SALTWATER CREEK
ESTUARY PROCESSES STUDY

Report No. MHL1126

NSW Department of Public Works and Services
Manly Hydraulics Laboratory

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Foreword

Kempsey Shire Council commissioned the NSW Department of Public Works and Services' Manly Hydraulics Laboratory (MHL) in association with The Ecology Lab Pty Ltd (TEL) to undertake an Estuary Processes Study of Saltwater Creek/Lagoon at South West Rocks. The first stage of the study involved the development of conceptual models, a list of references to be used in the processes study and the identification of issues of importance to the community. The development of conceptual models for Saltwater Creek and lagoon involved the review of available information and comparison with processes operating in similar systems.

The second stage of the study involved a review of collated literature and specific research culminating in this report, 'Saltwater Creek Estuary Processes Study'.

Executive Summary

This estuary processes study has been prepared on behalf of Kempsey Shire Council and the local community as part of the Estuary Management Process. The New South Wales Estuary Management Policy was developed to encourage the integrated, balanced, responsible and ecologically sustainable use of the State's estuaries. The policy is designed to reflect and promote cooperation between the State Government, local government, catchment management committees, landholders and estuary users in the development and implementation of estuary management plans for each estuary. Information presented in this report, along with further information gained from recommended studies, will provide the understanding of the Saltwater Creek estuary that is required to develop an estuary management plan.

The NSW Estuary Management Policy described above is one of a range of policies, programs and standards that are guided by the NSW Coastal Policy 1997, which aims to coordinate coastal zone planning and management within the State. The Coastal Policy is based on the principles of ecologically sustainable development and advocates that these principles be used to guide decision-making in all areas and activities affecting the NSW coast. Further legislation to be considered in the planning and management of coastal and estuarine areas is the recently gazetted State Environmental Planning Policy No. 71 - Coastal Protection. SEPP 71 has been made under the *Environmental Planning and Assessment Act 1979* to ensure that development in the NSW coastal zone is appropriate and suitably located, to ensure that there is a consistent and strategic approach to coastal planning and management and to ensure there is a clear development assessment framework for the coastal zone.

Waterway Characteristics

Saltwater Creek is an intermittently open and closed creek/lagoon that enters the ocean on the western side of Trial Bay at South West Rocks. The creek is approximately 3.2 km long culminating in Saltwater Lagoon with a waterway area of approximately 0.4 km^2. The system is very shallow, with bed levels in the creek down to -0.7 m AHD and in the broad flat lagoon the lowest height of the bed is only 0.3 m AHD. The creek is tidal while open to the ocean but while closed it is non-tidal and the water level fluctuates in response to rainfall/runoff, groundwater flows and evapotranspiration. The entrance morphology is affected by littoral transport within the Trial Bay beach system and the berm that often blocks the entrance is artificially breached to alleviate flooding around the lagoon.

Catchment Characteristics

Saltwater Creek is a discreet watershed within the coastal fringe, but is generally referred to as part of the Macleay River catchment which occupies 11,385 km^2. Saltwater Creek is fed by a number of small tributaries that drain the steep catchments of Smoky Cape to the east and south-east, the urban areas to the west and low-lying rural and wetland areas to the south. The catchment area is 8.7 km^2 and vegetation cover is predominantly comprised of *Melaleuca* swamp forest, dry *Eucalyptus* forest, *Acacia* scrub, sedgeland and *Spinifex* tussock grassland.

The wetland area surrounding the lagoon is protected under State Environmental Planning Policy No. 14 Coastal Wetlands. Hat Head National Park and Arakoon State Recreation Area border the creek and lagoon to the east. Urban and semi-rural developments exist in most areas not protected by National Parks and Wildlife Service zoning, along with Trial Bay caravan park (formerly Lagoon View caravan park) and golf course.

Climate

The prevailing climate of Saltwater Creek estuary is warm and temperate with a maritime influence. At South West Rocks, near the entrance to Saltwater Creek, mean daily maximum temperatures range from 18.5ºC in July to 26.7ºC in January and February. Mean annual rainfall at Smoky Cape is 1,500 mm, with the driest months being July to November and the wettest months January to April. The Southern Oscillation Index indicates that the period 1998 to 2001 was wetter than average years. Wind directions show a strong seasonal pattern, with summer winds predominantly onshore from the north-east whereas during autumn and winter light winds from the west and south-west prevail. Evaporation is typical of temperate climate areas, with high values in summer and lower values in winter. During the drier months evaporation exceeds rainfall.

Geology and Soils

The geology and soils of the area show a range of influences associated with different geological development periods. Saltwater Creek is a small coastal interbarrier stream located between the Holocene (11,000 years ago to present) outer-barrier of Trial Bay and a Pleistocene (11,000 to 1.8 million years ago (mya)) inner-barrier, within a coastal Quaternary (1.8 mya to present) sandplain landscape. The creek has been deflected northwards by the prevailing northerly longshore littoral drift associated with coastal currents in Trial Bay. The creek area has been mapped as the Macleay Arm (ma) estuarine soil landscape, which consists of level narrow meander flats with elevation below 1 m. Small tidal channels and swales occasionally traverse the rear of the flats and there is tidal connection with Saltwater Lagoon, a shallow sandy lagoon. The Saltwater Creek catchment is bounded by rolling to steep hills of Triassic (208 to 245 mya) granites and Permian (245 to 286 mya) sediments and metasediments to the east and south (Smoky Cape), and undulating granite rises to the west (South West Rocks). A small gap between the hills in the south is occupied by a Pleistocene transgressive sand dune which probably over-lies bedrock. A large flat inner-barrier swampy sandplain occupies the centre of the catchment. The Smoky Cape range contributes the majority of runoff, but there is no direct runoff to either Saltwater Creek or Saltwater Lagoon due to the permeable sandy soils of the sandplain; these water bodies are fed by an extensive sand aquifer. This aquifer probably extends seaward under the beach.

