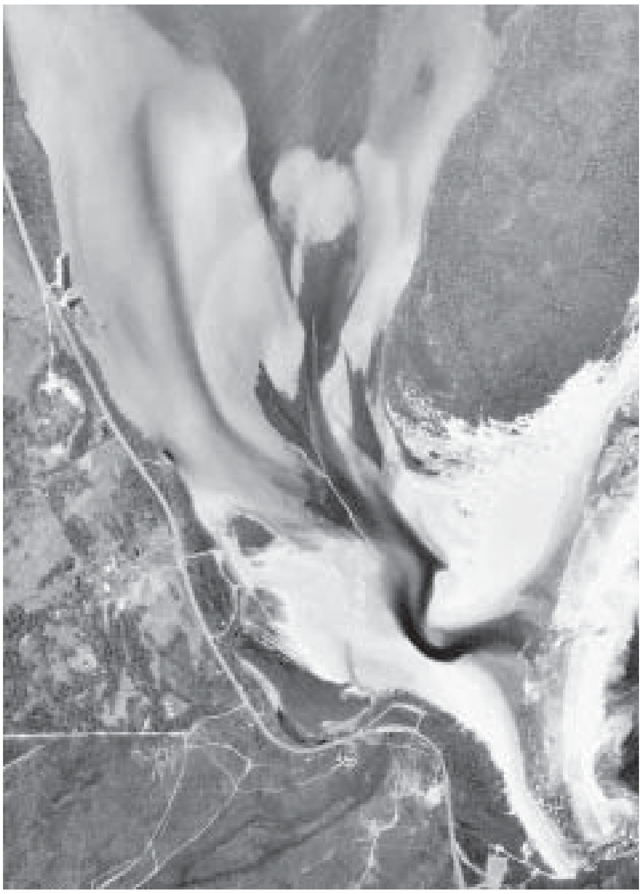

Figure 7: Aerial photo of bar in October 1986 showing migration of the bar channel from original opening position of 300 m.

Figure 8: Bar in January 1992 showing multiple rip cells, narrow beach in front of SLSC and migration of the bar channel from opening position of 450 m.

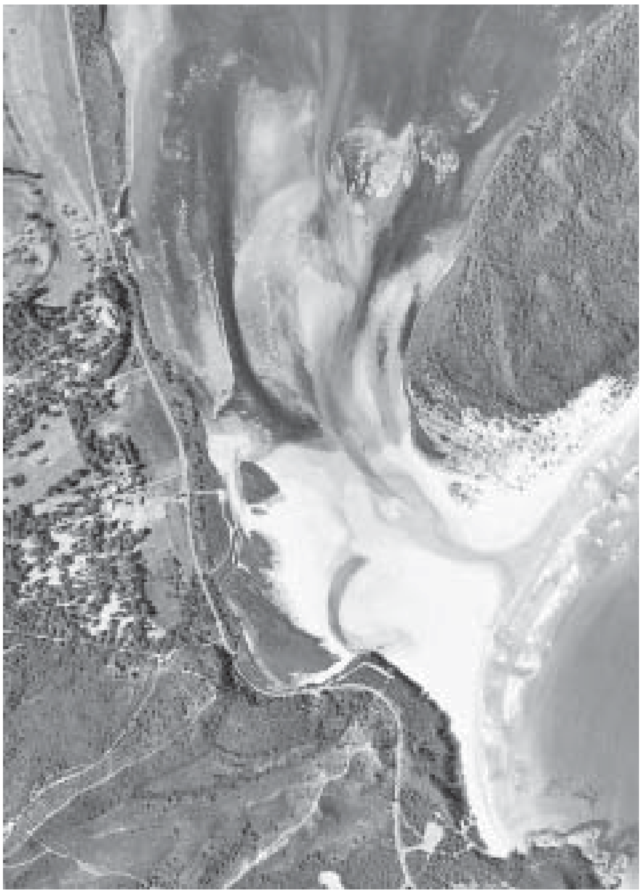

Figure 9: Aerial photo of bar in January 1991 showing migration of the bar channel from original opening position of 450 m.

