3. Hydrodynamics

3.1 Existing Hydrodynamic Data

3.1.1 Previous Studies

There are no previous studies of the hydrodynamics of the overall lagoon. Mounser (1981) conducted a flood study for a proposed residential development and as part of that study estimated water flow through the system. This study provides useful data for the lagoon but only considers the flooding in areas around Gregory Street and Frank Cooper Street. As such, the lagoon system is included only as a route for receding flood waters and the dynamics during dry periods are not included.

As part of this project MHL conducted a site inspection on 4 April 2001. At the time of inspection the entrance to the creek was open. During the inspection water quality data were collected using a Hydrolab Multiprobe to record vertical profiles of temperature, salinity, dissolved oxygen, pH and turbidity at three sites within the estuary (Figure 3.1). On 1 May 2001 DLWC conducted a more detailed exercise using more sophisticated instruments. They also deployed water level recorders near the entrance and in the lagoon for a two-month period. In addition DLWC conducted a detailed bathymetric survey of Saltwater Creek in early April. The collected data are described in MHL (2001) and sites are shown in Figure 3.1.

In the following sections the results of these field exercises are used to describe the hydrodynamic processes.

3.2 Tidal Characteristics of Saltwater Creek and Lagoon

3.2.1 Preliminary Volumetric Assessment

A simple volumetric analysis of the creek and lagoon provides a useful preliminary understanding of the tidal effects and impact of the changing level of the entrance bar. Using the cross-section data (depths to Australian Height Datum or approximately mean water level) provided in Mounser (1981) and water level measurements (MHL 2001), a range of variables that highlight the hydraulic characteristics may be derived (Figure 3.2).

Five cross-sections along Saltwater Creek between the entrance and the lagoon were surveyed by Mounser (1981). These sections were analysed to derive an estimate of the volume in Saltwater Creek at different levels (Figure 3.2). Note volume of the creek varies approximately linearly with increasing tidal height above the bed. The area of the lagoon varies in a similar manner. The cross-section area and width of Saltwater Creek were calculated by assuming a depth of 0.7 m AHD (Figure 3.2). The volume of Saltwater Lagoon was approximated by assuming the lagoon occupies an area of 24.4 hectares, the bed is 0.4 m AHD and that the sides are vertical. This assumption did not allow for inclusion of wetland area with increasing tidal height, which is estimated would increase the volumes approximately 50%. The total system volume was then estimated by adding the water body volumes.

The water level recorders deployed during the recent field exercise (see following sections) were analysed to provide the tidal characteristics. The difference in water volume between the High High Water Solstice Springs and Indian Spring Low Water was used to estimate the tidal prism while the lagoon is open. The tidal prism in the lagoon is about 12,000 m^3 and for the whole system is approximately 24,790 m^3, while the total system volume at 0.7 m AHD is 142,490 m^3 or approximately six times the tidal prism.

Using the mid-cross-section in the creek and assuming 75% of the tidal prism flows past this section then the average tidal flow velocity is estimated at 6 cm s^{-1} and tidal excursion 1,300 m. In the lagoon the tidal currents are estimated at about 0.2 cm s^{-1} and excursion around 60 m.

As more than half of the tidal prism is captured within the creek and the average tidal velocity is relatively low the mixing efficiency due to the tide is also likely to be very low. In such situations the flushing efficiency factor (fraction of tidal prism volume entering the system that remains after the next tidal cycle) is likely to be less than 10% while for more open systems this factor is generally between 20% and 30%. Assuming a 10% tidal flushing efficiency yields an estimate of the flushing time of about 60 tidal cycles or 30 days. However, the entrance is unlikely to remain open that long. Flushing will continue when the entrance reopens and hence total flushing time is expected to be longer than the stated time of 30 days.

On the other hand the salinity gradient enhances the gravitational flows resulting in more rapid exchange than suggested by the tidal flushing estimate. This mechanism is discussed further in Section 3.3.

These estimates are relevant while the entrance is open to the same degree as in May 2001. The entrance bar is thought to vary between 0.45 m AHD and about 1.45 m AHD and hence the tidal characteristics will vary depending on the degree of closure.

3.2.2 Water Level Variability

Changes in water levels within the estuary are influenced by a range of phenomena that operate at different time scales, from a few minutes to millennia, including:

- astronomical tides
- wind setup
- freshwater inputs and floods
- ocean storm surges
- coastal trapped waves, and
- sea level rise.

3.2.3 *Tidal Planes*

Astronomic tides are the ocean's response to the gravitational attraction of the planets. Each of the planetary and lunar orbits and the earth's rotation occur at set frequencies that force oscillations of the oceans - the tides – at similar frequencies. The major tidal components along the NSW coast occur in response to the lunar and solar attractions interacting with the rotating earth. The tides in the region are dominated by the semi-diurnal (twice per day) constituents with a strong spring-neap cycle as shown in the water levels recorded near the entrance, in the lagoon (see Figure 3.1 for locations) and in the ocean at Crowdy Head (Figure 3.3). The figure highlights the attenuation of the tides between the ocean and entrance gauge and further attenuation between the entrance and the lagoon.

The tidal planes are derived from results of an harmonic analysis of the time series water level measurements of at least one month's duration (MHL 2001). The harmonic analysis provides a measure of the true astronomic or tidal character of the water level variability. The tidal residuals (difference between the observed and tidal predicted water levels) provides a measure of the non-tidal variability (Figure 3.3) that is associated with the phenomena listed above.

The tidal planes for the two sites within the lagoon and the adjacent ocean (nearest measurement site at Crowdy Head boat harbour) are listed in Table 3.1.

Table 3.1 Tidal Planes for Saltwater Creek Estuary

Tidal Plane	Ocean Crowdy Head	Saltwater Creek Entrance	Saltwater Lagoon
HHWSS	1.139	0.794	0.771
MHWS	0.693	0.735	0.750
MHW	0.577	0.724	0.748
MHWN	0.462	0.713	0.746
MSL	0.037	0.704	0.744
MLWN	-0.388	0.694	0.741
MLW	-0.504	0.683	0.739
MLWS	-0.620	0.672	0.737
ISLW	-0.938	0.630	0.722
HHW(SS) to ISLW	2.077	0.164	0.049
MSR	1.313	0.062	0.013
MNR	0.850	0.019	0.005

Note: Data relative to Australian Height Datum (AHD)

HHW(SS) - Higher High Water (Spring Solstices)
MHWS - Mean High Water Springs
MHW - Mean High Water
MHWN - Mean High Water Neaps
MSL - Mean Sea Level
MLWN - Mean Low Water Neaps
MLW - Mean Low Water
MLWS - Mean Low Water Springs
ISLW - Indian Spring Low Water
MSR - Mean Spring Range
MNR - Mean Neap Range

(See Appendix D for definitions of tidal planes)

3.2.4 *Tidal Phasing*

The tidal phasing relates to the rate of propagation of the tides into the estuary. Using the data collected at the ocean, inside the entrance and upstream near the lagoon provides a measure of the time lag between high tide in the ocean and high tide at the two lagoon sites. As the tides are heavily damped across the entrance the tidal phase lags vary with the degree of entrance attenuation. At the entrance site the lag is relatively short while at the lagoon the lag appears to be around one to two hours.

3.2.5 *Low Frequency Sea Level Oscillations*

Low frequency sea level oscillations include phenomena with periods greater than about four days such as the coastal trapped waves that propagate up the NSW coast causing ocean water level changes of around 0.1 to 0.5 m. When the entrance is open these changes are transferred to the estuary and result in significant changes in the water volume within the estuary. The tidal residuals presented in Figure 3.3 highlight these oscillations during May 2001 when a significant increase in the average ocean water level occurred between 6 and 10 May and then a gradual decrease ensued between 10 and 18 May.

These oscillations and general spring-neap response in the lagoon are a major component of the water level variability. The exchange of water between the wetland areas surrounding the lagoon is likely to be influenced by these longer period water level changes as the tidal influence is negligible in these areas.

The gradual decrease in water level in the lagoon up to 17 May then gradual increase between 17 and 20 May prior to the rainfall event may be explained by an interaction between groundwater and baseflow inputs, groundwater discharge to the ocean, the entrance bar height and the mean ocean water level. This complex interaction is difficult to quantify in terms of the actual flows. The water level in the lagoon responds to freshwater runoff following rainfall events and the entrance bar height.

3.3 Freshwater Inflows

Freshwater inflows to the estuary from the local catchment have been modelled by Mounser (1981) for a flood study of residential lots east of Mitchell Street. The aim of the study was to estimate the 1-in-100-year flood level and hence the possible need for fill of the residential lots. The study derived estimates of the runoff hydrograph due to a range of extreme rainfall events determined from available data using methods described in *Australian Rainfall and Runoff* (Institution of Engineers Australia 1977). The catchment was divided into two main areas – the steeper slopes of Smoky Cape Range to the east and the floodplain and minor slopes of South West Rocks in the west. Hydrographs for the peak flows from these two catchment areas were estimated and the flows routed to the ocean via Saltwater Lagoon and Creek.

Estimates of the peak discharge are listed in Table 3.2. These flows are important for determining the extreme water levels, but from the water quality and ecosystem perspective estimates of the total volume entering the lagoon are of interest.

Table 3.2 Peak Inflow Discharge to Saltwater Lagoon for Extreme Rainfall Events
(after Mounser 1981)

Storm Duration (Hours)	Discharge (m^3/s)
1	45.2
6	67.3
12	69.8
18	63.5

The average monthly discharge entering the estuary from the local catchment area (8.7 km^2) may be estimated by assuming a runoff coefficient of 0.2 which is typical for these catchments and applying the average monthly rainfall statistics available for South West Rocks.

Table 3.3 Monthly Freshwater Inflow Volume to Saltwater Lagoon (,000 m^3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Runoff entering Saltwater Lagoon	264	283	341	292	239	234	142	148	100	161	196	216	2616

The influence of the freshwater inflow on the water levels in the lagoon is demonstrated in the data presented in Figure 3.3. Time series rainfall data from BoM's Smoky Cape station is used. The rainfall at Smoky Cape is indicated in the figure and the water level increase in Saltwater Lagoon occurs about one day after heavy rainfall at Smoky Cape (as determined from Figure 3.3). Prior to the event on 7 May the lagoon entrance was closed as indicated by the constant (non-tidal) water level near the entrance. The rise in water level in the lagoon from 0.87 m on 7 May to a peak of 1.22 m on 8 May corresponds to a volume change of 160,000 m^3 (Figure 3.2). The time for the water to discharge from the system depends on the entrance condition. The water level data indicate that the entrance opened during the high tide early on 8 May and the channel scoured over the subsequent few hours allowing the water level to drop and the higher tides to affect the system over the subsequent four days.

3.4 Evaporation

During dry and windy periods the relatively large surface area of Saltwater Lagoon acts as an effective evaporation pond. The magnitude of the evaporation rate may be estimated assuming the available monthly average evaporation data for Coffs Harbour represent the conditions at Saltwater Lagoon and multiplying by the lagoon surface area. The surface areas for the Saltwater Creek (72,000 m^2) and the Saltwater Lagoon area (551,700 m^2) were taken from the Kempsey Shire Council GIS creeks layer. Multiplying the surface area for the combined creek and lagoon by the monthly evaporation (see Chapter 2) yields the monthly water volume losses due to evaporation listed in Table 3.4.

Table 3.4 Monthly Evaporation for the Combined Surface Area of Saltwater Creek and Lagoon (,000 m^3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Evaporative losses from Saltwater Lagoon	117	98	95	73	54	47	50	67	87	102	113	120	1024
Fraction of runoff	44%	35%	28%	25%	23%	20%	35%	45%	87%	64%	58%	56%	39%

The percentage of monthly runoff is also listed in Table 3.4 and indicates that on an annual basis 39% of the catchment runoff is lost to evaporation, with the losses during the drier spring months up to 87%.

Evaporative losses are an important component of the water budget and will also affect water quality. The evaporation process essentially removes the fresh water from the system and leaves behind any salts and other constituents essentially leading to increased concentrations in the lagoon waters. When the creek is open evaporative losses in the creek and lagoon will be compensated by an influx of saline ocean water.

3.5 Conceptual Water Balance Model

A conceptual water balance model is shown in Figure 3.4. The major water inputs include contributions from the local catchment, groundwater flows from the surrounding floodplain areas and the tidal prism when the entrance is open. The major outputs are the tidal prism, evaporation and groundwater discharge through the dunes to the north of the creek and entrance area when the entrance is closed. The annual tidal flushing can be calculated from the tidal prism (approximately 25,000 m^3). Assuming that the lagoon is open for four months per year at full tidal efficiency (two tides per day for 120 days) and assuming a flushing efficiency of 0.1 the annual flushing volume is estimated at 600 ML.

Groundwater flows to and from the lagoon and creek are also likely to form an important contribution to the water budget. Quantitative data were not available for calculation of the total natural discharge of groundwater to Saltwater Creek and lagoon, however an estimate of the maximum average groundwater inflow may be derived using the following assumptions:

- Transmissivity of the sand aquifer is estimated to average 500 m^2/day.
- The hydraulic gradient towards the creek and lagoon is estimated as 0.001.
- The shoreline of the west side of the creek and the lagoon is approximately 6,200 m.

The average inflow can be calculated from the relationship that

$$Q = T\,I\,L$$

where Q = flow
T = transmissivity
I = hydraulic gradient
L = perimeter length

From this equation the maximum estimated groundwater flow into Saltwater Creek and lagoon is estimated to be 3.1 ML/day or 1,135 ML/year.

When the entrance is closed a small amount of flow will exit the Saltwater Creek system via groundwater to the ocean in the dune area near the creek entrance. An estimation of this outflow requires the following assumptions:

- Transmissivity of the sand aquifer is estimated to average 500 m^2/day.
- The hydraulic gradient from the creek to the ocean is estimated as 0.005.
- The perimeter length between the creek and the ocean where groundwater discharge occurs is 200 m.

Using the above equation the maximum estimated groundwater discharge from Saltwater Creek to the ocean is estimated to be 0.5 ML/day or 182.5 ML/year.

3.6 Stratification and Mixing Processes

The recent vertical water quality profiler measurements collected by MHL on 4 April 2001 and DLWC on 1 May 2001 show the presence of stratification in the creek even though the water depths are less than 2 m (Figure 3.5 and Table 3.5). Prior to 4 April heavy rains in the Saltwater Creek catchment occurred in early March and the entrance was scoured by the exiting flood waters. Following this event the entrance appears to have remained open and the freshwater stored in the low lying areas of the catchment gradually drains to the ocean while saltwater enters only during the highest tides. The salinity stratification at any given time reflects the preceding conditions. The data for 4 April are typical of tidal estuaries after freshwater inflow events with low salinity water at the upstream Site 3 and a deeper saline intrusion near the entrance at Site 1 which was only 0.5 m deep. The higher salinities on 1 May (12 ppt at Site 3 and 33 ppt at Site 1) indicate an intervening drier period (between 4 April and 1 May) with open entrance conditions when the saline ocean water penetrates upstream causing a general increase in salinity. While the presence of stratification is of interest the significant factor is how long the stratification persists and hence affects the water residence time. If the stratification persists and inhibits vertical exchange between surface and deeper water layers then the dissolved oxygen in the lower layer will decrease due to consumption by microbial activity.