Soils

The Saltwater Creek and lagoon catchment can be divided into three soil categories; sandy, swampy and bedrock soils. The sandy soils to the north and immediately south of Saltwater Creek, and to the south of Saltwater Lagoon, are well drained with no surface run-on due to highly permeability. Swampy soils to the west and south-west of Saltwater Lagoon are poorly drained to a shallow water table, below which acid sulphate soil conditions occur. The steep bedrock soils of Smoky Cape to the east and south-east of Saltwater Lagoon have high erosion hazard with high runoff, but large amounts of suspended sediments would not be expected to reach Saltwater Creek due to interception by sands.

Land Use

The region is a popular recreational destination for a range of outdoor activities including swimming, camping, boating and fishing. Recent changes in land use patterns and the increased pressure on the estuarine environment due to a range of human influences have resulted in a perceived deterioration of the water quality in Saltwater Creek. Land use in the catchment is 13.5% urban, 36.1% grazing/cultivation and grazing only, 10.7% timber, and 39.7% cliffs, lakes and swamp areas. Urban development has increased rapidly over the last 30 years, with accelerated growth over the past few years.

Nutrient Loads and Stormwater

Nutrient loads from catchment runoff have been estimated using nutrient generation rates from the Hawkesbury-Nepean Basin. These first-order estimates show a total catchment nitrogen load of 5,300 kg/yr and phosphorus load of 1,000 kg/yr. It is estimated that approximately 15% of that load, or 795 kg/yr nitrogen and 150 kg/yr phosphorus, is delivered to the creek and lagoon as stormwater point sources. A stormwater management plan is in preparation by Kempsey Shire Council and identifies three management areas in the Saltwater Creek catchment. The plan outlines potential issues, threats and pressures as well as strategies to prevent and mitigate detrimental impacts on the creek and lagoon system. With development pressures increasing it is critical that Council and developers make a cooperative effort to manage stormwater to prevent impacts on the discreet and sensitive estuarine system.

Flooding

Flooding is an issue of concern for the community, as the intermittent closure of the creek entrance can result in significant increases in water level after heavy rain in the catchment. The Lower Macleay Floodplain Management Strategy presents a 1-in-100-year flood level around South West Rocks of 2.30 m AHD. A flood study by Mounser in 1981, conducted for a proposed residential development, predicted peak 1-in-100-year flood heights for Saltwater Creek ranging from 2.25 m AHD at the ocean to 2.85 m in Saltwater Lagoon. Mounser's calculations assumed a maximum height of the entrance berm of 1.45 m AHD, but recent survey data indicates that under closed entrance conditions the berm reaches heights of at least 1.6 to 1.8 m. The role of the berm in flooding may thus be underestimated in Mounser's report, and it is recommended that a comprehensive flood study be undertaken that considers the whole Saltwater Creek and lagoon catchment and takes into account a range of berm conditions, entrance management strategies, stormwater inputs and flood flows.

Tides and Flushing

An assessment of the hydrodynamics of the estuary estimated that while the entrance is open the tidal prism for the whole system is approximately 24,970 m^3 and the total system volume at 0.7 m AHD is 142,490 m^3, or approximately six times the tidal prism. Average tidal flow velocity is estimated at 6 cm/s in the creek and 0.2 cm/s in the lagoon, and tidal excursion is 1,300 m in the creek and 60 m in the lagoon. With more than half of the tidal prism being captured in the creek and the average tidal velocity relatively low, the flushing efficiency is likely to be less than 10%, indicating an estimated flushing time of at least 30 days while the entrance is open. This flushing time is greatly affected by the entrance conditions that significantly influence water quality and ecosystem dynamics in the estuary.

Water Balance

Water levels in the creek and lagoon are affected by tidal conditions (when the entrance is open), freshwater inflows, both overland and via groundwater, and evaporation. Estimates of average monthly discharge entering the estuary from the catchment indicate a range from 100 ML in September to 341 ML in March, with an average annual freshwater inflow volume of 2,616 ML. When the entrance is closed increases in water level related to high freshwater inflow events can result in overtopping and scouring of the entrance berm and represent a natural reversion to open entrance conditions. Estimates of groundwater flow to and from the lagoon and creek indicate an inflow of 1,135 ML/year and an outflow in the dune area near the creek entrance (when closed) of 182.5 ML/year. Evaporative losses from the surface of the creek and lagoon can account for up to 87% of catchment runoff in the drier spring months and on an annual basis 39% of catchment runoff is estimated to be lost to evaporation.

Circulation and Flushing

Circulation and flushing within the estuary is strongly influenced by entrance conditions. Saline, dense water from the ocean sinks to the deeper areas of the creek while fresh water from catchment runoff floats on the top, forming distinct layers known as stratification. When the entrance is open tidal action mixes the fresh and saline water forming a brackish mixture. A lack of tidal flushing under closed conditions allows distinct horizontal stratification to form. Circulation and flushing mechanisms play a role in processes affecting water quality, for example algal blooms can occur with limited flushing as phytoplankton requires reasonably stable conditions to build large populations.

Water Quality

The community is concerned about water quality in the estuary due to increasing development in the catchment. Water quality data provided by Kempsey Shire Council indicate that there may be concerns regarding low levels of dissolved oxygen and high levels of chlorophyll-a, nitrogen and phosphorus in the creek and lagoon when compared to ANZECC guidelines. It is strongly recommended that a regular water quality monitoring programme be established that will provide baseline data on the water quality of the system and facilitate understanding of the relationships between salinity and chlorophyll-a, and entrance conditions and water levels.