Figure 10: Bar in November 1996 showing multiple rip cells, narrow beach in front of SLSC and migration of the bar channel from opening position of 100 m.

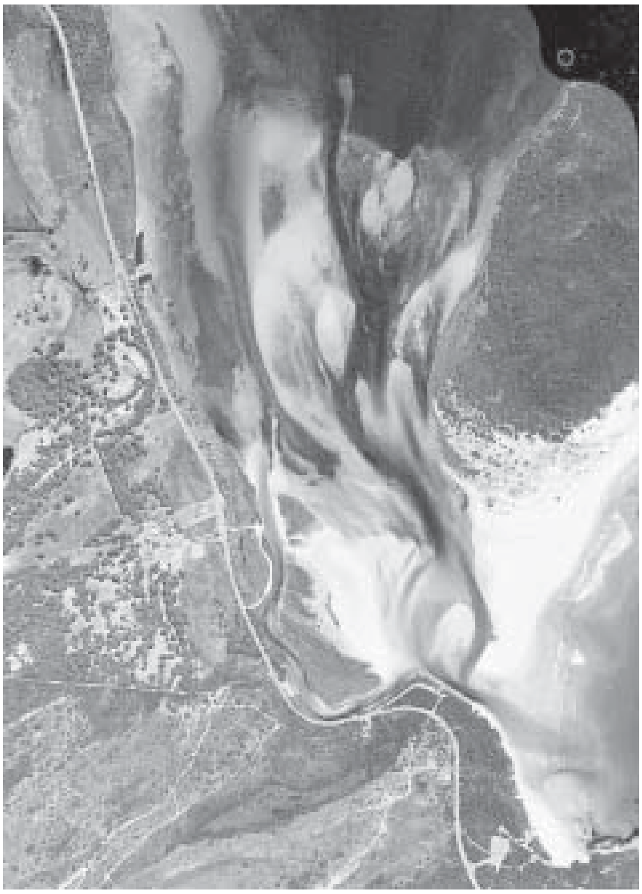

Figure 11: Aerial photo of bar in December 1996 showing much wider beach berm than in November 1996 and January 1992 as seen in Figures 8 and 10.

Closed wet (typically June or July to August): Bar is closed so there is no marine water input, catchment is wet so there is freshwater input.

Open wet (typically August to October or November): Bar is open so there is marine water input, catchment is wet so there is also freshwater inflow

Open dry (typically October or November to December or January): Bar is open so there is marine water input, catchment is dry so there is little freshwater inflow.

Depending on which state the Inlet is in, a number of different processes may be occurring.

Freshwater flow and circulation

Freshwater runoff from the catchment jets out as buoyant overflows across the surface of the saltier and therefore denser Inlet waters. Due to the effects of the Earth's rotation the freshwater tends to flow around the southern shore of the Inlet and is mixed into the Inlet by wind action. Modelling shows that, depending on flow rate, water particles that enter the eastern end of the Inlet take between 5 and 45 days to reach the mouth of the Inlet.

Initial outflow and marine intrusion

The Inlet water level takes 3 to 4 days of constant outflow after opening of the bar to fall from approximately 1m above mean sea level down to mean sea level. For those few days the average flow rate of water out through the bar is about 10 to 15 GL/day. Once the water level has fallen to mean sea level and the river flow has fallen below about 3 GL (usually river flow is higher than 3 GL only 1 or 2 weeks per year) marine water is able to intrude into the Inlet on the flooding tide.

Tidal effects

With the bar open the Inlet experiences oceanic tides. The oceanic tides at the mouth of Wilson Inlet can be divided into three components: astronomic, barometric and long term.

Astronomic tides are due to the relative positions of the sun, the moon and the earth. Off the south coast of WA the astronomic tidal cycle is largely diurnal (one high and one low per day). The daily tidal range varies from about 1 m down to about 30 cm then back up to 1 m again on a roughly fortnightly basis.

Barometric tides occur as a result of changes in the air pressure. Changes in air pressure can force the water level up and down by up to 30 cm on cycles that are typically 5 to 7 days long.