The data presented in Figure 3.5 indicate a complex pattern of mixing, with the different variables suggesting different processes. The dissolved oxygen (DO) data on 4 April indicates relatively high levels (greater than about 70% saturation) suggesting a rapid recent turnover of lagoon and creek waters by the freshwater inflow of oxygenated waters. On 1 May the DO is much lower at the upstream site indicating the consumption of DO in the lagoon and brackish creek waters but near the entrance the well-oxygenated oceanic water has recently entered the creek from the ocean. The tidal mixing would appear to be limited to the downstream end of the creek and the gravitational (or density-driven) flows are an important factor in the water exchange.

The density-driven circulation is manifest in the typical salt wedge flows that are common in estuaries. The brackish and lighter water of the lagoon essentially floats on the heavier saline waters from the ocean. As this saltier water propagates upstream vertical mixing between the two water types causes the formation of the brackish waters. This process is likely to have implications for the water quality.

Chlorophyll-a data indicate a healthy algal population with mixing throughout the water column. As discussed further in Section 4.4, measured chlorophyll-a values are generally in exceedance of ANZECC (2000) guidelines.

The lagoon is flushed by the freshwater inflow events and gravitational flows when the entrance is open. During dry windy periods evaporation from the lagoon surface may also be an important contributor to water losses and the salinity concentration. As the fresh water evaporates it leaves salt behind resulting in an increase in salinity of the lagoon water. The balance between the evaporation and inflow of groundwater during drier conditions is likely to affect water quality.

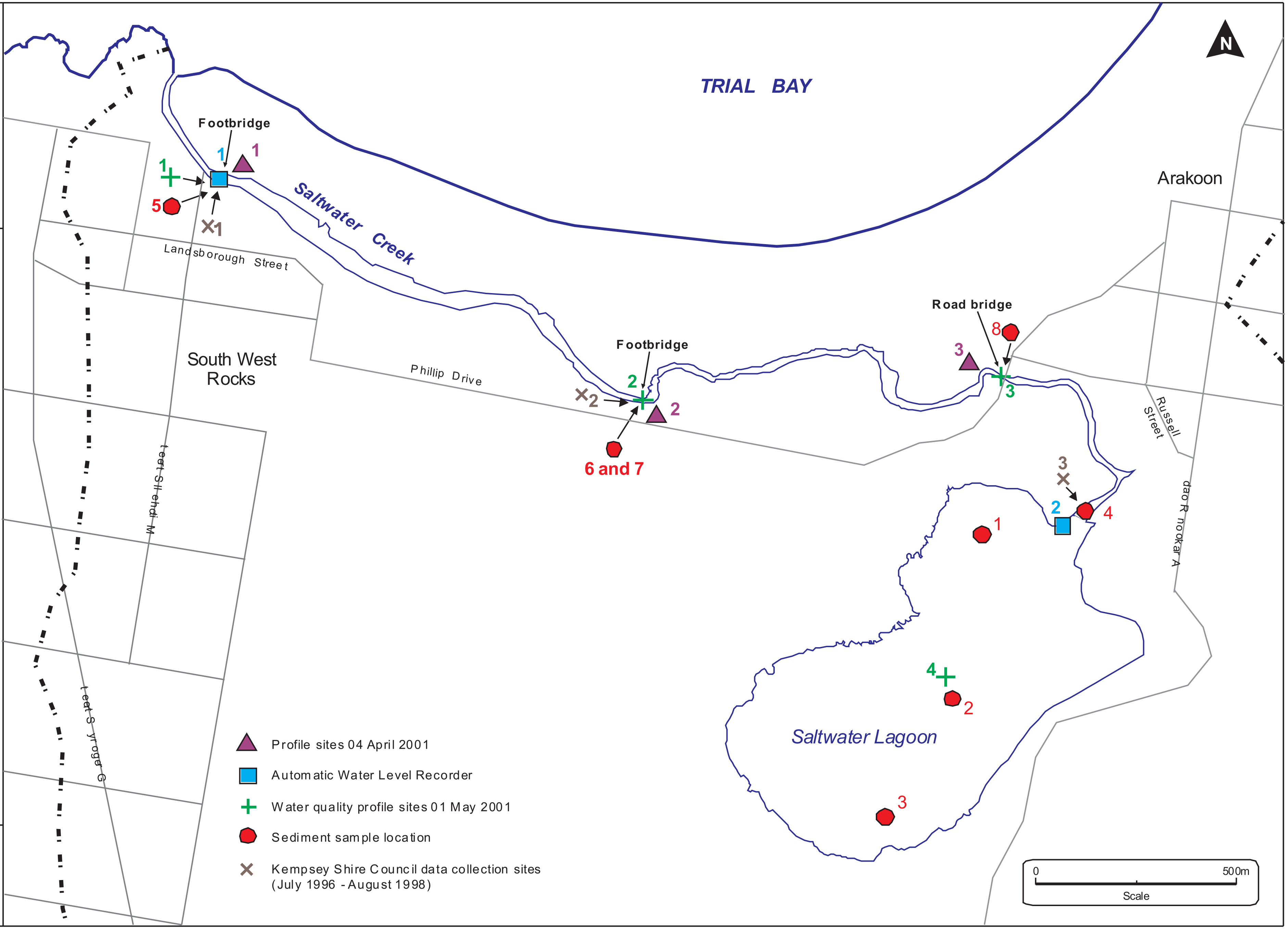
Table 3.5 Depth Averaged Values of Water Quality Profile Measurements Collected on 4/4/01 (MHL) and 1/5/01 (DLWC)

Site	Date and Time	Depth (m)	Temp. (°C)	pH	Salinity (ppt)	DO (% sat.)	Back-scatterance (NTU)	Chl-a (µg/L)
1	4/4/01 14:10	0.25	25.17	6.70	7.19	86.09	1.95	8.17
1	1/5/01 10:02	0.90	22.22	8.05	32.32	80.39	2.60	3.75
1	1/5/01 16:11	0.70	22.90	8.01	31.93	101.39	3.98	4.26
3	4/4/01 14:42	1.03	24.21	6.63	0.28	69.59	5.15	8.59
3	1/5/01 11:02	1.60	20.89	6.83	11.70	22.39	4.00	6.87
3	1/5/01 16:49	1.70	21.08	6.63	12.04	17.69	3.36	6.86

3.7 Conceptual Model of Circulation and Flushing

Water circulation is dominated by tidal flows and superimposed over these daily variations is a long-term salt wedge-like exchange flow driven by the freshwater inputs to the creek. The intrusion of saline water (from the ocean) into the creek occurs only when the creek mouth is open (Figure 3.6). Salty (and hence dense) water from the ocean intrudes into the estuary and sinks to the deeper areas of the creek. Fresh water from catchment runoff enters the estuary and floats on top of the denser salt water forming distinct layers (stratification). Tidal action essentially mixes the fresh low salinity water with the saline intrusion and forms a brackish mixture. When the creek is closed off from the ocean no saline water enters the estuary and the lack of tidal flushing allows distinct horizontal stratification to form (Figure 3.7). Stratification is broken down by turbulent mixing caused by wind and tidal exchange (when open) and by mixing between the layers. When the mouth is closed, mixing only results from wind-generated turbulence and mixing between the layers.

Large freshwater inflows can completely flush the creek but regular rainfall events generally cause only limited mixing and exchange. These flushing characteristics result in longer residence times in deeper areas of the creek/lagoon, while the reaches both upstream and downstream of deeper areas are characterised by shorter residence times. These flushing characteristics hence play an important role in determining the distribution of phytoplankton which require reasonably stable (residence times >3-4 days) conditions to reach bloom proportions.



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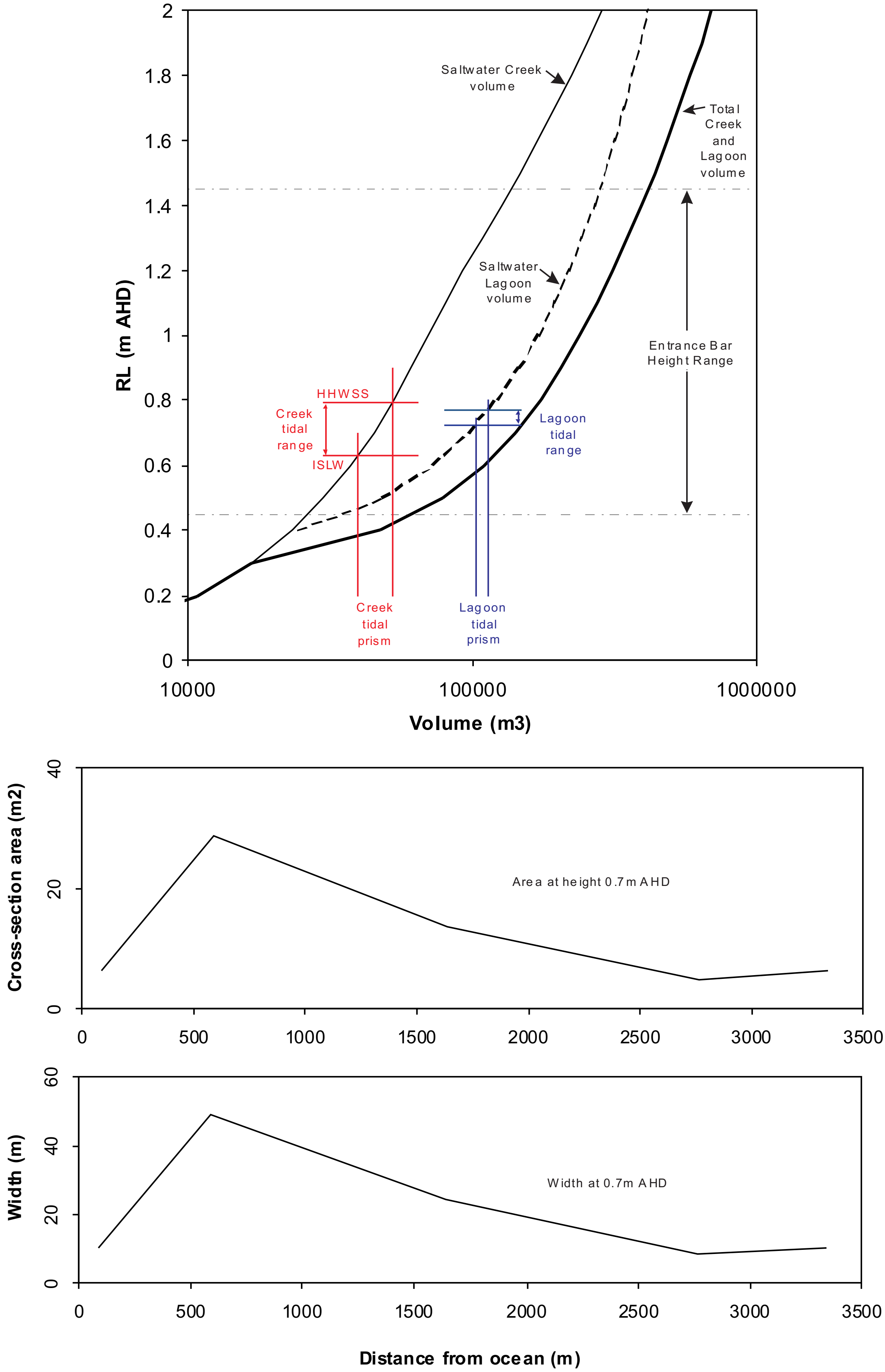
SALTWATER CREEK
WATER QUALITY SAMPLING SITES

MHL Report 1126

Figure 3.1

DRAWING 1126-03-01.CDR



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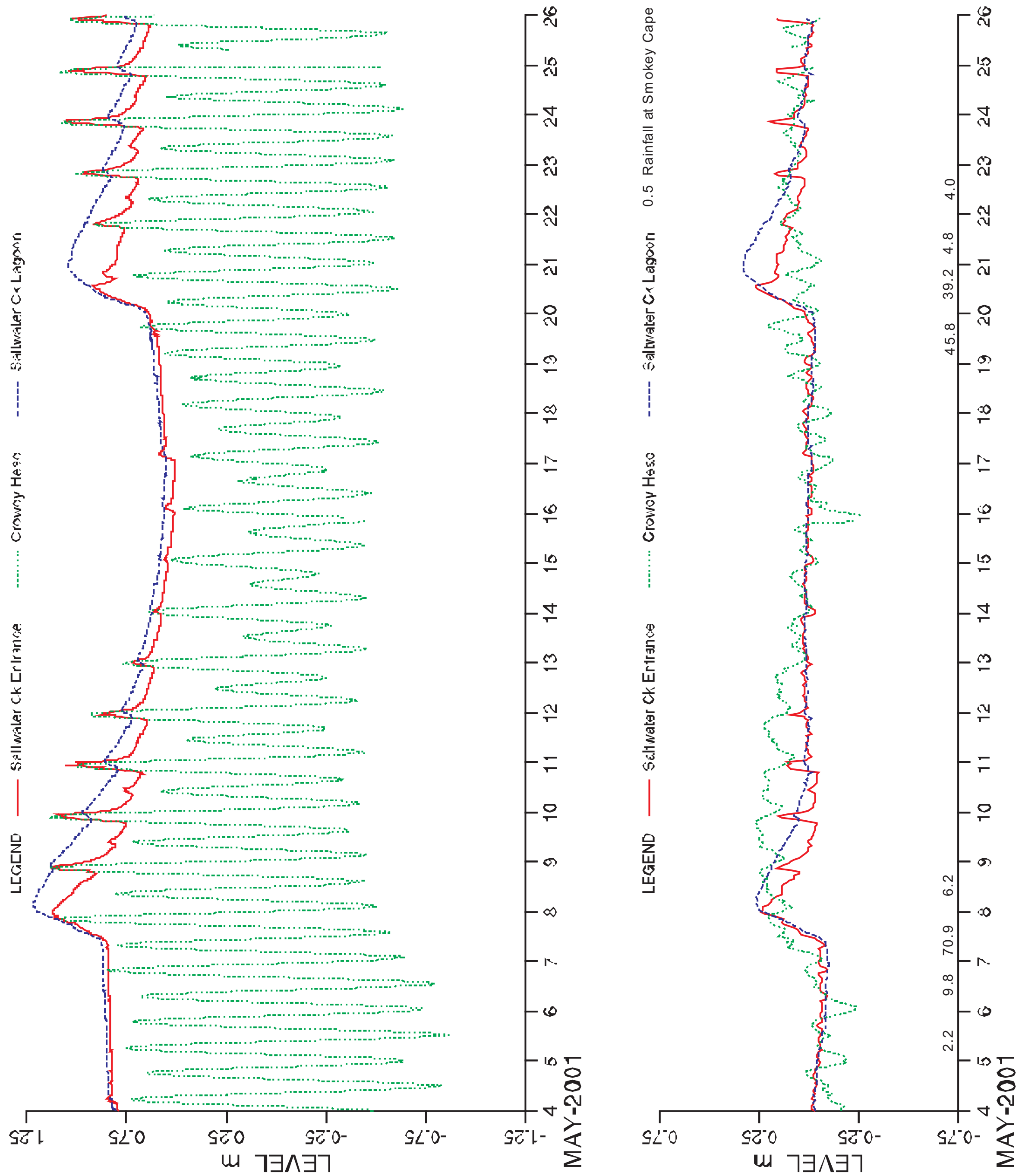
WATER VOLUMES AND PHYSICAL CHARACTERISTICS OF SALTWATER CREEK AND LAGOON