Nutrient Budget

A nutrient budget for the Saltwater Creek and lagoon system indicates that even under open entrance conditions with tidal flushing to the ocean, around 95% of nutrients are retained and cycled within the system. With closed conditions the rate of retention and cycling is 100%, with cycling processes including uptake by plants and algae, denitrification, and burial in the sediments. With such high proportions of nutrients remaining in the system, the importance of reducing nutrient loads to the creek and lagoon cannot be understated.

Acid Sulphate Soils

Acid sulphate soil (ASS) risk is high in the low-lying areas adjacent the creek and lagoon. Disturbance of soils or vegetation cover in these high risk areas should be avoided or strictly managed to prevent acid generation and possible environmental impacts. Changes to the entrance 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 possible that more regular opening of the entrance may lead to a lower water table and possible exposure of ASS.

Water Quality and Biota

Water quality is a critical issue for the management of aquatic ecosystems. While there is no evidence in the available literature of poor water quality having detrimental impacts on the biota of Saltwater Creek, there have not been many studies aimed at establishing the link between water quality and biota in the system. A number of observations during a field inspection, including juvenile mullets with their heads out of the water and fine algae on the sediments and on the surface of the lagoon, indicate that water quality may be affecting the ecosystem.

Flora

The majority of Saltwater Creek and lagoon area has been designated as SEPP 14 Coastal Wetland No. 439, and there are several other SEPP 14 wetlands in the surrounding area. This designation provides the estuary with a level of protection from development in the immediate vicinity. National Parks and Wildlife Service mapping shows that the dominant vegetation types surrounding 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*. The composition of vegetation communities is influenced by soil types and their linkages to the groundwater system, the depth of the water table, frequency and duration of inundation, surface water salinity and fire regimes.

Fauna

There is little existing information on the fauna of Saltwater Creek and lagoon. Studies of the surrounding region suggest that the area may be of importance for wading birds, such as the whimbrel, grey-tailed tattler, masked lapwing, greenshank, bar-tailed godwit, whit-headed stilt and sandpiper. Other non-wading birds that feed and roost in the area include 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. Seine netting in the creek during a field inspection netted a total of 150 fish from 15 different species, with five of those species being of economic importance. All of the fish collected were common estuarine species, with at least three of the species, including yellowfin bream, tarwhine and sand whiting, known to spawn in coastal waters, indicating an ecological link with the adjacent coastline.

Entrance Impacts on Ecosystem

Conceptual models of ecological processes, primarily based on studies done in other estuaries and intermittently closed coastal lagoons in NSW, indicate the importance of the entrance conditions to the processes of spawning, recruitment and dispersal of biota. Seasonal processes influencing the ecosystem that are potentially affected by the entrance conditions include the recruitment of fish and invertebrate species from late winter to early summer, the influx of nutrients from ocean upwelling events in spring and summer, and the movement of pre-spawning fish out of the estuary in autumn and late winter. There is currently insufficient data from the Saltwater Creek and lagoon system to confirm the extent that these key processes and entrance conditions may interact to influence the ecology of the estuary.

Ecosystem Health

The lack of existing ecological data relating to Saltwater Creek and lagoon makes it difficult to comment on the ecological health of the system. However, knowledge of similar systems and the background conditions of Saltwater Creek indicate that human-induced changes, such as mechanical entrance opening, foreshore development, and increased nutrient loads, are likely to result in changes to the distribution and dominance of species in the system. The morphology of the system – a narrow, intermittently open entrance, a long creek and large shallow lagoon – indicate that it is likely to be relatively sensitive to environmental disturbance, and it is recommended that further detailed studies be undertaken to assess the ecological condition of the system.

Conclusions and Recommendations

It is clear from the above discussion that conditions at the entrance of Saltwater Creek, i.e. whether the creek is open to the ocean or closed and the height of the berm if closed, influence a number of important processes operating within the estuarine system. These interacting processes include circulation and flushing, water quality, water levels and flooding, and ecological processes such as recruitment, migration and dispersal of species. A number of important decisions and strategies regarding the management of the estuary thus require knowledge of the effects of varying berm heights and entrance conditions, which will require well-planned, detailed and in some cases long-term studies.

Some recommended studies include:

- *Mapping* – detailed surveying of the entrance berm at regular intervals and immediately after breakout events and installation of a permanent water level gauge in Saltwater Lagoon.
- *Flooding* – a definitive flood risk assessment, including a detailed flood study with a range of flood risk scenarios and entrance berm heights.
- *Biota* – detailed surveys of flora/fauna communities both in main drains into the creek and the foreshores of the creek and lagoon, which combined with good quality entrance survey information and water quality data will help determine the impact of the hydrological regime and catchment inflows on biota.
- *Water quality* – installation of a water quality monitoring device capable of measuring chlorophyll-a and salinity, which in combination with the survey task described above will enhance understanding of the effects of changing entrance conditions and water levels on water quality.

Summary Statistics

Saltwater Creek is located at the township of South West Rocks in the sub-tropical climate of the mid-north coast of NSW. Saltwater Creek estuary falls into the category of intermittently closed and open lakes and lagoons (ICOLLs).