Long term components are related to global scale ocean-atmosphere interactions, such as the *El Niño* Southern Oscillation, the effects of which last for many months to a year or more and shift the mean sea level up or down by approx 10 cm or so.

The astronomic tide is attenuated (reduced) by the restriction on flow caused by the bar and delta. By the time that the rising tide is starting to become noticeable in the Inlet it is already starting to fall again in the ocean. As a result the maximum astronomical tidal range in the Inlet is less than 10 cm, even when it is up to 1 m in the ocean.

On the other hand with its much longer period of 5 to 7 days the full displacement of barometric tides can be observed in the Inlet (up to 30 cm). Barometric tides can pump large volumes of water into or out of the Inlet and therefore the passage of low or high air pressure systems has a much larger influence on exchange than the astronomic tide.

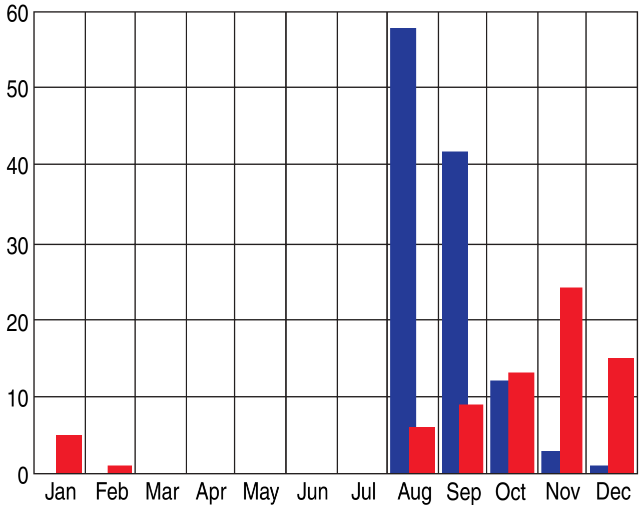

Figure 12: Monthly volumes (in GL) of flushing (blue) and marine exchange (red) averaged over past 5 years.

Flushing

The flow of water out of Wilson Inlet occurs through two mechanisms that are distinct from one another; flushing and marine exchange. Flushing occurs when water from the catchment displaces water in the Inlet whilst marine exchange occurs when water from the ocean displaces water in the Inlet. The main driver of flushing is the rainfall and runoff.

In the past 5 years flushing has displaced on average about 40% more water from the Inlet each year than marine exchange (the two are linked – poor river flow means a less effective bar opening which means poor marine exchange). However flushing removes more than twice as much nutrient as marine exchange. This is because flushing occurs earlier in the season when nutrient concentrations are higher and therefore is more effective at removing nutrients than marine exchange (Figure 12).

Marine exchange

Marine exchange is the process of marine water entering the Inlet on rising ocean water levels and displacing water already in the Inlet as ocean levels fall again. Model results indicate that the quantity of marine exchange in the years 1994 to 1999 ranged from about 60 GL to more than 250 GL (despite the same opening regime in each year) with an average of 140 GL. The major drivers of this variation included the tidal pumping, the mean sea level, the channel dimensions and the duration of opening (and hence rainfall and runoff and ocean conditions).

While marine exchange does remove some nutrient it is much less effective at removing nutrients from the Inlet than flushing. This is because plants have already taken up much of the nutrient before marine exchange is able to remove it and concentrations in the water are therefore lower. Marine exchange also leads to the problem of stratification.

Stratification

Stratification describes the situation where there are two different, unmixed layers of water, lying on top of one another. In Wilson Inlet the marine water intrusion after bar opening is saltier and hence heavier than the fresher water in the Inlet and consequently forms a density stratification (the marine water pools in the deepest parts of the Inlet after bar opening as shown in Figure 13).

The stratification resists mixing (mixing in the Inlet is largely driven by wind) because it takes more energy to mix the layers together than it would if they were the same density. As discussed in other Wilson Inlet Reports to the Community, stratification can have profound negative effects on the Inlet's water quality by causing nutrient releases and algal blooms.