MHL Report 1126

Figure 3.2

DRAWING 1126-03-02.CDR



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WATER LEVELS AND RESIDUALS FOR SALTWATER CREEK FROM 04 MAY 2001 TO 25 MAY 2001

MHL Report 1126

Figure 3.3

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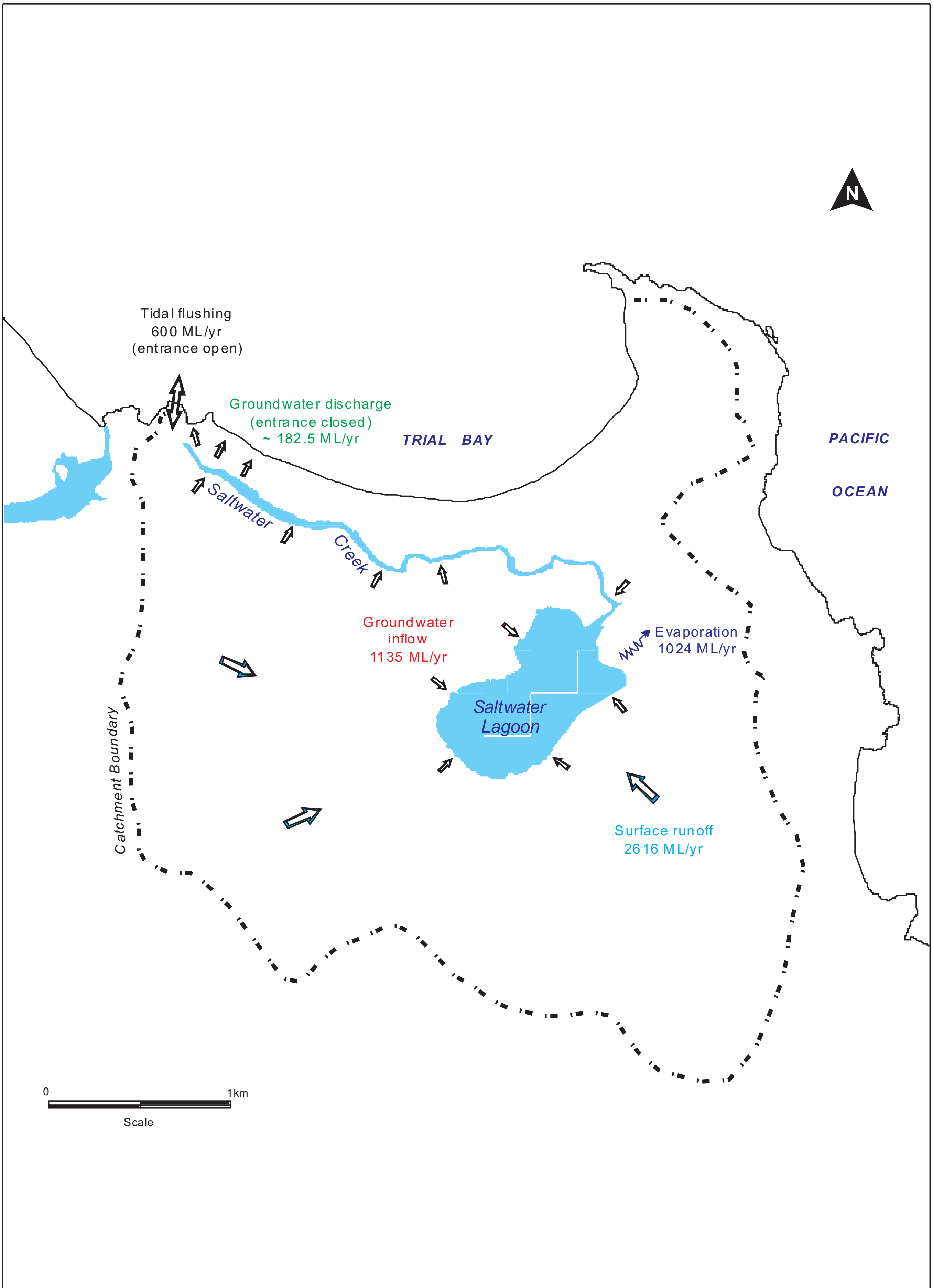

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CONCEPTUAL WATER BALANCE MODEL

MHL Report 1126

Figure 3.4

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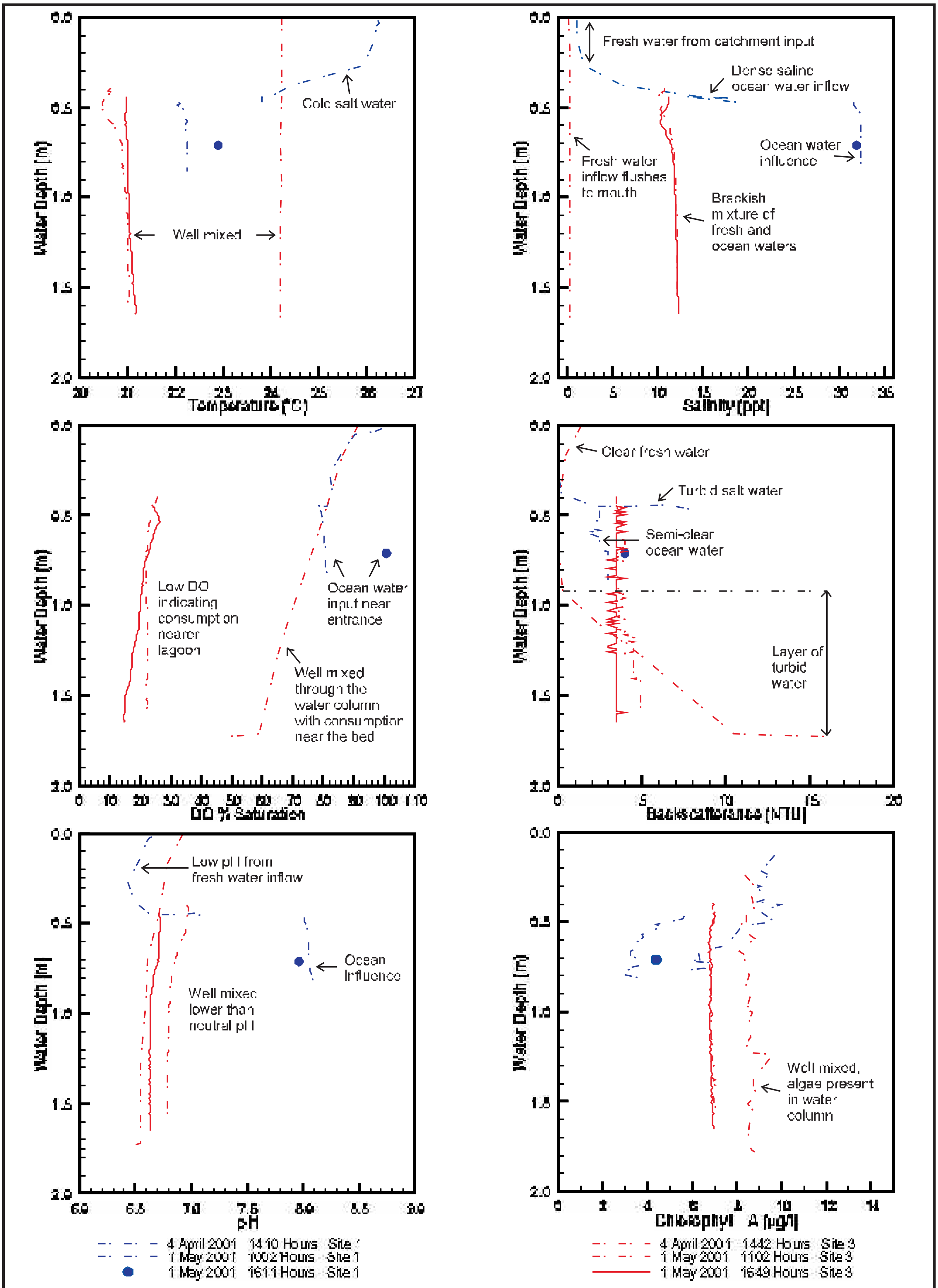

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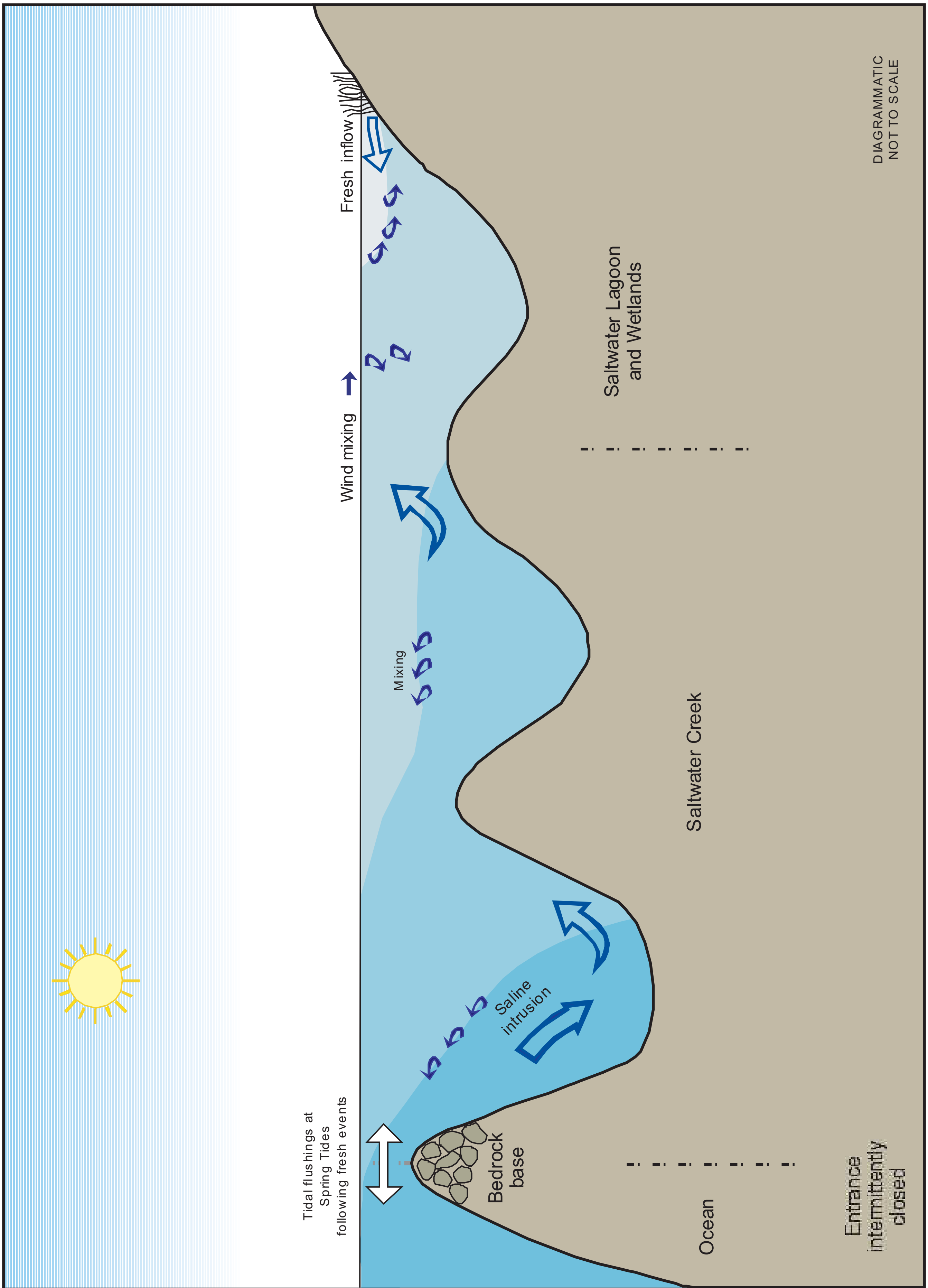
SALTWATER CREEK - WATER QUALITY

SITE 1 (NEAR ENTRANCE) AND SITE 3 (NEAR SALTWATER LAGOON)

MHL Report 1126

Figure 3.5



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CIRCULATION AND FLUSHING - OPEN

MHL Report 1126

Figure 3.6

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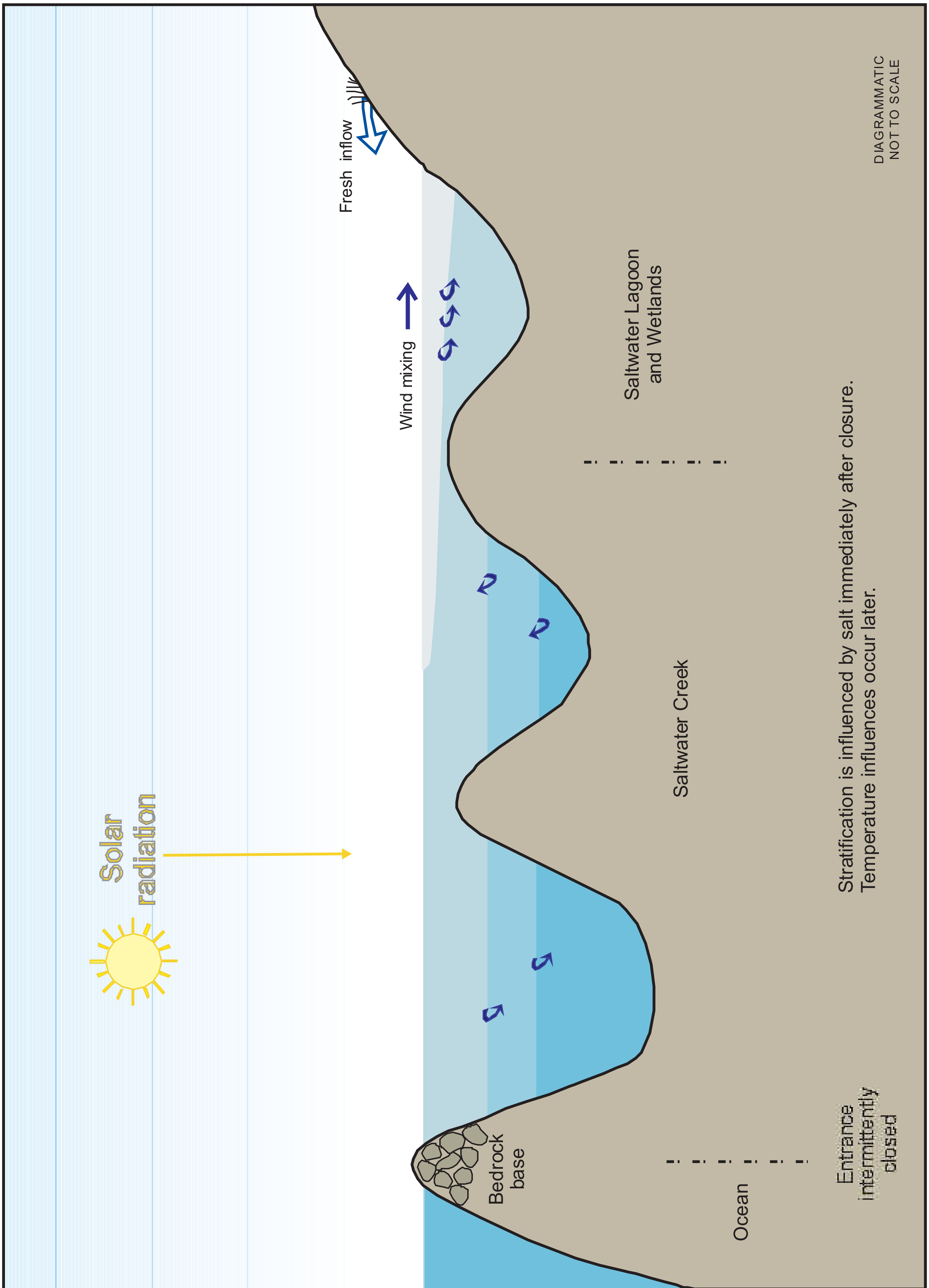

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CIRCULATION AND FLUSHING - CLOSED

MHL Report 1126

Figure 3.7

DRAWING 1113-03-07 CDR

4. Water Quality

4.1 Introduction

Water quality in Saltwater Creek/Lagoon is influenced by inflows from the catchment, from water exchange with the ocean and by bio-geochemical cycling within the estuary.