Table S1 Characteristics of Saltwater Creek Estuary

Catchment area	8.7 km^2
Waterway area	0.4 km^2
Length of creek	3.2 km
Major tributaries to Saltwater Creek	small tributaries draining catchment of Smoky Cape
Mean air temperature	19C° (winter)–26C° (summer)
Mean annual rainfall	1,500 mm (Smoky Cape)
Catchment runoff into Saltwater Lagoon	2,616 ML/yr
Tidal prism	24,790 m^3

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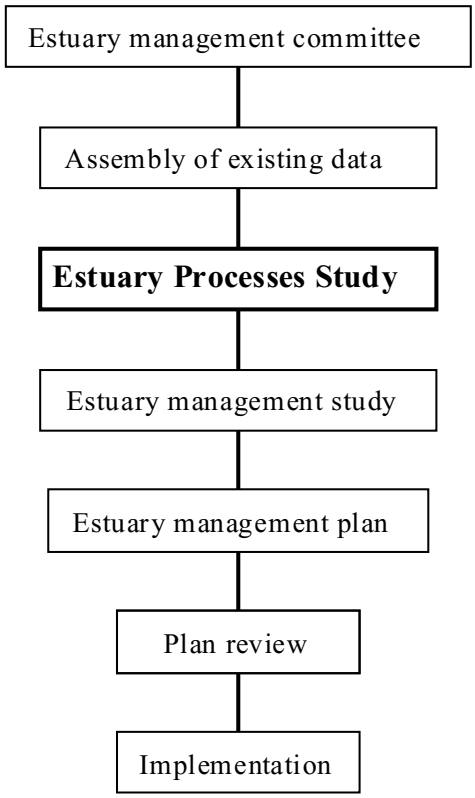
1. Introduction

1.1 Scope of Work

The Department of Public Works and Services' Manly Hydraulics Laboratory has been commissioned by Kempsey Shire Council to undertake an Estuary Processes Study for Saltwater Creek at South West Rocks. MHL has engaged The Ecology Lab Pty Ltd. as sub-consultants.

The consultants were engaged by Council to undertake an Estuary Processes Study as part of the Estuary Management Process. The New South Wales Estuary Management Policy was developed to encourage the integrated, balanced, responsible and ecologically sustainable use of the State's estuaries. The policy is designed to reflect and promote cooperation between the State Government, local government, catchment management committees, landholders and estuary users in the development and implementation of estuary management plans for each estuary.

To assist in the development of estuary management plans, an Estuary Management Manual (NSW Government 1992) was published to outline the processes of implementation. The estuary management process is outlined below.



The NSW Estuary Management Policy described above is one of a range of policies, programs and standards that are guided by the NSW Coastal Policy 1997, which aims to coordinate coastal zone planning and management within the State. The Coastal Policy is based on the principles of ecologically sustainable development and advocates that these principles be used to guide decision-making in all areas and activities affecting the NSW coast. Further legislation to be considered in the planning and management of coastal and estuarine areas is the recently gazetted State Environmental Planning Policy No. 71 - Coastal Protection. SEPP 71 has been made under the Environmental Planning and Assessment Act to ensure that development in the NSW coastal zone is appropriate and suitably located, to ensure that there is a consistent and strategic approach to coastal planning and management and to ensure there is a clear development assessment framework for the coastal zone.

The following program of works was outlined in MHL's proposal to Kempsey Shire Council:

- a site inspection of Saltwater Creek/Lagoon with the Saltwater Creek Working Group and the Coastal and Estuary Management Committee
- one day of field investigations at Saltwater Creek/Lagoon (to be supplemented with limited further field work)
- community meeting to present conceptual diagrams and identify issues of importance, attended by interested South West Rocks residents, visitors and invited guests
- production of a report on the issues of importance to the community and presenting the conceptual diagrams of Saltwater Creek derived from similar studies
- assembly of existing literature on Saltwater Creek and similar systems
- review of collated literature and specific research culminating in a report 'Saltwater Creek Estuary Processes Study'.

1.2 Data Compilation

A literature search of a number of reference databases has been undertaken including university libraries and databases, MHL's own library and reports, The Ecology Lab's library and report collection, and libraries at Kempsey Shire Council and Department of Land and Water Conservation (DLWC).

GIS map layers have been sourced from Kempsey Shire Council, DLWC and National Parks and Wildlife Service. The information has been collated and used as a base for the conceptual models. In addition DLWC has recently completed the first detailed bathymetric survey of the creek and their data will be available in the near future.

Conceptual models have been derived for Saltwater Creek/Lagoon based on information from previous studies both within Saltwater Creek and from similar systems and observations made during the site inspection. Conceptual models provide information on the processes operating in the creek and the interactions between these processes.

1.3 Community Consultation

An open meeting was held at the surf club in South West Rocks on 4 April 2001. The meeting aimed to inform the local community of our understanding of processes and seek input from the attendees on issues of importance to the local residents. The meeting was attended by about 30 residents who provided lively discussion on a range of issues summarised in Chapter 8.

Prior to the meeting, a letter requesting submissions of information on Saltwater Creek/ Lagoon was sent to 34 contacts from the Saltwater Creek Working Group and the Coastal and Estuary Management Committee, whose details were supplied by Council. In addition, eight local residents provided their contact details at the community meeting in order to make a submission and were sent the original letter and a questionnaire. The deadline for submissions was originally 6 April 2001 but was extended by two weeks to 20 April 2001, to allow for extra submissions to be received after the meeting. A sample letter, a questionnaire, a list of recipients and a list of people who made submissions are included in Appendix A.

2. Catchment Characteristics and Processes

2.1 Introduction to Saltwater Creek Estuary

Saltwater Creek is an intermittently open and closed creek/lagoon located near the mouth of the Macleay River at South West Rocks (see Figure 2.1). The creek is approximately 3.2 km long culminating in Saltwater Lagoon with a waterway area of approximately 0.4 km^2. The creek is tidal while open to the ocean but while closed it is non-tidal. Saltwater Creek estuary falls into the category of intermittently closed and open lakes and lagoons (ICOLLs). Figures 2.2a, 2.2b and 2.3 show three aerial photographs of the ICOLL taken in 1956, 1966 and 1997.