Stratification starts in the western basin. Within 4 weeks after opening there can be a saline bottom layer up to 1 m deep in the western basin and within a further 2 weeks a saline bottom layer up to 50 cm deep in the eastern basin. Moderate wind mixing is generally insufficient to destroy the salinity stratification. Only strong, continuous winds are able to completely mix the water column.

For example a 10 knot wind (the annual average) with 14 knot gusts would take 2 weeks to mix a 5 ppt.* stratification in 3 m of water and 6 weeks to mix a 15 ppt stratification. As the water column is mixed the overall salinity of the Inlet increases. The well mixed water column does not persist for long after strong winds cease, as the stratification is re-established by successive tidal inflows bringing new marine water into the Inlet.

Although calms can occur at any time of the year, wind speeds (and therefore mixing) are usually at their minimum in October as winds shift from the predominant winter pattern of NW and NE to the summer pattern of SW and SE.

*Note: ppt stands for parts per thousand and is a measure of the salt content.

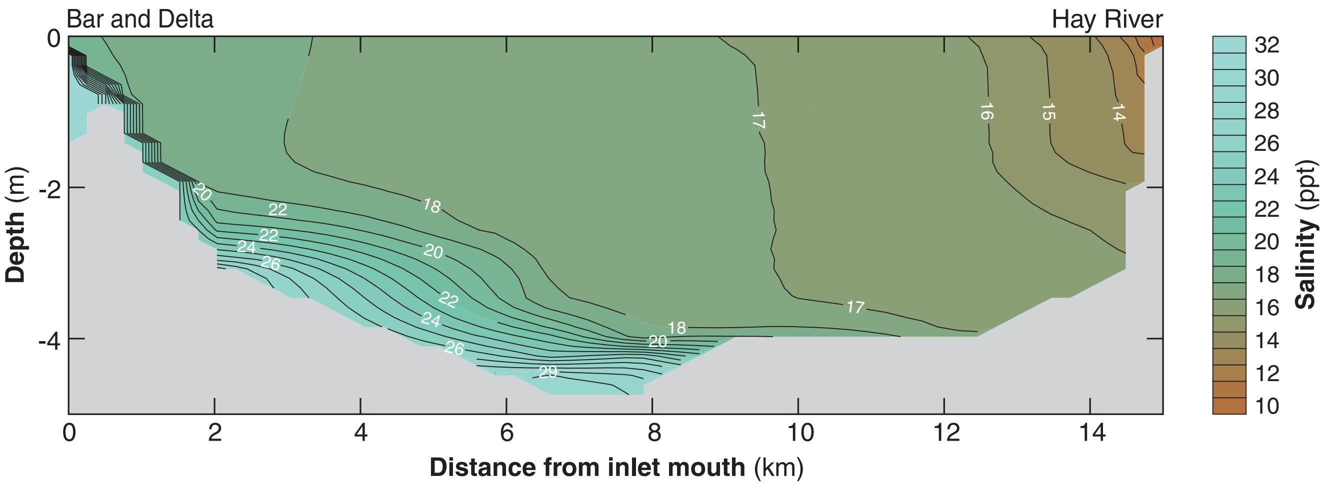

Figure 13: Cross-section of salinity contours through Wilson Inlet from the Inlet mouth to the Hay River during spring. The plot illustrates freshwater flow (brown) entering from the Hay River on the right and being mixed into the Inlet, and marine water (blue) intruding from the ocean on the left and forming a strongly stratified layer in the bottom of the Inlet.

Figure 14: Wind waves in Wilson Inlet. W. Hosja

Winds blowing along the Inlet can cause wind waves up to 1.2 m high (Figure 12). Winds can also push the water into one end of the Inlet causing the water level to rise and fall up to 0.2 m at opposite ends of the Inlet; like water sloshing back and forth in a giant bathtub (known as seiching).

Stratification ceases to occur once either the bar has shoaled and marine water may no longer enter the Inlet, when the Inlet salinity itself is close to marine, or when the weather is consistently stormy enough to keep mixing the Inlet.

The amount of stratification that occurs in a year shows a reasonable correlation to the amount of marine exchange that occurs; the more marine exchange the more stratification. The main drivers of stratification are Inlet salinity, wind mixing, and the amount of marine exchange (which in turn is related to rainfall and run off and channel dimensions).