Urbanisation of the catchment has led to an increase in sediment and nutrient loads to the estuary. During rainfall events these pollutants are washed into the creek from diffuse sources such as South West Rocks urban areas and rural areas. They may also be discharged directly into the creek from point sources such as at stormwater inputs (as indicated in Figure 2.12). A discussion on sediment processes can be found in Chapter 7.

When the mouth is open during summer nutrient-enriched water from oceanic upwelling and suspended sediments caused by wave motion enter the lower reaches of the creek (Figure 4.1). When the creek is closed off from the ocean, nutrient sources include catchment runoff, groundwater and benthic sediment efflux. Nutrient release from the sediments and exchange with macrophytes and microalgae become more important for nutrient cycling when the entrance is closed (Figure 4.2; MHL 2000).

These water quality impacts also influence the estuarine processes within Saltwater Creek and Lagoon. Pollutant and hydraulic loads affect the bioavailable nutrients, which are integrated by and therefore affect the macroalgae, phytoplankton and zooplankton communities. Phytoplankton, as well as being dependent on bioavailable nutrients, are also affected by environmental factors such as light and temperature. It is likely that a complex population of microalgae and biofilms exists within the sediments and in a surface algal mat (microphytobenthos) in the lagoon. This population will respond to changes in nutrient inputs, light and temperature and may have the ability to store nutrients and metals from the water.

Water quality in Saltwater Creek is a major concern for the community and one which greatly affects recreation and tourism. When the mouth is closed for extended periods the water in the creek is turned a dark tannin colour by nearby tea trees (*Melaleuca*) and starts to smell badly due to decomposition of organic materials. Although these are natural processes the results are unpleasant and of concern to the community.

Opening of the Saltwater Creek entrance requires permission from NSW Fisheries and the Department of Land and Water Conservation. Permission to dredge the mouth was sought by Council in November 2000, but rejected by NSW Fisheries since there was no evidence of public health, safety or flooding impacts that would be resolved by opening the creek (NSW Fisheries pers. comm. 2000).

The community is also concerned about the possible soil and groundwater contamination at the former Caltex oil terminal site close to Saltwater Creek. In 1992 significant soil and groundwater contamination was discovered and during 1993 investigations were carried out by consultants for Caltex to determine the nature and extent of this contamination on and off the site. Testing indicated that hydrocarbon contamination was present in the soils on the terminal site. More importantly, the principal contamination off-site was a plume of hydrocarbons in the groundwater (EPA 1995). The plume emanated from the former Caltex terminal and extended under the adjoining road, a number of private residences, a proposed resort development site and through a Crown reserve to Saltwater Creek. This off-site contamination was believed to have the potential to affect human health and the aquatic organisms of Saltwater Creek (EPA 1995).

A Steering Committee consisting of affected residents, landholders and representatives from Caltex, Kempsey Council and the EPA was established to oversee the clean-up program. Clean-up standards were established and remediation technologies included a soil 'bioremediation cell' and 'air sparging', which involves pumping air through the groundwater to remove the volatile hydrocarbons. This also enhances the natural breakdown of contaminants in the soils and groundwater. The EPA is awaiting the results of an ecological study to determine whether hydrocarbon contamination has affected the creek. The remediation of the contaminated groundwater, once complete, should prevent contamination reaching the creek.

4.2 Existing Water Quality Data

Water quality information was provided to MHL by Kempsey Shire Council and included data collected as part of the Beck Development Environmental Study (Kempsey Shire Council, unpublished) as well as routine water quality monitoring results. For both of these sets of data three sites were investigated, namely Brighton Park approximately 100 m from the creek mouth (1), a site opposite the old oil terminal (2) and Lagoon View caravan park ((3) now Trial Bay caravan park) (Figure 3.1). For the Beck Development Environmental Study, data was collected on nine days between July 1996 and August 1998. The monitoring data includes 31 sampling occasions between July 2000 and February 2002.

These data are presented in Section 4.4. They should be interpreted with caution as there is no record of sampling and analytical methods, exact locations of sampling or quality control. Moreover it is not clear whether the entrance was open or closed at the time. There is insufficient data to enable analysis of trends.

4.3 Field Observations

As part of this project MHL conducted a site inspection on 4 April 2001. During the inspection water quality data were collected using a Hydrolab Multiprobe to record vertical profiles of temperature, salinity, dissolved oxygen, pH and turbidity at three sites within the estuary (Figure 3.1). On 1 May 2001 DLWC conducted a more detailed exercise using a Sea-bird Seacat SBE25-03 water quality profiler. They also deployed water level recorders near the entrance and in the lagoon for a two-month period. Details of these site investigations are presented in Section 3.

4.4 Comparison of Water Quality Data to ANZECC Guidelines

The two sets of water quality data collected by Kempsey Shire Council between July 1996 and August 1998 and July 2000 and February 2002 were compared to the ANZECC (2000) guidelines. Guidelines for the protection of aquatic ecosystems are divided into six ecosystem types, one of which is estuaries. The ANZECC (2000) guidelines, however, recommend that detailed local water quality studies are undertaken to determine appropriate and acceptable background levels for specific water bodies. Trigger values are presented which represent the best currently-available estimates of ecologically low-risk levels of water quality indicators. If values exceed these or fall outside a specified range it is recommended that management action is taken. For the purposes of this report guidelines for recreational waters are used for those water quality variables that do not have an aquatic ecosystem trigger value. A summary of relevant ANZECC guidelines is shown in Table 4.1.

Table 4.1 ANZECC (2000) Guidelines for Water Quality Parameters

Water quality parameter	Aquatic ecosystem trigger value	Recreational guideline
Dissolved oxygen		> 6.5 mg/L
pH	7 – 8.5	
Temperature		15 – 35 ^{0}
Total phosphorus	30 μg PL^{-1}	
Total nitrogen	300 μg N L^{-1}	
NO_x	15 μg N L^{-1}	
Chlorophyll-*a*	4 μg/L	
Faecal coliforms (cfu/100mL)		1^0 contact < 150 2^0 contact < 1000

The data from the Beck Development Environmental Study (BDES) indicate that DO levels fell below 6.5mg/L on 13 of the 18 sampling occasions. Three of these measurements were below 3.0 mg/L. Similarly, the Council water quality monitoring data show that DO levels are frequently below the guideline level of 6.5 mg/L at all three sites. The data show a trend for DO levels to decrease away from the entrance and there were seven sampling occasions with DO less than 3.0 mg/L at Site 3, compared to three at Site 1. Dissolved oxygen is an important water quality constituent as it plays a role in many biotic and chemical processes. Low DO can cause stress in biota and at very low levels can be fatal, for example fish kills. High DO levels are also necessary for the efficient functioning of some estuarine processes, such as denitrification (see Section 4.5.1). DO is strongly influenced by temperature, salinity and diurnal biotic activity, and without any indication of the time of day or salinity conditions these values should be interpreted with caution.

Values for pH in Saltwater Creek vary between 6.2 and 8.0, with a mean value of 7.06 across all of the sampling sites in the BDES. The majority of the Council water quality monitoring data indicate pH values of 7 ± 0.5. Marine environments typically have a pH of 8.0 to 8.3, while low pH values are usually related to freshwater inputs. This is particularly the case in areas draining acid sulphate soils. The presence of potential acid sulphate soils in the area (see Section 4.7) suggests that localised acid runoff may occur although its area of influence is likely to be small. The available data indicate that measured levels of pH are not of concern at the sites sampled. Significant changes in pH can have adverse effects on biota and can cause changes in the toxicity of pollutants.

Water temperatures in the creek range from around ~17°C in winter up to ~28°C in summer. These are well within the recreational guidelines and would only be of ecological concern if significant changes were experienced in a short period of time, for example a ~2°C change over an hour.

Salinity values for Saltwater Creek range from 2 to 28 g/L (approximately parts per thousand by weight, ppt). In estuarine environments salinity is highly variable, related to tidal variations and changing freshwater inputs. Salinity and stratification are discussed in detail in Section 3.6.

The 2000 ANZECC guidelines suggest a trigger value for chlorophyll-a concentrations of 4 µg/L. Values observed by MHL on 4 April and 1 May 2001 varied between 4 and 9 µg/L indicating a healthy population of phytoplankton and likely blooms at certain times. High chlorophyll-a values can be an indication of nutrient enrichment and often coincide with high nutrient values (see Section 4.5 below).

Faecal coliforms are generally used to provide an indication of potential human health concerns associated with immersion in water. ANZECC (2000) guidelines stipulate that for primary contact, such as swimming, median counts (determined from at least five samples collected at regular intervals not exceeding one month) should not exceed 150 cfu/100 mL and for secondary contact, such as watersports, median counts should not exceed 1000 cfu/100 mL. The nine values recorded for the BDES were well under this value except on one occasion when values in all three locations exceed 3,200 cfu/100 mL. Conditions and activities on the day of sampling are unknown and thus little can be interpreted from this result. The Council water quality monitoring data show that of the 31 sampling occasions the primary contact value was exceeded on seven occasions at one or more sites, and the secondary contact value was exceeded on three occasions. Two of the values greater than 1000 cfu/100 mL were recorded at Site 1 and one at Site 2, indicating that the source may be related to proximity to the township of South West Rocks. Faecal coliforms provide a measure of pathogens derived from warm blooded animals and without additional information it is not possible to speculate further on the source of the measured values.

Water clarity measurements are not available to compare to the ANZECC guidelines. However, water clarity is also an important determinant of water quality. The water clarity is generally measured by turbidity which provides a measure of the light scattering that is influenced by the number, size and character of suspended particles. Water clarity is also affected by colour that is typically determined by the concentrations of dissolved organic compounds such as tannins derived from *Melaleuca* forests. There is some evidence of the brown colouring typical of the coastal lakes of the NSW north coast with adjacent *Melaleuca* wetland areas.

Suspended particulate matter is generally comprised of inorganic clay material and fine organic particles. The concentrations of suspended particulates at any given time depends on the inflows and resuspension of bottom material due to wind- or tidally-induced turbulence. Water clarity will therefore vary considerably with the weather and runoff events. Water clarity affects the penetration of light into the water column and hence depth to which plants such as phytoplankton, cyanobacteria and macroalgae can photosynthesise.

4.5 Nutrient Inputs and Cycling in Saltwater Creek

Nitrogen and phosphorus are the two most commonly measured nutrients and in high levels can result in nuisance plant growth, excessive algal proliferation and increased levels of oxygen-consuming microbes causing low DO concentrations.

The ANZECC (2000) guidelines suggest an aquatic ecosystem trigger value for total phosphorus of 30 µg/L. The values from the BDES vary approximately between 10 and 300 µg/L, with values exceeding 30 µg/L on ~80% of the sampling occasions. The water quality monitoring data include one value for total phosphorus greater that 30 µg/L. There may be many reasons for high phosphorus levels including sampling and analysis methods, inflows from the catchment via stormwater or release from the sediment. From the available information it is not possible to determine the reason for the higher values.

Guidelines for oxidised nitrogen (nitrate and nitrite) are provided in ANZECC (2000) with values recommended to not exceed 15 µg/L. Values in Saltwater Creek are typically much higher, with minimum values of 61 µg/L and maximum measured values of above 1,000 µg/L. Possible reasons for high values are similar to those described above for phosphorus. High values are typical in highly productive shallow ecosystems but again it is not possible to determine the specific reason for the higher values in this situation from the available information.

4.5.1 Nutrient Budget

The nutrient budget for the system may be estimated by considering the nutrient compartments within the system and the inputs and outputs. Nutrient inputs to the creek and lagoon are derived from the catchment inflows and also from nutrient recycling from the sediments. Nutrient losses from the system are due to sedimentation from the water to the sediment, denitrification, uptake by biota and when the entrance is open flushing of nutrients to the ocean (Figures 4.1 and 4.2).

Catchment inflows have been calculated in Section 2.8 using nutrient generation rates derived from the Catchment Management Support System. Nitrogen loads were estimated to be approximately 5,300 kg/year and phosphorus loads approximately 1,000 kg/year.

The rate of flushing to the ocean, which only occurs when the entrance is open and spring tides occur, has been estimated at 600 ML/year (see Section 3.5). Assuming from the available data that average concentrations in the creek of nitrogen are 500 µg/L and of phosphorus are 100 µg/L, annual nutrient flushing rates of 300 kg/year for nitrogen and 60 kg/year for phosphorus are derived.

The above calculations conclude that while flushing to the ocean is occurring there is a nutrient retention and cycling rate in the system of around 95%. When the entrance is closed all of the catchment nutrient load will be retained or cycled in Saltwater Creek and lagoon. Cycling processes include uptake by plants and algae, denitrification, and burial in the sediments.

There is likely to be a relatively high rate of sediment burial of phosphorus, as this is a conservative compound which adsorbs to sediment surfaces and is buried by deposition processes. A management implication of this is that disturbance of the creek and lagoon sediments should be minimised to prevent the release of large quantities of phosphorus into the system.

As Saltwater Lagoon is very shallow and generally the water depth is less than the photic depth the partitioning of nutrients between waterborne phytoplankton and benthic species is likely to favour the benthic species. Nutrients are brought into the waterway in a range of forms including dissolved inorganic forms that are available for uptake by biota (phytoplankton and macroalgae), particulate forms that generally settle to the bottom, and organic-bound forms locked up in leaf litter and detrital matter. These different forms are then subject to transformations through a range of processes that operate under differing conditions. There are no detailed measurements that may provide information on the different regimes and temporal trends.