The dynamics of river entrances are a result of the interaction between fluvial, tidal and wave processes. In wave-dominated entrances the wave action may become so dominant that entrance closure occurs on an intermittent basis thus creating ICOLLs (Hanslow et al. 2000). Many ICOLLs in NSW are kept open artificially. Council generally mechanically opens Saltwater Creek between October and December when there is inundation risk or concern for public health. When Saltwater Creek entrance closes the community perceives a problem with water quality and high water levels.

Saltwater Creek is fed by a number of small tributaries that drain the steep catchments of Smoky Cape and those adjacent to the waterway. The catchment is 8.7 km^2 and is comprised of coastal complex, moist eucalyptus forest and disturbed forest woodland vegetation. Hat Head National Park and Arakoon State Recreation Area border the creek and lagoon to the east. Urban and semi-rural developments exist in most areas not protected by National Parks and Wildlife Service zoning along with Trial Bay caravan park (formerly Lagoon View caravan park) and golf course.

Saltwater Creek estuary is generally referred to as part of the Macleay River catchment which occupies 11,385 km^2 (Bucher and Saengar 1989) and is presented in Figure 2.4. Saltwater Creek is in fact a separate watershed within the coastal fringe. This study will refer to the Macleay River catchment where it is considered relevant to Saltwater Creek.

2.2 Climate

2.2.1 Introduction

Weather and climate variables are measured at a number of sites around Saltwater Creek and in the Macleay catchment by the Bureau of Meteorology (BoM), Manly Hydraulics Laboratory and the Department of Land and Water Conservation.

Weather and climate impact upon hydrodynamic processes, geological, geomorphological processes and ecological processes and are therefore important forcing factors driving many of the estuarine processes. The variability of weather and climate is also important for the interpretation of natural versus anthropogenic changes in ecosystem variables.

Since the time of settlement the Macleay catchment has experienced climatic extremes of drought and floods at regular intervals. In particular, droughts have been known to be severe and in the 1940 to 1942 drought local residents reported that the Macleay River ceased to flow. A further notable drought was experienced in 1994, when the total rainfall for the year (as measured at the MHL Euroka upstream rain gauge) was 559 mm compared to the annual average rainfall of 1,219.5 mm (nearby at Kempsey (BoM)).

The prevailing climate of Saltwater Creek estuary is warm and temperate with a maritime influence.

2.2.2 Temperature

Temperatures vary across the Macleay River catchment depending on the local incidence of sea breezes and elevation above sea level. Table 2.1 and Figure 2.5 present the mean daily maximum temperatures for two stations at either end of the catchment, showing the large variation across the area. BoM's Smoky Cape Lighthouse Station at South West Rocks (SWR) is the station nearest to Saltwater Creek estuary, while Armidale is in the upper area of the Macleay catchment.

Table 2.1 Mean Daily Max Temp (degrees C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SWR	26.7	26.7	26.0	23.9	21.3	19.1	18.5	19.6	21.5	23.0	24.4	25.8
Armidale	27.1	26.1	24.1	20.6	16.4	13.1	12.2	14.2	17.6	21.2	24.3	26.5

Source: Bureau of Meteorology

2.2.3 Rainfall

Mean annual rainfall in the Macleay catchment ranges from 800mm around Armidale to 1,500 mm at Smoky Cape on the coast. Figure 2.6 presents mean monthly rainfall and shows that the driest months are July to November and the wettest months are January to April.

The Southern Oscillation Index (SOI) gives an indication of whether a year was particularly wet or dry. The monthly SOI is plotted for 1990 to the present in Figure 2.7. Negative values indicate drier than average years and positive indicate wetter years. Sustained values of less than –10 indicate an El Niño Southern Oscillation (ENSO) event and dry weather across northern and eastern Australia. It can be seen that major ENSO events have occurred in 1991-92, 1992-93, 1993-94, 1994-95 and 1997-98 and that on average 1998 to 2001 have been wetter than average years.

2.2.4 Wind

Wind directions show a strong seasonal pattern. Summer winds are predominantly onshore from the north-east whereas autumn and winter show light winds from the west and south-west. In late winter and spring winds are strong and often cold and dry from the west. In summer typical sea breezes are 15-25 km/h, with gusts to 50 km/h and occasionally to 100 km/h.

2.2.5 Evaporation

Evaporation is typical of temperate climate areas, with high values in summer and lower values in winter. Monthly averages for the Coffs Harbour Station are presented in Table 2.2.

Table 2.2 Monthly Average Evaporation (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coffs Harbour	201.5	169.5	164.3	126.0	93.0	81.0	86.8	114.7	150.0	176.7	195.0	207.7

Source: Bureau of Meteorology

Climatic data indicates an excess of evaporation over rainfall for the period from July to December and the reverse during January to June. If evaporation greatly exceeds rainfall then excessive drying can occur which exposes and oxidises sulphidic sediments causing acid sulphate soil problems.

2.2.6 Solar Radiation

Solar radiation forms an important contribution to the estuary processes in two ways: as a source of heat influencing the thermal stratification in the creek and as a source of sunlight for photosynthesising aquatic plants and algae (e.g. phytoplankton). Plant growth is stimulated at wave lengths in the photosynthetically active radiation (PAR) band of 400-700 nm. The incoming solar energy occurs at a broad range of wavelengths and solar energy in the PAR range is generally about 40% of the global incoming radiation.

BoM provides daily estimates of the Global Solar Exposure derived from satellite images for specific sites. Global Solar Exposure is expressed as an amount of energy per unit area (MJ/m^2). Data for 1998-2001 are shown in Figure 2.8 and indicate the seasonal cycle and also daily variations associated with cloudy and clear days.