Natural variability

As we have seen a number of variables have been identified as fundamental drivers of the water circulation within the Inlet, water exchange between the Inlet and the ocean and sand movement into and out of the Inlet. There are significant seasonal and interannual variations in the magnitude and effect of these variables that result in very different rates of water and sand movement from year to year.

Those variables and some idea of the magnitude of their fluctuations are:

Rainfall/river flow and evaporation: The volumes of rainfall and river flow are major drivers of the water level and salinity in the Inlet and the flushing of the Inlet water out to sea. They have a major impact on the scour of the bar, the dimensions of the channel through the bar and the duration of opening and hence also influence the volume of marine exchange. In the past 50 years the annual Denmark rainfall ranged from 795 mm to 1580 mm; a range of 785 mm, with an average of 1030 mm. *The rainiest year had almost twice the rainfall of the driest year.*

In the past 25 years the annual Denmark River flow ranged from 5 GL to 81 GL; a range of 76 GL, with an average of 32 GL. *In other words the highest flow year had about 16 times as much river flow as the lowest flow year.*

In the past 25 year the annual Albany evaporation ranged from about 1200 mm to about 1600 mm; a range of 400

Figure 15: Prawn Rock Channel. K. Parker

mm, with an average of about 1400 mm. *In other words the driest year had 30% more evaporation than the wettest year.*

Ocean storminess (swell, sea-breeze waves and storm waves): The ocean storminess is a major driver of sand transport onto, along, and off of Ocean Beach and therefore is a major driver of bar closure and bar channel dimensions, and influences the infill of the delta. Because of its effects on the bar and delta channel dimensions the ocean storminess also effects the amount of marine exchange and therefore stratification. In the past 25 or so years the annual south west WA ocean storminess, based on an arbitrary scale ranged from 0.06 to 4.6; a range of about 4.5, with an average of 1.0. *In other words the stormiest year was about 75 times stormier than the calmest year.*

Ocean mean sea level and tides: (astronomic tides and most significantly barometric effects.) The ocean mean sea level and tidal effects are major drivers of the scour of the bar channel and more importantly are major drivers of the marine exchange via the pumping of water into and out of the Inlet. Consequently they are also important influences on the salinity of the Inlet and the extent of stratification. In the past six years the annual Albany mean sea levels ranged from 8 cm below AHD to 10 cm above AHD; a range of 18 cm, with an average of 1 cm above AHD. *In other words the mean sea level was 18 cm higher in the highest year than in the lowest; this volume represents about 10% of the Inlet volume, and roughly a 20% difference between years in scouring capacity when the bar is opened.*

In the past six years for the spring period the average Albany barometric pressure ranged from 1014 hPa to 1020 hPa with between 4 to 8 low pressure systems passing through, while the sum of air pressure changes varied from 550 hPa to 850 hPa over the spring period. *In other words there was at least 1.5 times more barometric pumping of water into and out of the Inlet in some years compared to others.*

Wind (direction, speed and persistence): The wind is the major driver of vertical mixing in the Inlet and therefore has an impact on the extent of stratification. An analysis of Albany wind data gives some broad indication of variability. The annual average of the magnitude of the Albany half hourly mean wind speed data for the past six years ranges from 3.4 knots to 5.1 knots; a range of 1.7 knots. *In other words the windiest year was 1.5 times windier than the least windy year.*