Denitrification efficiency refers to the biological 'self cleaning' ability of an estuarine ecosystem to convert bio-available nitrogen into nitrogen gas that is then lost to the atmosphere. Denitrification is an important process as it reduces the quantity of available nitrogen in the water column and thus restricts the development of harmful or excessive algal blooms. The process is carried out by groups of bacteria inhabiting the estuarine sediments.

The denitrification process has two steps and requires certain environmental conditions to proceed efficiently. The first step is 'nitrification' which involves the conversion of ammonium to nitrate and requires the presence of oxygen. The second step (denitrification) uses the nitrate in the breakdown of organic matter and produces nitrogen gas, requiring sufficient organic matter and nitrate. Denitrification efficiency can be impaired by chronic algal blooms as the breakdown of large amounts of algal material depletes oxygen in the water and sediments, stopping the process at the initial nitrification step.

Direct measurement of denitrification efficiency involves the collection and incubation of sediment cores and subsequent laboratory analysis using membrane inlet mass spectrometry. This procedure has not been undertaken in the Saltwater Creek estuary. The closest study performed was in the Brunswick estuary, where it was found that denitrification efficiency reduced towards the middle and upper sections of the estuary during the occurrence of large algal blooms (MHL 2000). The denitrification efficiency rates for most of the sites in the study were similar when compared with other shallow sub-tropical estuaries, although they were extremely high compared to efficiencies measured in other estuarine systems around the world.

It is recommended that measurements of denitrification efficiency be undertaken in Saltwater Creek at various temporal and spatial scales, as it has been suggested as a potentially useful health indicator in shallow sub-tropical estuaries where benthic microalgae and bioturbation are prevalent.

4.6 Conceptual Model of Water Quality

Phytoplankton blooms respond relatively quickly to changes in water quality and are therefore a good indicator of the condition of the estuary. The processes that control phytoplankton blooms in open and closed conditions are schematised in Figures 4.1 and 4.2. Nutrient inputs provide a continuous food source for phytoplankton and when there exists sufficient light and optimal temperature the phytoplankton populations can multiply very quickly. This rapid growth is then countered by the flushing effect (when the lagoon is open) and zooplankton grazing.

Bioavailable nutrients are derived from episodic inputs from the catchment during inflow events and more continuous supply via recycling through the sediments. The latter supply will vary depending on the entrance condition, organic content of the sediment, stratification and resuspension events.

During periods when the entrance is open tidal flushing will effectively disperse the suspended matter including algal cells and introduce saltwater that may also affect the algal species composition. By contrast, when the entrance is closed the system will continue to produce biomass until some other factor such as zooplankton grazing effectively limits the algal population.

It is likely that the factors controlling algal growth and mortality vary over seasons and with entrance condition.

It is difficult to assess the likely water quality status of the system prior to artificial entrance opening and urbanisation of the catchment. More frequent entrance opening has increased flushing and reduced retention times for nutrients entering the system but urban developments and channelling of stormwater to the lagoon has increased nutrient loads. In addition the more frequent opening has lead to an influx of salt water and hence the creek areas are subject to larger saline variations that will cause a shift from freshwater to salt-tolerant species.

4.7 Acid Sulphate Soils

Acid sulphate soils (ASS) are sediments deposited under estuarine conditions which contain the sulfidic mineral pyrite. As long as the acid sulphate soils are not disturbed or drained, these materials are relatively harmless and called *potential* acid sulphate soils. If the soils are exposed to air, the pyrite oxidises and sulphuric acid is generated. Drainage from acid sulphate soils areas severely affects water quality as aluminium, iron and sulphuric acids are washed into the waterways.

Priority areas for management of acid sulphate soils in the lower Macleay floodplain have been mapped by the Department of Land and Water Conservation (DLWC 1999). Priority areas are areas where land management decisions in relation to acid sulphate soils may cause severe soil acidification, poor water quality, reduction in agricultural productivity, loss of estuarine habitat and degraded vegetation and wildlife. Figure 4.3 presents a map of acid sulphate soils risks around Saltwater Creek and lagoon.

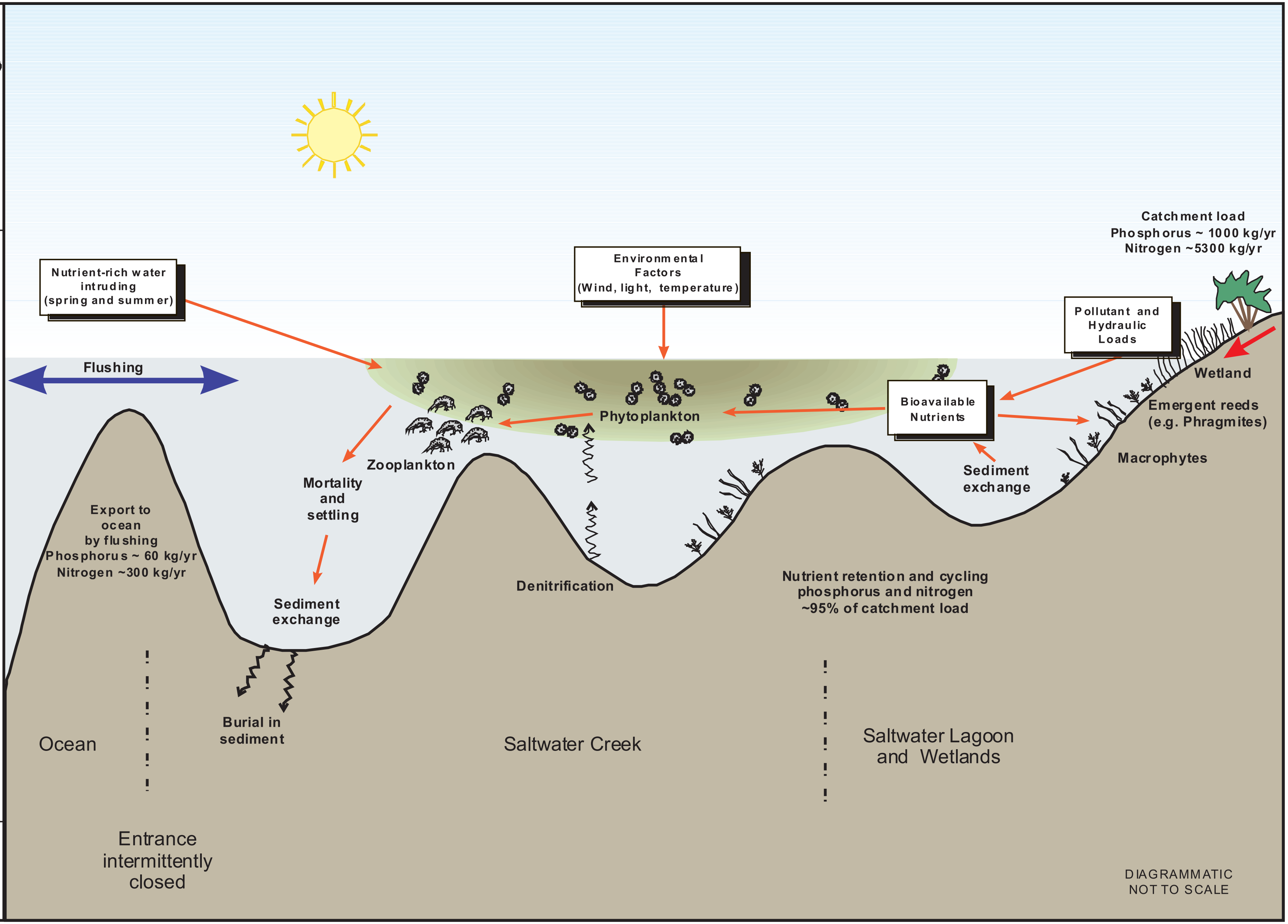
High risk areas are predominantly in the low-lying areas adjacent to the creek and lagoon. Any proposed disturbance of soils or vegetation cover in these high risk areas should be subject to an assessment of potential for acid generation and possible environmental impacts. The pH measured in the creek on 4 April and 1 May varied between 6.5 and 7.0 which is typical of these systems. There is no suggestion from these data that acid runoff within the previous week had caused a major decline in pH.

Changes to the opening regime may affect the water table levels adjacent to the creek and lagoon with flow-on effects on groundwater flows and acidity with the ASS. It is likely that more regular opening has lead to a lower water table and possible exposure of ASS and hence a possible lowering of pH in the creek and lagoon. Alternatively, during extended periods of closure and dry weather the water level may drop due to evaporation, hence creating a similar condition to the open system. There are a number of mechanisms that may affect the acid runoff and pH of the water. These issues should be considered carefully for any proposed developments within the high risk ASS areas.

4.8 Implications of Poor Quality Water on Biota of Saltwater Creek

Water quality is a critical issue for the management of aquatic ecosystems. There is no evidence in the available literature of poor water quality having detrimental impacts on the biota of Saltwater Creek. There have not, however, been many studies aimed at establishing the link between water quality and biota in the system. Juvenile mullet observed with their heads out of the water during the field trip by The Ecology Lab on 4 April 2001, however, may indicate that oxygen levels in the lagoon are low. The profile data (Figure 3.5) indicate low DO in deeper waters but surface water was around 100% saturation.

Some of the fish caught by TEL in 2001 had ‘red-spot disease’ (epizootic ulcerative syndrome). Acid waters have been implicated in the occurrence of this disease in other areas (TEL 1996). Unfortunately, due to the limited amount of data available, it is difficult to determine if there has been significant acid sulphate soil pollution in Saltwater Creek. However, water quality data collected by Kempsey Shire Council as part of the Beck Development Environmental Study did not record pH levels lower than 6.17 over the two years of the study (Kempsey Shire Council, unpublished). Furthermore, fine algae noted on the sediments and on the surface of the lagoon may indicate high nutrient loads. Although high nutrient loads cannot be confirmed as the reason for the algae found in the lagoon, nitrate and phosphate levels were found to be high in samples taken from Saltwater Creek (see Section 4.5).



NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES

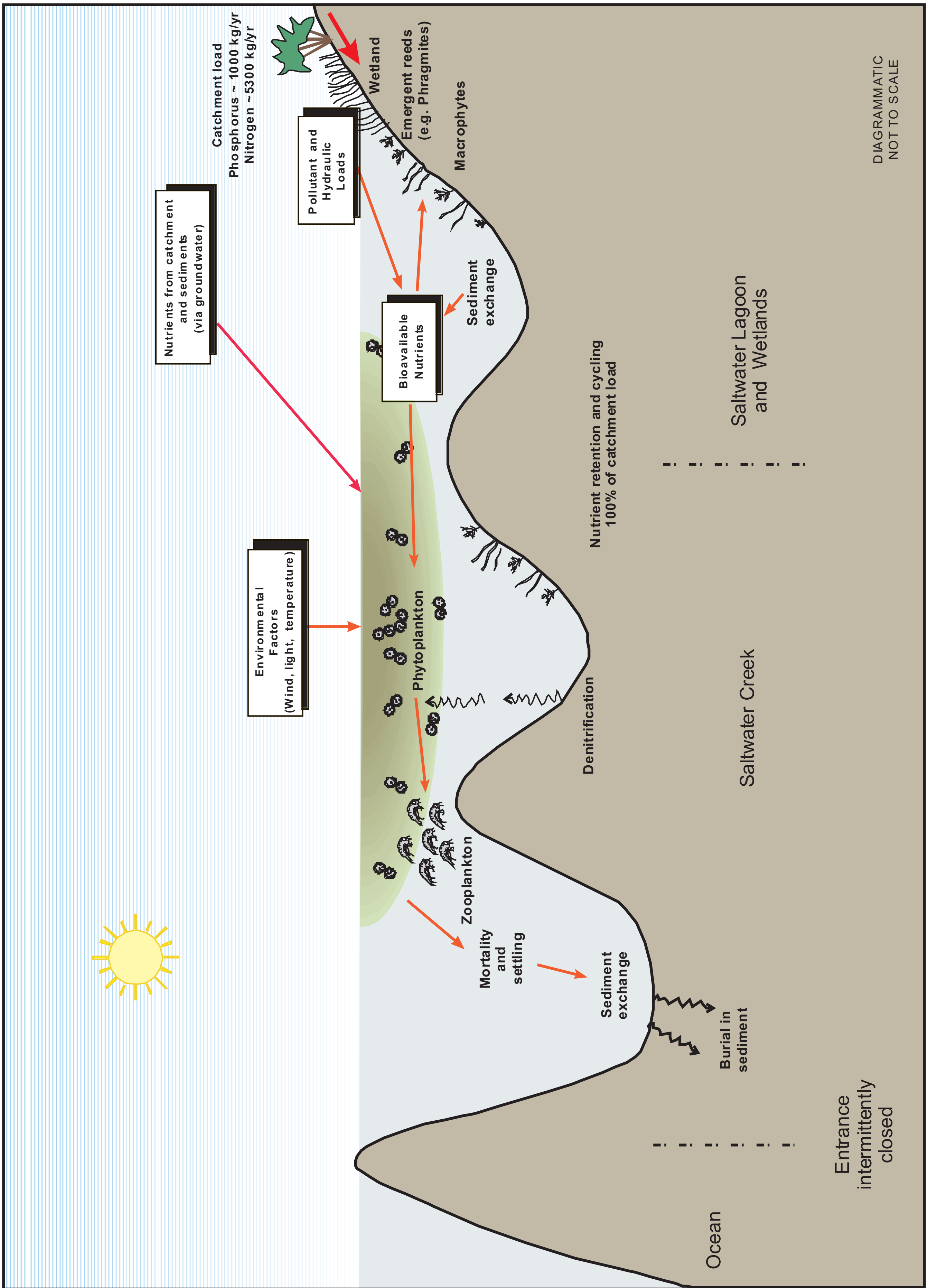
MANLY HYDRAULICS LABORATORY

NUTRIENT BUDGET AND CYCLING - OPEN

MHL Report 1126

Figure 4.1

DRAWING 1113-04-01.CDR



NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES
MANLY HYDRAULICS LABORATORY