2.3 Geology and Topography

Saltwater Creek is a small coastal interbarrier stream located between the Holocene (recent) outer-barrier of Trial Bay and a Pleistocene inner-barrier, within a coastal Quaternary sandplain landscape. The creek has been deflected northwards by the prevailing northerly longshore drift of coastal currents in Trial Bay. It has been mapped as the Macleay Arm (ma) estuarine soil landscape, which consists of level narrow meander flats with elevation below 1 m. Small tidal channels and swales occasionally traverse the rear of the flats. There is tidal connection with Saltwater Lagoon, a shallow sandy lagoon.

Saltwater Creek has a small catchment, bounded by rolling to steep hills of Triassic granites and Permian sediments and metasediments to the east and south (Smoky Cape), and undulating granite rises to the west (South West Rocks). A small gap between the hills in the south is occupied by a Pleistocene transgressive sand dune which probably over-lies bedrock. A large flat inner-barrier swampy sandplain occupies the centre of the catchment. The Smoky Cape range contributes the majority of runoff, but there is no direct runoff to either Saltwater Creek or Saltwater Lagoon due to the permeable sandy soils of the sandplain; these water bodies are fed by an extensive sand aquifer. This aquifer probably extends seaward under the beach. Figure 2.9 presents a geological map for Saltwater Creek and lagoon catchment.

2.4 Soils

The flats of Saltwater Creek have poorly drained, 60–100 cm, Humic Gleys and Solonchaks (Oxyaquic and Extratidal Hydrosols) and Peats (Organosols), consisting of peats overlying saturated sands. The surface is above daily tidal inundation, but may be subject to occasional overbank flooding (and streambank erosion) with heavy rains in the catchment. During heavy rains, Saltwater Creek carries high suspended organic matter derived from peats in the adjacent swampy sandplain. Water tables are shallow, the groundwater is brackish and may be charged with fresh water from the adjacent sand aquifer. Acid sulfate soil conditions occur below the water table. Figure 2.10 presents a soil distribution map of the Saltwater Creek and lagoon catchment. A cross-section through Saltwater Creek and lagoon showing soil distribution and relationships with vegetation ecotypes is presented in Figure 5.3.

The Holocene beach and foredunes on Trial Bay to the north have been mapped as the Goolawah (go, goa) soil landscape. Soils are rapidly drained deep siliceous sands. The inner-barrier swampy sandplain to the south of the creek has been mapped as a number of soil landscapes, reflecting complex landform history.

The Stuarts Point (sp) aeolian soil landscape occurs on well-drained Pleistocene sand plains immediately to the south of Saltwater Creek. Soils are freely-drained Podzols (Aeric Podosols). Some of this area has been disturbed by past industrial developments. The Korogoro (ko) aeolian soil landscape occurs on low Pleistocene transgressive dunes in the south. Soils are deep freely drained Podzols (Aeric Podosols). There is no surface run-on due to highly permeable soils on these soil landscapes. The Hat Head (hh) swamp soil landscape occurs on Pleistocene sandy swale swamps north of Saltwater Lagoon, with deep poorly drained Acid Peats (Organosols) and Peaty Podzols (Aquic Podosols).

The Clybucca (cy) swamp soil landscape occurs on a Pleistocene muddy closed depression to the south of Saltwater Lagoon, with sandy clays overlying saturated sands. Soils are Humus Podzols (Semiaquic Podosols), poorly drained to a shallow water table which may be perched on a near-surface clay layer. The low-lying area around Saltwater Lagoon is Holocene lagoon-floor sediments, mapped as the Seven Oaks (se) swamp soil landscape. This is at or close to sea level. Soils are poorly drained, deep Humic Gleys (Sulphidic Hydrosols) and Acid Peats (Sulphidic Organosols). Acid sulfate soil conditions occur below the water table.

Soils on the steep hills of Smoky Cape consist of shallow to moderately deep and moderately well drained Red Podzolic Soils (Red Dermosols/Kurosols), Red Earths (Red Kandosols), and shallow Lithosols (Leptic Tenosols). Soils on the lower slopes and the undulating granitic low hills are imperfectly drained Yellow Podzolic Soils and Soloths (Brown/Yellow Kurosols). There is high erosion hazard and runoff is high but large amounts of suspended sediments would not be expected to reach Saltwater Creek, being intercepted by the sands.

2.5 Foreshore Features

Saltwater Creek enters the sea at South West Rocks. Local features near the mouth include a surf club, some residential development and a footbridge. Some of the major foreshore features including rock protection are presented on photographs in Figure 2.11(a) and 2.11(b).

2.6 Land Use and Zoning

The region is a popular recreational destination for a range of outdoor activities including swimming, camping, boating and fishing. Recent changes in land use patterns and the increased pressure on the estuarine environment due to a range of human influences have resulted in a perceived deterioration of the water quality in Saltwater Creek.

The catchment characteristics including land zonings and prominent features are shown in Figure 2.12. Urban land use represents 13.5% of the catchment, grazing/cultivation 29.9%, grazing only 6.2%, timber 10.7%, and cliffs, lakes and swamp areas 39.7%. Urban development has increased rapidly over the last 30 years, with accelerated growth over the past few years. A sewage treatment plant (STP) located in the catchment services the growing population, however rural residential areas east and south of the creek are unsewered. This plant discharges treated effluent to a dune exfiltration system located between the mouth of the Macleay River and South West Rocks Creek.