Management option	Marine exchange	Potential for stratification	Initial capital cost	Annual maintenance cost	Prawn Rock Channel	Ocean Beach	Action Plan recommendation
Western opening 0 – 100 m	Status quo	Status quo	Nil	$5 000	Status quo	Status quo	**Recommended option.** Combined with implementation of nutrient reduction activities.
Opening at higher water levels	Slight increase	Similar	Not known	$5 000	Similar	Similar	Possible option. Detailed analysis of flooding and extent of flooding required.
Opening at lower water levels	Slight decrease	Similar	Nil	$5 000	Similar	Similar	Not recommended. With consistent river flow the reduced residence time of nutrients in the inlet would only be a few days whilst scour of the bar would be reduced.
Eastern opening	Possible slight increase	Similar	Nil	$20 000	Link channel required	Not known	Not recommended. Similar efficiencies to western openings given the range of natural variability.
Existing channel extended by 375 m through sand island and deepened to – 0.7 m AHD	Increase (≅ 60%)	Slight increase	$50 000 removal of 9 000 m^3 sand	> $10 000	Similar	Similar	Not recommended. Modest increase in ocean inflow. Better value for money by dredging the delta restriction.
As above deepened to – 1.5 m AHD	Increase (≅ 90%)	Slight increase	$100 000 removal of 24 000 m^3 sand	> $10 000	Similar	Similar	Not recommended. Better value for money by dredging the delta restriction.
Existing channel deepened and extended by 825 m through the sand island to the deeper natural channel in Inlet	Increase (≅ 200%)	Increase	$500 000 removal of 59 000 m^3 sand	> $10 000	Higher velocities	Not known	Not recommended. Risk of increased nutrient release from sediment greater than benefit from comparatively small increase in nutrient export.
Deepening of natural channel restriction	Slight increase (≅ 40% increase)	Slight increase	$20 000 removal of 3 500 m^3 sand	> $10 000	Similar	Similar	Possible option. Implementation may allow assessment of stratification risk of increased marine exchange and evaluation of potential to improve. Located away from sand deposition area.
Channel through delta (as proposed by WIRG, 1994)	Similar (≅ 5% increase)	Similar	$500,000 removal of 123 000 m3 sand	> $10 000	Similar	Similar	Not recommended. High cost, high disturbance and little potential for improvement.
Proposed WIRG (1994) channel extended through to the bar	Increase (≅ 230%)	Increase	$1 million removal of 163 000 m^3 sand	> $10 000	Higher velocities	Not known	Not recommended. Risk of increased nutrient release from sediment greater than benefit from comparatively small increase in nutrient export.
Permanent opening	Large increase depends on dimensions and length	Increase	Up to $10 million. Depends on depth, length and groyne type, disposal costs	> $10 000	Higher velocities or cut off depending on design or groynes	Not known	Not recommended. Benefits exceeded by the impact. Unlikely to have much effect on nutrient concentrations or plant growth but would reduce periods of anoxia. Potential impact on Ocean Beach from engineering structures, more marine water would change the fishery, increase tidal fluctuations, and may effect riparian vegetation.
Controlled closure	Similar	Similar	Nil	$10 000	Similar	Similar	Possible option. Would reduce sand over wash and build up of sand banks in the delta in the period from January on. Depends on effect of summer rain.

Figure 16: Comparison of Management Options. Changes are in reference to a western opening 0-100 m from the cliffs.

Management options

A range of management options for the bar opening have been evaluated using the current understanding of the hydrodynamics and coastal processes as outlined and our scientific understanding from the NEMP studies. Because of the complexity of the natural system and the limits of current understanding, some options will involve a degree of risk. The options examined include:

- Western opening (status quo)
- Opening at higher Inlet water levels
- Opening at lower Inlet water levels
- Eastern opening
- Existing channel deepened and extended through to the bar
- Existing channel deepened to –1.5 m AHD
- Existing channel deepened to – 0.7 m AHD
- Channel through delta restriction
- Channel through delta (as proposed by WIRG 1994)
- Proposed WIRG 1994 channel extended through to the bar
- Permanent opening
- Controlled closure

The main features of each option are outlined in summary in Figure 16. The table contains an assessment of each option relative to the present management (western openings). The assessments are based on the investigations and modelling completed and the expert knowledge of the reviewers.

The main focus of these management options is, by and large, to increase the amount of marine exchange with the aim of removing more nutrients from the Inlet. Since flushing occurs as a result of rainfall and runoff these management options can only effect marine exchange as they have no influence on the rainfall and runoff from the catchment.

It has also been noted that there is a trade off between marine exchange and stratification; if marine exchange is increased, stratification is likely to increase also. Unless the volume of marine exchange is very large, the stratified layer will deoxygenate causing the release of nutrients from the sediment. So, while increased marine exchange will remove nutrients from the water column, it may also cause the release of further nutrients from the sediment.