NUTRIENT BUDGET AND CYCLING - CLOSED

MHL Report 1126

Figure 4.2

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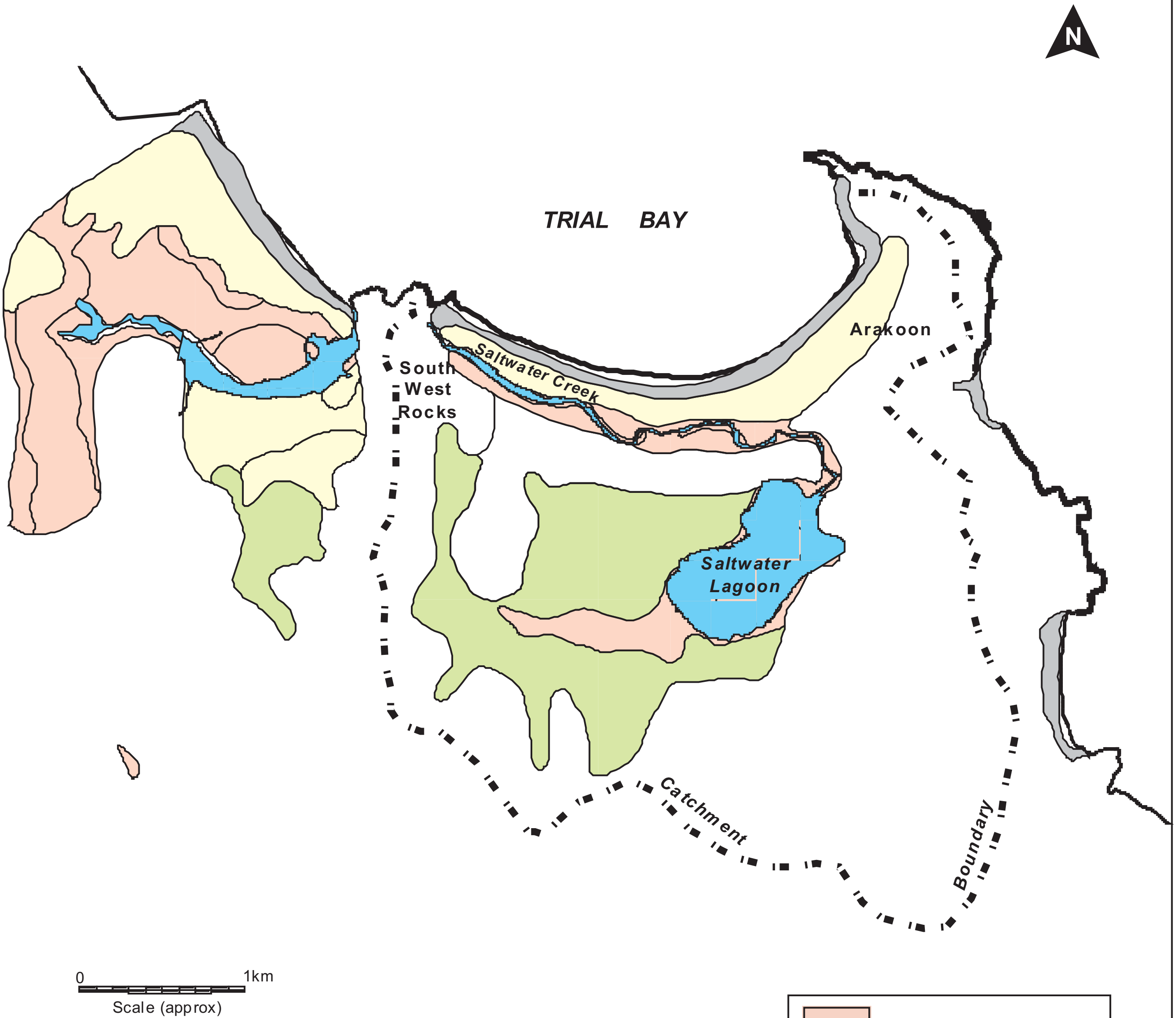

NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES

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ACID SULPHATE SOILS

MHL Report 1126

Figure 4.3

DRAWING 1126-04-03.CDR

5. Ecological Processes

5.1 Existing Ecological Data

5.1.1 Introduction

Manly Hydraulics Laboratory provided TEL with a list of references, and those of relevance to the ecological component of the study were reviewed and summarised. The library database of TEL was also searched for relevant material. The NSW National Parks and Wildlife Service's Wildlife Atlas was searched for records of protected flora and fauna in the area and the Environment Australia website for the *Environment Protection and Biodiversity Conservation Act 1999* was searched for threatened species, marine protected species and migratory species likely to occur in the region. Finally, the World Wide Web was also searched for current information on Saltwater Creek and surrounding areas.

5.1.2 Flora

Virtually all of Saltwater Creek has been designated as SEPP 14 Coastal Wetland (No. 439, Map 12 in Adam et al. 1985) (Figure 5.1). In NSW, State Environmental Planning Policy No. 14 (SEPP 14) covers the management of estuarine and freshwater wetlands, i.e. land that is temporarily or permanently covered by water. These wetlands were mapped and numbered by Adam et al. (1985) and have since been amended by DUAP (1998). SEPP 14 Wetland 439 encompasses Saltwater Creek and Lagoon. There are several other SEPP 14 wetlands in the area. These include South West Rocks Creek (436), a small wetland to the south of South West Rocks township (438) and three others that drain into Spencers Creek (446, 437, 443), a tributary of the Macleay River.

West et al. (1985) mapped estuarine habitats in NSW using a combination of aerial photography and ground surveys. They reported that Saltwater Creek has a 'map water area' of 0.078 km^2, but it is unclear if this includes Saltwater Lagoon. They also reported that no seagrasses, mangroves or saltmarshes occur within Saltwater Creek, which does suggest that Saltwater Lagoon was not included in the mapping by West and his co-workers, as we know that extensive saltmarshes occur around Saltwater Lagoon (see below). In contrast to Saltwater Creek, West et al. (1985) reported that in South West Rocks Creek, which has a map water area of 0.118 km^2, there were extensive seagrasses (2.4 ha), mangroves (52.8 ha) and saltmarshes (14.1 ha). Based on this comparison alone, Saltwater Creek has far less extensive estuarine vegetation than nearby South West Rocks Creek. It should be noted that West et al. (1985) mapped vegetation at a scale of 1:25,000. Therefore, small, fringing beds of vegetation tended to be overlooked by their mapping.

A vegetation survey carried out by Dwyer (1995) focused on the area between the creek and the beach within Arakoon State Recreation Area. Three vegetation communities were identified in the area including estuarine, coastal scrub and wet sclerophyll forest. The dominant vegetation types within each of these communities were listed and evidence of fauna was recorded. In total, 48 plant species were identified along the transect. It was concluded that the environment was quite undisturbed considering its proximity to urban development.

NSW National Parks and Wildlife Service has produced a vegetation map for Hat Head National Park which includes the area surrounding Saltwater Creek. A map of the creek and surrounds has been reproduced in Figure 5.2. The dominant vegetation types that surround the creek and lagoon include:

- Sedgeland – dominated by *Baumea juncea*
- Swamp forest and woodland – dominated by *Melaleuca quinquinerva*
- Dry forest and woodland – dominated by *Eucalyptus* sp.
- Foredune complex
- Dry sclerophyll scrubland – dominated by *Acacia sophorae*, and
- Tussock grassland – dominated by *Spinifex sericeus.*

Eddie (DLWC, unpublished) identifies three main physiographic environments in the Saltwater Creek and lagoon catchment, namely bedrock hills, sandplains (including sand ridges, sandplains and sand swamps) and estuarine flats. A cross-section representing these environments and their relationship with vegetation communities is reproduced in Figure 5.3. Groundwater-dependent ecosystems have developed on the sandplains and the estuarine flats, where the highest quality and most accessible groundwater is found. Water tables in the sandplain regions would respond rapidly to groundwater extraction with significant ecotone shifts resulting (Eddie, DLWC unpublished). In the estuarine flat regions very low substrate permeability means that the effects of water table lowering are usually localised. Vegetation communities form complex mosaics depending on depth of water table, frequency and duration of inundation, and groundwater and surface water salinity. Fire regimes are also important controls (Eddie, DLWC unpublished).

5.1.3 Fauna

Wading birds feed and roost on many intertidal flats and marshes and many migrating birds have been recorded on the beach extending north of the Macleay River entrance. Common species include the whimbrel, grey-tailed tattler, masked lapwing, greenshank, bar-tailed godwit, whit-headed stilt and sandpipers. Many other wader species inhabit the area but have not been studied in detail (SPCC 1986).

The area around Saltwater Creek and lagoon provides feeding and roosting areas for many birds other than waders. The most important species are the crested tern, little tern, silver gull, white-breasted sea eagle, pelican, chestnut teal, darter mangrove warbler, mangrove honeyeater, gull-billed tern, azure kingfisher, mangrove bittern and four species of cormorant. The white–fronted chat also reaches the northern limit of its New South Wales distribution at the Macleay estuary (Morris et al. 1984).

No additional existing information was available on the estuarine fauna of the creek or lagoon.

5.1.4 Catchment Flora and Fauna

An indication of the flora and fauna in the catchment of Saltwater Creek was obtained through a search of the Wildlife Atlas of the National Parks and Wildlife Service. It should be noted, however, that these lists are indicative only and cannot be considered comprehensive. The searches cover an area within approximately 20 km of South West Rocks. The results of these searches are presented in Tables B.1 and B.2 in Appendix B.

5.1.5 Rare or Endangered Species and Communities in Saltwater Creek

The NSW *Threatened Species Conservation Act 1995* (TSC Act) is aimed at protecting animals and plants considered vulnerable and endangered from human activities. The legislation provides for the listing of threatened species, populations and ecological communities and has replaced the endangered fauna list known as Schedule 12 of the *National Parks and Wildlife Act 1974*. 'Threatened' species are now listed in Schedules 1 and 2, endangered and vulnerable species respectively. New Commonwealth legislation, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) also lists threatened species. Threatened species identified under each of these pieces of legislation within approximately 20 km of Saltwater Creek are highlighted in Tables B.1, B.2 and B.3 in Appendix B.

Four species of endangered fauna, one endangered plant, 29 species of vulnerable and three plant species identified under the TSC Act have been recorded within 20 km of Saltwater Creek. A search of the EPBC Act database found 10 endangered and 21 species of vulnerable flora and fauna. The search also detected a number of animals protected under other sections of the EPBC Act including 14 marine birds; six marine species; seven terrestrial species and six wetland bird species covered by the migratory provisions of the Act; and 24 birds; 19 fish and four reptiles covered by the marine provisions of the Act.

The *Fisheries Management Act 1994* protects fish species listed as endangered or vulnerable. None of the species on this list is likely to be found in Saltwater Creek or lagoon. The Fisheries Management Act also provides protection for estuarine habitats including seagrass and mangroves, both of which occur within Saltwater Creek (Section 5.2).

5.2 Field Investigations

5.2.1 Introduction

Staff from The Ecology Lab visited the creek on 4 April 2001 for a general site inspection. Photographs were taken of the dominant habitats and of any evidence of degradation (e.g erosion, dead mangroves etc). The habitat type and dominant vegetation were recorded at each of four sites along the creek and near the entrance to the lagoon, and the presence of fauna was recorded. A seine net was used to sample fish near the mouth of the creek. The purpose of the seining was to understand better connectivity between the creek and the ocean, as suggested by the species present. Note that the site inspection and field sampling were extremely limited by difficult access to the creek and lagoon and by the resources available to do the project. Moreover, at the time of the visit, water clarity was extremely poor due to recent rain, hence it was not possible to observe creek-bed habitats, such as seagrasses, that might have been present.

5.2.2 Site 1 Creek Entrance

The entrance to the creek is shallow and sandy with a rock shelf at the mouth. An artificial rock wall extends along the western bank. Upstream of the footbridge, a mixture of riparian vegetation lines the western bank, including large paperbarks (*Melaleuca* sp.), small patches of reeds (*Phragmites australis*), coral trees, occasional banksias (*Banksia* sp.) and strangler figs. Exotic species observed include lantana (*Lantana camara*) and morning glory. On the eastern bank, the beach near the entrance is approximately 2–4 m wide with a bar near the surf club. This beach narrows upstream towards the footbridge. Vegetation on the eastern bank above the footbridge included a variety of grasses, acacias (*Acacia* sp.), banksia and some bitou bush (*Chrysanthemoides monilifera* ssp *rotundata*). Further upstream, there are paperbarks, some lantana and rushes (*Juncus* sp.).

During community consultation, one of the residents advised that there had been seagrasses in the creek upstream of the first footbridge (see reported zone in Figure 5.2). The resident also suggested that these seagrasses had declined in recent years. We were not able to observe any seagrasses during the site visit to Saltwater Creek, but this was not surprising given the limited access available and poor water clarity at the time.

During the site inspection, a little black cormorant (*Phalacrocorax sulcirostris*), a white-faced heron (*Egretta novaehollandiae*) and a little pied cormorant (*Phalacrocorax melanoleucos*) were sighted along with many silver gulls (*Larus novaehollandiae*). Fish observed included snub-nosed garfish (juv.), mullet (juv.), gobies, whiting (juv.) and crescent perch (*Terapon jarbua*). Towards the entrance, there were many small invertebrate burrows evident on the fine sediments of the bottom of the creek. No seagrass was present near the mouth of the creek. However, it was not possible to determine whether seagrasses were present in the creek due to the brown staining of the water. According to a local resident, seagrasses do occur in the lower portion of the creek but the total area has declined in recent years.

A 25 m seine net was used to sample juvenile and sub-adult fish at this site. The net was set in a U-shape and then hauled up on to the shoreline. For each of three hauls, fish were identified, counted and released and the caudal fork length (LCF, mm) of economically important species was measured. Results of the beach seines are presented in Table B.4 in Appendix B. A total of 150 fish from 15 different species were caught, five of which are economically important. All the fish collected are common estuarine species, apart from some unidentified fish larvae that were probably mullet (Table B4). At least three of the species, including yellowfin bream, tarwhine and sand whiting, spawn in coastal waters (SPCC 1982a), indicating an ecological link with the adjacent coastline. Five of the fish collected had red spot disease, although it is difficult to interpret the significance of this from the limited sampling done (see below).

5.2.3 Site 2 Second Footbridge

The eastern bank of this site was lined with reeds (*Phragmites australis*) and rushes (*Juncus* sp.) and backed by a paperbark forest. The western bank had many paperbarks and swamp she-oaks (*Casuarina glauca*) overhanging the creek. No fish or waterbirds were visible.

5.2.4 Site 3 Road bridge (Phillips Drive)

Phillips Drive crosses Saltwater Creek near the entrance to the caravan park. The creek narrows upstream and there was a visible flow in the stream (approximately 50 mm of rain on the previous day). The edge of the creek was lined with paperbarks and swamp she-oaks standing over reeds (*Phragmites australis*) and rushes (*Juncus* sp.). A number of fish were seen in the creek including mosquito fish (*Gambusia holbrookii*), a small unidentified shrimp and many larval fish which could not be identified (possibly mullet or galaxids).

5.2.5 Site 4 Entrance to Saltwater Lagoon (near Caravan Park)

The small embayment on the north-western edge of the lagoon was surrounded by a range of wetland vegetation including small mangroves (*Avicennia marina* and *Aegiceras corniculatum*), reeds (*Phragmites australis),* paperbarks and swamp she-oaks. Large black cormorants and unidentified ducks were seen on the lagoon. A filamentous algae coated with mud floated on the water surface of the lagoon. Many juvenile mullet could be seen in the shallows, some of which had their heads out of the water. The presence of algae and the mullet behaviour could indicate eutrophic conditions with low levels of dissolved oxygen in the water, however, without more information (e.g. concentrations of nutrients and oxygen) we cannot be confident of the cause or significance of these observations.

5.3 Conceptual Models of Ecological Processes

To illustrate the ecological processes operating within Saltwater Creek, three conceptual models have been developed and are presented in Figures 5.4–5.6. These models are based on the graphical interpretation of very limited existing information on the system as well as background knowledge of similar systems. The sections below provide a brief explanation of each of the models to aid understanding of the processes that have been illustrated.

Figure 5.4 illustrates some of the important physical and biotic characteristics of the creek and their relationships to ecological processes. It is not possible to map the distribution of aquatic habitats as there is no information available. According to local residents, seagrasses occur in the lower portions of Saltwater Creek, but there has been some decline in recent years. Also included on the model is a list of the data gaps that are considered to be of major importance to ecological processes within Saltwater Creek and lagoon.