2.7 Catchment Runoff and Stormwater Loads

Nutrient and sediment loads from catchments depend on soil types, land use types and drainage patterns. Many empirical studies over the years have measured nutrient loadings from different land use types with similar results appearing around the world (Marston et al. 1995). Catchment characteristics such as geology, rainfall and slope also influence loadings and should be taken into consideration when selecting nutrient generation data, but in a general sense derived nutrient loadings can be applied to multiple catchments. The Catchment Management Support System (CMSS) developed by the CSIRO has brought together results reported in a range of literature pertaining to nutrient loadings to enable general application to other similar systems (Marston et al. 1995). The CMSS system reports annual export rates per hectare for a range of systems according to geographic location. These rates may then be applied to systems with similar geographic and climatic conditions. It is recommended that error rates be applied to the chosen generation rates to reflect the degree of uncertainty involved.

Diffuse source nutrient generation rates have been derived for the Hawkesbury-Nepean Basin (Marston 1993). Due to a lack of available nutrient data pertaining to the Saltwater Creek catchment the rates derived for that study will be used as a first-step approach to estimating nutrient loads. Table 2.3 shows the Hawkesbury-Nepean nutrient generation rates for the land use types identified by CMSS.

Table 2.3 Diffuse Nutrient Generation Rates for Land Uses in the Hawkesbury-Nepean Basin

Land use	Phosphorus (kg/ha/yr)	Nitrogen (kg/ha/yr)
Bushland	0.1 ±0.10	1.50 ±0.50
Established Sewered Urban	1.3 ±0.40	5.00 ±2.00
Recent Sewered Urban and Disturbed	20 ±10	63 ±40
Unsewered Peri-urban	0.60 ±0.30	4.00 ±3.00
Industrial and Commercial	1.80 ±0.40	6.00 ±2.00
Intensive Vegetable Growing	8.00 ±4.00	8.00 ±3.00
Orchards	0.30 ±0.20	4.70 ±3.00
Turf Farming	8.00 ±4.00	8.00 ±3.00
Fertilised Grazing	1.25 ±0.50	8.00 ±4.00
Unfertilised Grazing	0.25 ±0.10	0.90 ±0.50
Extensive Agriculture - Arable	2.50 ±2.30	12.50 ±12.50

The land use types used in the Hawkesbury-Nepean Basin categorisation differ from those shown in the available GIS land use maps for the Saltwater Creek catchment. An estimation of equivalent land uses has been made as follows:

Saltwater catchment land use type	Equivalent Hawkesbury-Nepean land use type
Urban	Established sewered urban
Grazing/Cultivation	Extensive agriculture - arable
Grazing	Unfertilised grazing
Timber	Bushland
Other – cliffs, lakes, swamps	Bushland

The high generation rates for extensive agriculture–arable land have been used as a substitute for grazing/cultivation in the Saltwater Creek catchment due to observations during the field inspection that there was a large degree of surface disturbance around the lagoon related to land cultivation and clearing. It should be noted from Table 2.3 that there is a large error range provided for the generation rates, indicating the highly variable nature of the values derived from previous studies. Loads provided here for the Saltwater Creek catchment should therefore be considered a first order estimate. Rainfall in the Hawkesbury-Nepean Basin is likely to be similar or a little lower than in the Saltwater Creek area and thus loading estimates may be conservative.

Catchment nutrient loadings are calculated by multiplying the area of catchment containing each land use by the nutrient generation rate for that land use (Table 2.4). From these calculations a total catchment nitrogen load of 5,304.6 kg/yr and phosphorus load of 1,004.3 kg/yr is derived.

Table 2.4 Nitrogen and Phosphorus Loadings for Land Use Types in the Saltwater Creek Catchment

Land use type	Area (ha)	Nitrogen loading (kg/yr)	Phosphorus loading (kg/yr)
Urban	137.5	687.5	178.75
Grazing/Cultivation	303.4	3792.5	758.5
Grazing	63.4	57.6	15.85
Timber	108.7	163.05	10.9
Other	403.0	604.5	40.3
Total		**5304.6**	**1004.3**

A proportion of the calculated catchment nutrient loads is captured in the stormwater system of South West Rocks and delivered to the creek and lagoon as point sources (Figure 2.12). The stormwater system is estimated to include approximately 15% of the total catchment runoff, thus providing a stormwater nitrogen loading of 796 kg/yr and phosphorus loading of 151 kg/yr.

2.8 Stormwater Management

The Kempsey Shire Urban Stormwater Management Plan 2001-2005 (Kempsey Shire Council, in prep.) identifies three management areas in the Saltwater Creek catchment: Arakoon - rural residential, Arakoon Road – Saltwater Creek, and South West Rocks - South West Rocks CBD and Saltwater Creek. These areas each have different characteristics in terms of stormwater quality, current management practices, and potential issues, threats and pressures.

The stormwater system in the Arakoon - rural residential area demonstrates 'soft' engineering with a semi-natural watercourse draining the area, capturing pollutants and providing ecological habitat. According to the Management Plan the watercourse functions effectively to convey storm floodwaters safely while achieving high aesthetic and property value appeal.

The Arakoon Road – Saltwater Creek area contains sub-tropical rainforest, wetland and saltwater lagoon which are affected by stormwater drainage from rural residential lands, with the main concerns being nutrients and weeds. On site sewage disposal systems also contribute nutrients and organic matter to the area via drainage watercourses. Strategies of the Management Plan include monitoring of the local watercourses particularly for nutrients and weeds and involving the community in effective on-site sewage treatment operations to reduce pollutant export.

The South West Rocks CBD and Saltwater Creek area is the area of greatest concern in terms of stormwater management. The urban area drains to the mouth and lower reaches of Saltwater Creek, which is popular for swimming and recreation. There is risk of pathogenic pollutants being carried into the waterway by stormwater, as well as litter and associated health and aesthetic problems. Strategies included in the Management Plan to improve public health safety risks include dog control and facilities in the sub-catchment, auditing of sewer systems to ensure no leaks, providing end-of-pipe treatment for litter and reducing litter in the sub-catchment with more bins and street sweeping.