The options were assessed in terms of their potential to improve flushing and exchange, their potential for increasing stratification, their costs and their impacts on Prawn Rock Channel and Ocean Beach.

Location of opening

In terms of marine exchange it is clear that the difference between an east or west opening is liable to be much smaller than the interannual variation that already occurs between years. In terms of costs, historically little has been spent on bar openings. A major difference between east and west openings is that the bar channel for a western opening connects with Prawn Rock Channel. To maintain the amenity of Prawn Rock Channel with eastern openings would need regular dredging of an east-west channel behind the bar to connect with Prawn Rock Channel. This would add to the annual cost of using an eastern opening compared to a western opening.

Timing and water level of opening

It has been suggested that openings earlier in the winter would reduce the time that nutrients from runoff remained in the Inlet. The drawback to this being that earlier openings would be at lower Inlet water levels, resulting in less scour through the bar and delta. Computer modelling suggests that even for high river flow rates it takes at least 5 days for river flow entering at the eastern end of the Inlet to reach the mouth. This period of time is more than sufficient for plants to absorb as much of the nutrients as they need. Therefore the only effect of an earlier, lower opening would be to reduce the scour of material from the bar and delta. There is no advantage in earlier, lower openings.

In contrast opening at higher Inlet water levels would mean greater potential energy available to scour sand from the bar and delta into Ratcliffe Bay, however the flooding of adjacent lands (which has not been investigated here) then becomes an issue. It should also be noted that opening much later than the present situation risks increasing stratification events as the winds required for mixing are at a minimum in October.

Controlled closure of the opening is seen as a possible option, when the bar is close to closing naturally, so as to prevent sand washed in from the ocean building up in the delta.

Dredging

Numerical and hydraulic modelling have been used to investigate different dredged channel configurations. The configurations investigated represented both major and minor dredged channels reaching back from the bar, in some cases as far as Poddyshot Point. The results indicate that there would be a substantial increase in the channel flow rate by creating better flow paths through the shallow delta area and comparatively little would be gained by dredging further back in the Inlet. In other words the most value for money in terms of increased marine exchange would be achieved by dredging the area immediately behind the bar as this is the main hydraulic control. This is also a very dynamic part of the delta and would probably fill back in again relatively quickly, requiring regular dredging. Compared to the other dredging works examined here the scale, costs and ecological impacts of a permanent opening are likely to be an order of magnitude greater.

Figure 17: Bar opening. N. Boughton

It should be remembered that dredging to increase nutrient removal by marine exchange might also increase nutrient release by stratification. Even with increased marine exchange nutrients released from the sediment in stratified conditions are not removed fast enough compared to the rate that plants can take them up. Therefore the management of stratification must be considered, especially given that marine exchange is not an efficient nutrient removal mechanism in Wilson Inlet (compared to say the Peel-Harvey where nutrient concentrations in the water when the Dawesville Channel was proposed were 4-5 times higher than in Wilson Inlet), and a balance between the processes must be struck. The balance will vary from year to year depending on factors such as winds.

Summary of findings

- There are four key drivers of the water exchange and sand movement in Wilson Inlet: rainfall and runoff in the catchment, the wind conditions over the Inlet, and the ocean wave conditions and the ocean sea level conditions at the mouth of the Inlet.
- The natural variability in the system's drivers is high. As a result the variations in marine exchange between years can be more than four fold simply due to the natural variation in the drivers.
- The marine exchange in any year is somewhat dependent on the events that have occurred in previous years. For example the build up of sand from a late closing in May 1999 took two subsequent openings to remove.
- In terms of management options at the bar we have virtually no ability to influence the main drivers of the water exchange and sand movement in Wilson Inlet. Those factors that we can influence (the water level at opening, dredging of the delta, the closure time) are of secondary importance compared to the four main drivers.
- Increasing marine exchange may remove more nutrients but carries the risk of causing a release of nutrients from the sediments greater than that removed through the bar.