Figures 5.5 and 5.6 illustrate the processes of spawning, recruitment and dispersal which would be expected to operate in the creek and lagoon during open and closed entrance conditions. In general, seasonal effects are not likely to be very strong and the influences of entrance condition and flooding are likely to be the major natural structuring processes. There are three exceptions to this. First, many fish species and some invertebrates typically recruit to estuarine habitats in the period from late winter to early summer (SPCC 1981b). Thus, if the entrance were open during spring there may be a large recruitment at that time. Conversely, if it is closed at that time, diversity and abundance of fish through summer may be relatively small in Saltwater Creek.

Second, the NSW coast is often subject to a large influx of nutrients from upwelling events in spring and summer. Hence, if Saltwater Creek is open during an upwelling and at a time of spring tides, there may be an influx of nutrients and/or phytoplankton into the creek. The effect of this on the ecology of the creek is unknown.

The third exception is that pre-spawning fish often make their way out of estuaries in autumn and late winter. A good example of this is sea mullet, which migrate out of estuaries and northward from autumn into winter. If the creek entrance is open at such times, fish will be able to move out of the creek, but if it is closed they become trapped.

Thus, the timing of various estuary conditions can have a large effect on the biodiversity and abundance of fauna in Saltwater Creek. Moreover, several major processes can interact (e.g. estuary condition, recruitment) to affect the ecology of Saltwater Creek.

Most of the information presented in these two models is drawn from studies done in other estuaries and intermittently closed coastal lagoons in NSW (e.g. SPCC 1981a,b, Allan et al. 1985, Bell et al. 1988, Bell and Pollard 1989, Lincoln Smith 1991, 1998, Pollard 1994a, b, The Ecology Lab 1993, 1995, 1998a,b,c, Griffiths 1998, 1999). Although it is expected that some of the key processes occurring in these other places are relevant to Saltwater Creek and lagoon, data are not currently available to confirm this. Comparison of the two models highlights the importance of entrance conditions to the distributions, densities and age structure of fish populations within the lagoon. It should be noted, however, that these two models represent extreme conditions of prolonged opening or closure and the actual situation at any time would be expected to fall somewhere between the two.

5.4 Estuarine Processes and Ecological Health

As outlined in the sections above, there is very little data available on the aquatic ecology of Saltwater Creek. In particular there is a lack of replicated spatial and temporal information to determine the variability of the system. This limits our ability to accurately define the processes operating within the creek and restricts the potential to adequately model these processes. As a working hypothesis, ecological processes in Saltwater Creek are fundamentally similar to those in other estuaries operating as ICOLLS along the NSW coast. The system, however, has features that make some of these processes of particular importance to the community and the managers responsible. Clearly the most important feature is the intermittent nature of the creek entrance, which has important implications for water quality and the ecological processes mediated by water flow such as the recruitment and migration of fishes and invertebrates. In addition, the presence of the long, narrow creek leading to a shallow lagoon suggests that the system may be poorly flushed.

The background conditions of Saltwater Creek are those of a small coastal creek with inputs of fresh water, nutrients and sediments and an intermittently open entrance. These conditions favour the presence of certain habitats and the growth of particular species of macrophytes and macroalgae. Human-induced changes to these conditions (mechanical entrance opening and foreshore development) are likely to result in changes to the distribution and dominance of species. Determining the relative contributions to temporal variability in the system attributable to natural and human-induced causes is difficult. Thus, although it is clear that catchment development and anthropogenic uses of the catchment and the creek itself have altered the inputs to the creek, it is not possible to determine the extent of the changes.

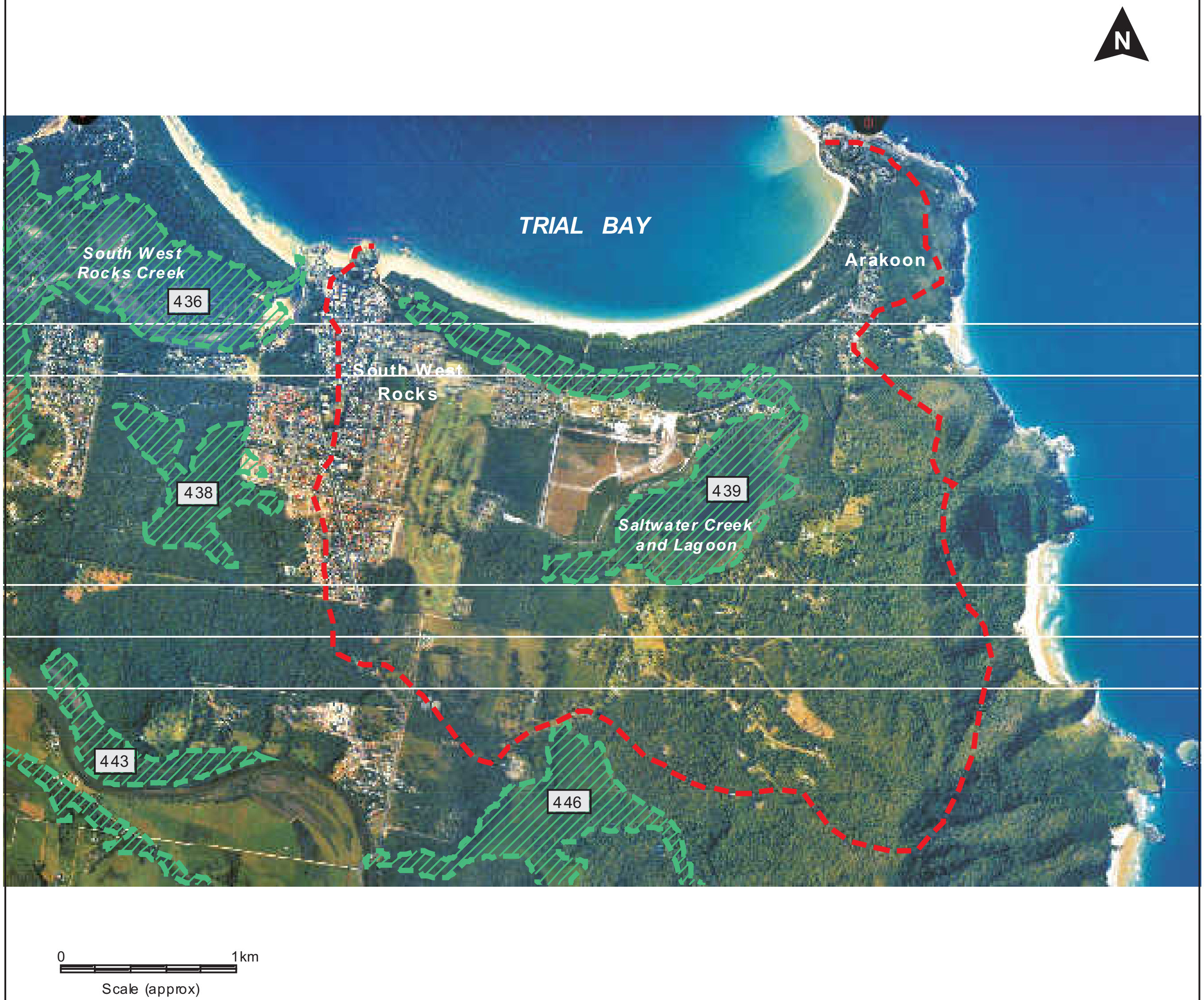
It is difficult to assess the status of the faunal assemblages of the creek, due to a limited amount of information. Data on spatial and temporal patterns of abundance and distribution of most faunal groups are lacking, and further work is required to provide an adequate description of baseline conditions from which to identify principal factors that influence these components. Factors that are likely to have a negative impact on the biotic health of the lagoon and creek system include deoxygenation due to changing water levels and poor circulation and/or flushing, acid sulphate soil pollution and other anthropogenic pollutants such as oil and nutrients.

Drying effects within wetlands (including sedgelands) could obviously affect aquatic flora and fauna living there, by reducing available aquatic habitats, isolating populations within pools or providing an advantage to certain species. For example, mosquito larvae and/or mosquito fish (*Gambusia holbrooki*) often survive well in small, isolated pools. If water levels increase (for example due to extended closure of the creek), the sedgelands might encroach into the lowlands between the lagoon and the creek (Figure 5.3). In addition, there may be some colonisation of shallow inundated areas by mangroves, but this would also be influenced by salinity.

The potential effects of acid sulfate soils can also be altered by changes in water levels, particularly removal of surface water or changes in the depth of groundwater. This can be exacerbated by small to medium floods, which can flush acid into waterways causing fish kills and other problems. Other than outlining general effects, it is important to recognise that more detailed information is necessary to better understand these processes, or to predict when environmentally damaging events may occur.

In terms of aquatic ecology, this study indicates that Saltwater Creek does not support large areas of seagrasses and mangroves, which are common in South West Rocks Creek and the Macleay River. Given the morphology of the system – a narrow, intermittently open entrance, a long creek and large shallow lagoon – it is likely to be relatively sensitive to environmental disturbance and it would often have little or no flushing. Furthermore, given the limited resources available for the study, it is not possible to provide a confident assessment of the current health of the system. We did note the following, however. First, there was some evidence of growth of algae in the lagoon, possibly indicating nutrient enrichment. Second, mullet 'gulping' may indicate low levels of dissolved oxygen. Third, red spot disease observed in some fish also may indicate water quality problems. These observations suggest that further investigation would be useful to assess the environmental condition of the system.

The natural patterns and processes occurring within Saltwater Creek are likely to interact strongly with human activities which, in turn, would probably have altered these natural processes. Without data from prior to development within the catchment, we can generally only speculate on the effects of these interactions. Some of these are discussed in Section 6 of this report.



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SALTWATER CREEK AND SURROUNDS SHOWING SEPP 14 WETLANDS

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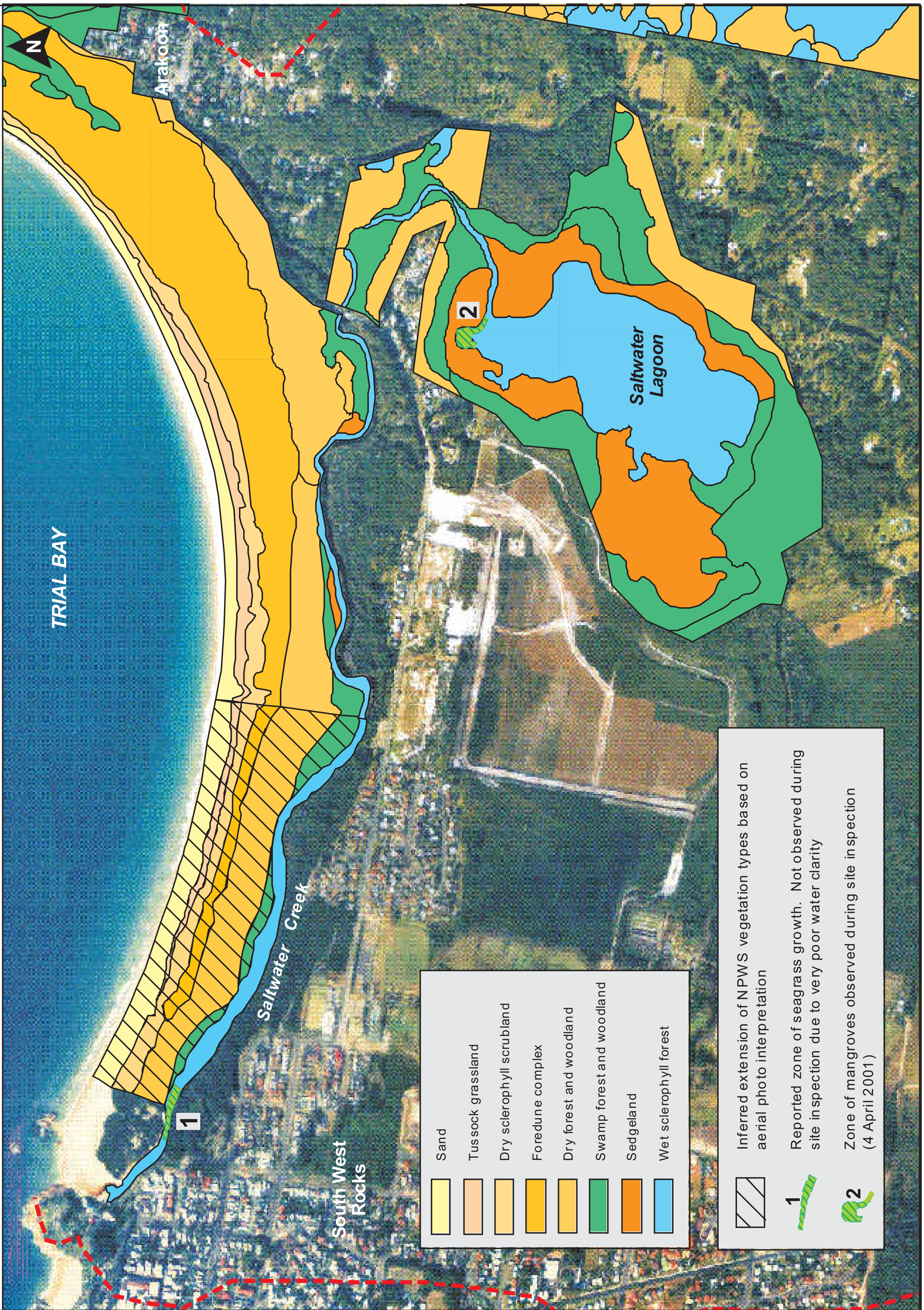
Figure 5.1