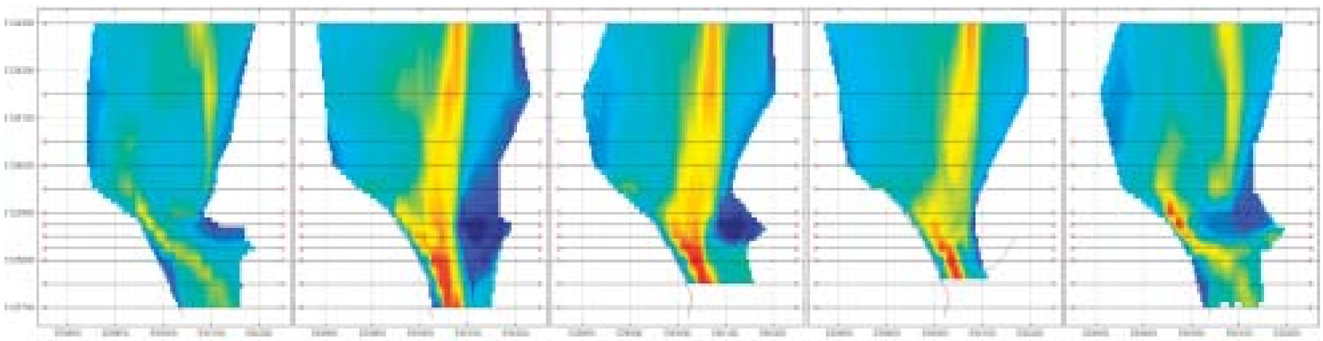

Figure 18: Evolution of the bar channel over time, demonstrating the initial scour then infill of the channel. This series of plots of survey data in the region of the sand bar and delta during the 1998 bar opening begin before bar opening, then 5 days after opening, then 2 weeks, 6 weeks and 3 months after bar opening. Red and yellow contours indicate channels below mean sea level, blue indicates sand bars above mean sea level and green represents mean sea level.

- Marine exchange can most effectively be improved by removing the constrictions close to the mouth of the Inlet rather than large scale dredging. Given the variability in climactic conditions from year to year the effects of any such dredging through the bar should be observed over more than one year to gauge the risks of sediment nutrient release in the Inlet.
- The review of the investigations, monitoring and modelling conducted during the period 1994 to 2001 have shown that the hydrodynamic and coastal processes of Wilson Inlet are both complex and variable. Available knowledge on the risk and effects of the various options is limited, hence there is some uncertainty in the assessments.
- Managing the stratification risk is the most important imperative of any bar opening strategy.

Actions for the bar and Inlet

An Action Plan for Wilson Inlet and it's catchment is being developed based on the views and wishes of the community and the available information on the environmental condition of the catchment and the Inlet. In addition to nutrient reduction activities in the catchment the action plan for the Inlet recommends:

- Continuation of western openings within 100 m of the western cliffs to stabilise and deepen opening channels with a consistent opening.
- Evaluation of opening the bar at a higher level to obtain maximum sand movement and scouring.
- Dredging in Wilson Inlet to increase marine exchange to be limited to works on the existing channel so that changes in water quality can be assessed whilst managing the risks of stratification.
- Manage Inlet floodplain to improve nutrient reduction.
- Investigate potential local causes of algal growth at Poddy Shot point and evaluate algal removal strategies.
- Although the Inlet is under stress from catchment derived nutrients, the water quality is in sufficiently good condition that large scale intervention in the form of a permanent opening (with its attendant impacts) is not recommended. The rate of decline is sufficiently slow that there is time for nutrient reduction activities in the urban and rural catchment to improve water quality in the short to medium term.

Figure 19: Outflow of estuarine water 24 hours after bar opening, 1997. N. Boughton

Figure 20: Prawn Rock Channel K. Parker

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For more information contact

Water and Rivers Commission

Denmark Office
Suite 1, 55 Strickland Street
Denmark WA 6333

Telephone (08) 9848 1866
Facsimile (08) 9848 1733

Head Office
Aquatic Science Branch
3 Plain Street
East Perth WA 6004

Telephone (08) 9278 0300
Fascimile (08) 9728 0586
Web site <www.wrc.wa.gov.au>

Project manager Malcolm Robb

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