DRAWING 1126-05-01.CDR



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SALTWATER CREEK VEGETATION COMMUNITIES AS MAPPED BY NPWS

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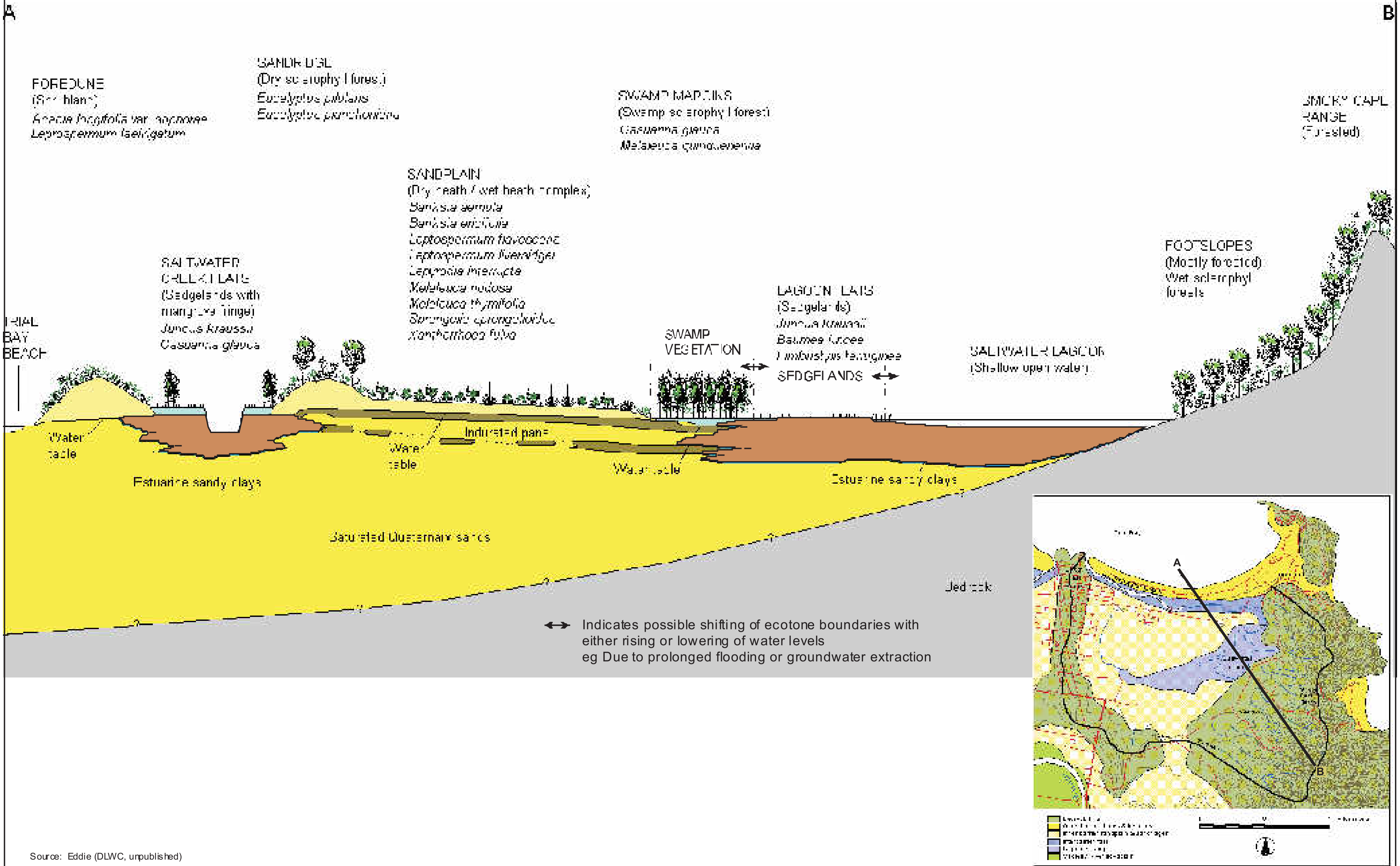
Figure 5.2

DRAWING 1126-05-02.CDR



Source: Eddie (DLWC, unpublished)

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SCHEMATIC CROSS SECTION OF
SALTWATER CREEK CATCHMENT

MHL
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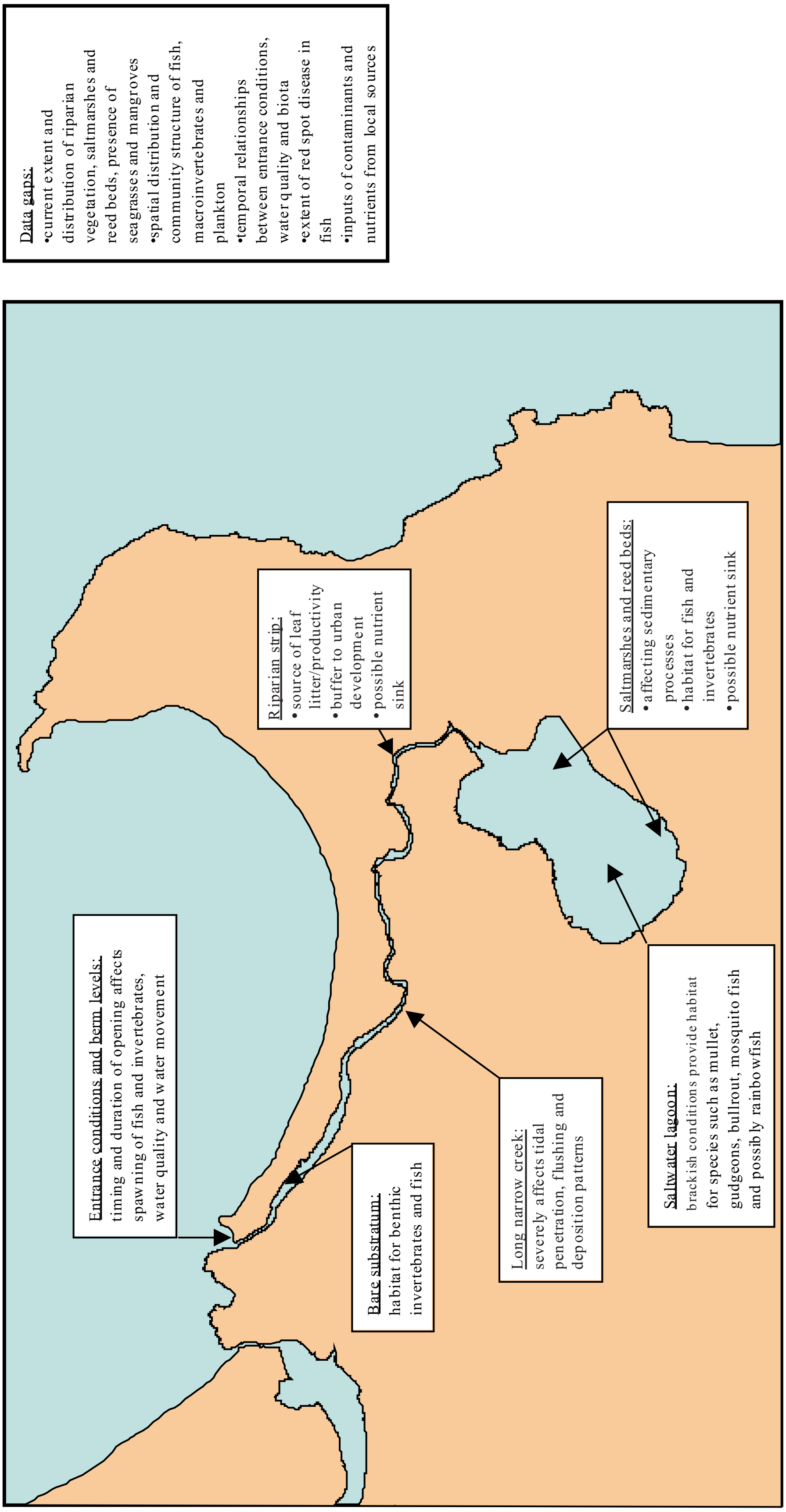
Figure
5.3



Source: Produced by The Ecology Lab Pty Ltd - Maritime and Freshwater Studies

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OVERVIEW OF THE PROCESSES OPERATING IN SALTWATER CREEK WITH EMPHASIS ON DATA GAPS

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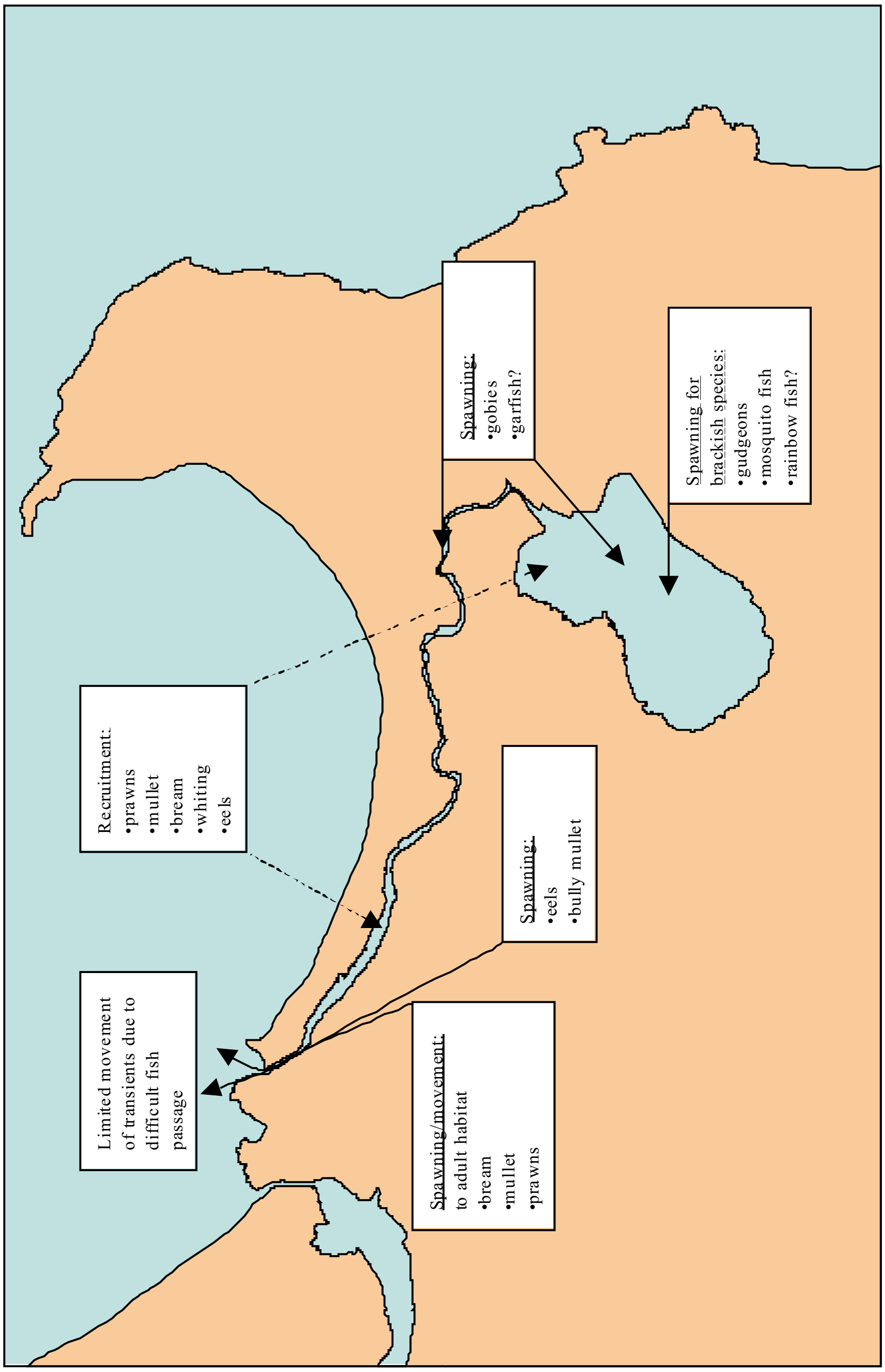
Figure 5.4

DRAWING 1126-05-04.CDR



Source: Produced by The Ecology Lab Pty Ltd - Maritime and Freshwater Studies

BASED ON INFORMATION FROM OTHER NSW ESTUARIES

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EXPECTED PATTERNS OF SPAWNING OF FISH IN SALTWATER CREEK DURING OPEN ENTRANCE CONDITIONS

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Figure 5.5

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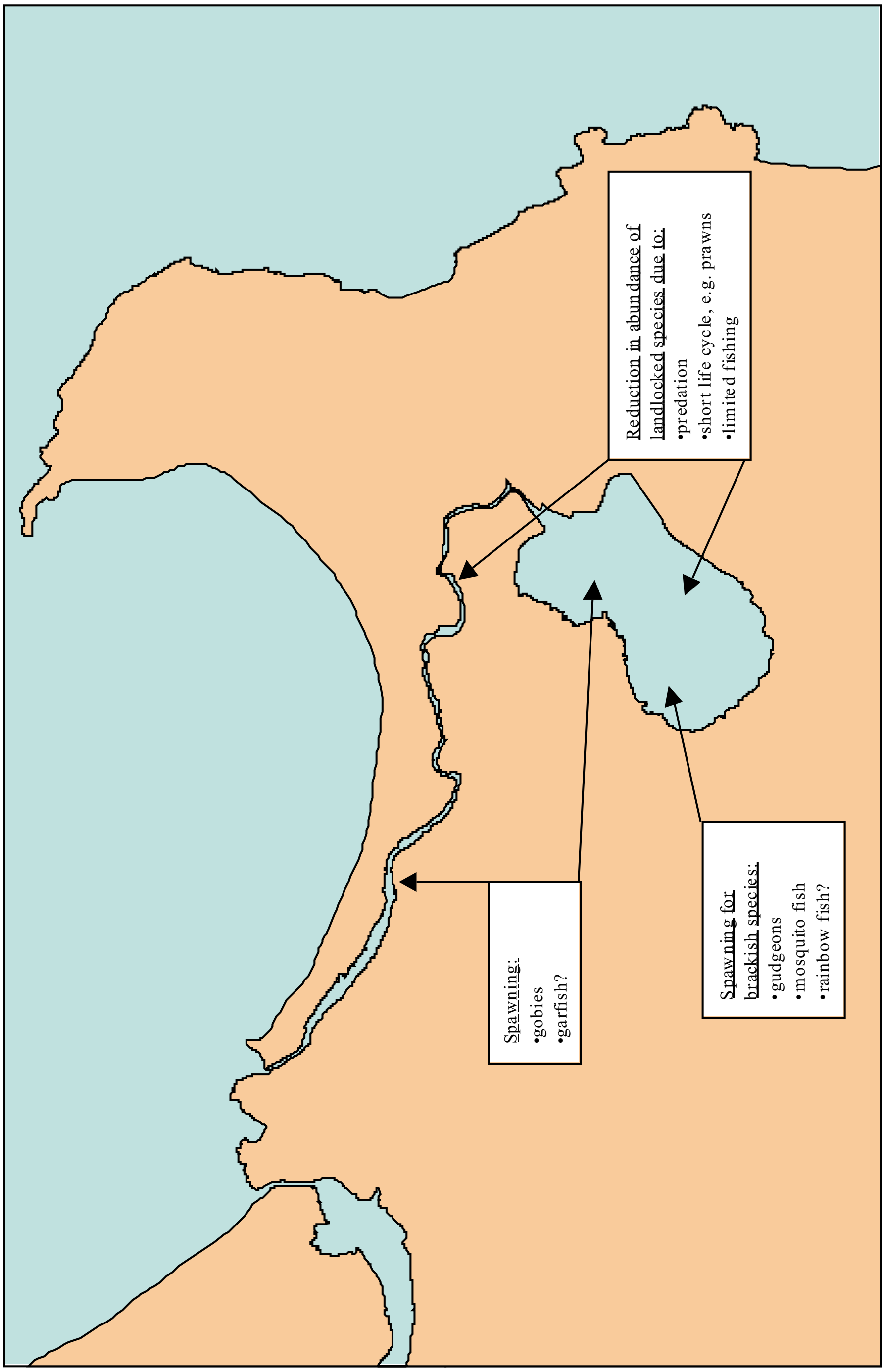

Source: Produced by The Ecology Lab Pty Ltd - Maritime and Freshwater Studies

BASED ON INFORMATION FROM OTHER NSW ESTUARIES

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EXPECTED PATTERNS OF SPAWNING OF FISH IN SALTWATER CREEK DURING CLOSED ENTRANCE CONDITIONS

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Figure 5.6

DRAWING 1126-05-06.CDR