While the formulation of the Stormwater Management Plan is an important step in the mitigation of stormwater impacts on local waterways, it is also critical that potential future urban development, of which there are a number of proposals, adequately considers stormwater issues. Saltwater Creek and lagoon is a discreet and sensitive system that has the potential to be detrimentally affected by insensitive planning and zoning. The lagoon and creek are poorly flushed and hence inputs from the catchment are retained in the creek/lagoon system where they contribute to the alteration of the ecosystem. Adequate planning of flooding associated with stormwater inputs must also acknowledge the entrance management policy that will affect potential flood levels. Council and developers must make a cooperative and integrated effort to manage stormwater, with the common goals of minimising urban inputs to the creek and maintaining and improving water quality.

2.9 Flood Control

A floodplain management plan has been developed for the lower Macleay (Webb McKeown 1999). The Lower Macleay Floodplain Management Plan recommends establishing 12 drainage management areas. Saltwater Creek and lagoon are situated in the Jerseyville management area, which has not yet undertaken a management strategy.

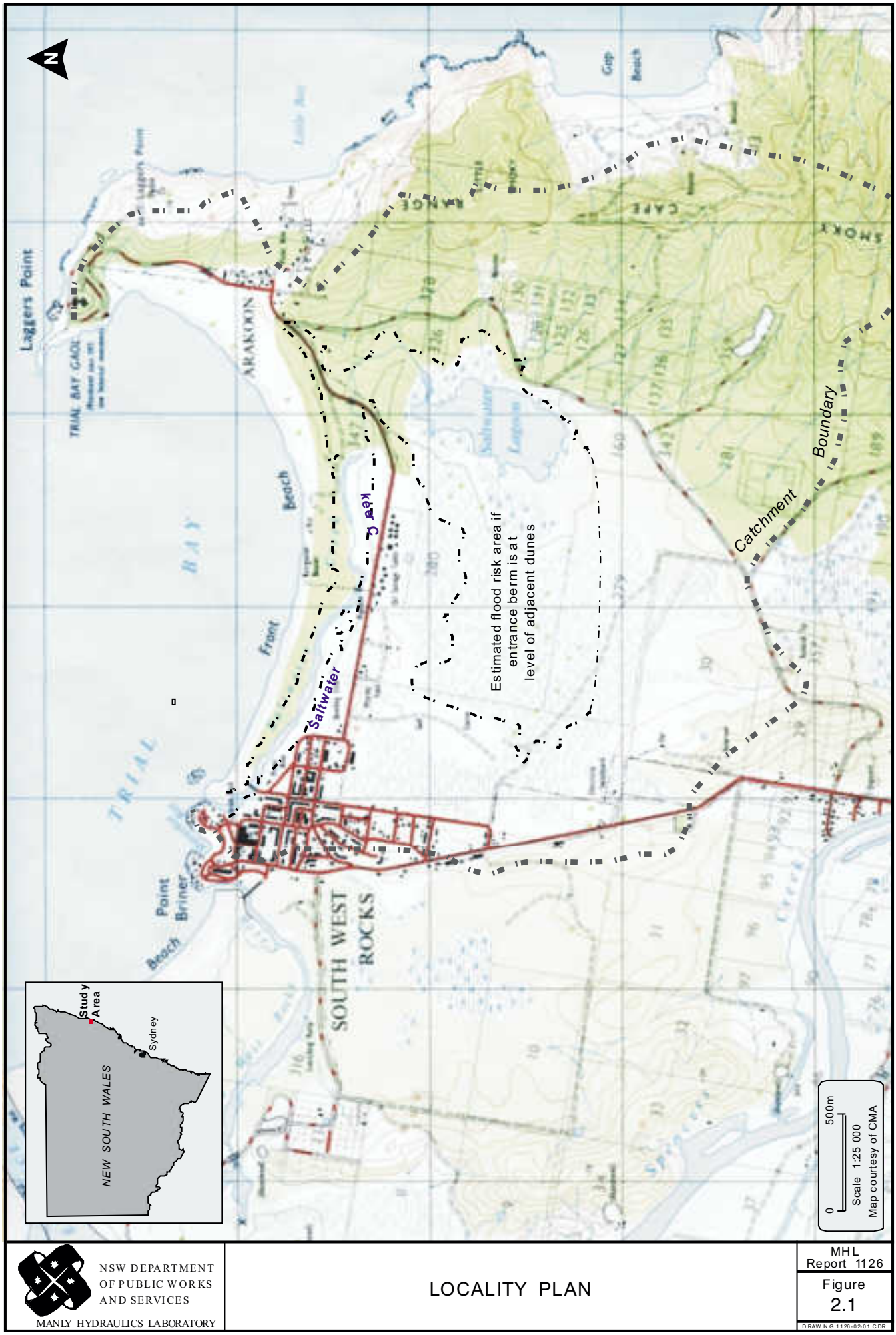
The Lower Macleay Floodplain Management Plan accepts the 1-in-100-year (or 1%) flood as the de facto flood standard. Flood probabilities are expressed in terms of the chances of an event occurring, or being exceeded in any given year. The 1-in-100 year flood level around South West Rocks, as determined by Webb McKeown (1999), is 2.30 m AHD.

Mounser (1981) determined 1-in-100-year flood levels for a proposed development site to the east of South West Rocks. In his report he states that an important feature of the catchment is the large proportion of swamp areas which constitute a large floodplain with considerable storage capacity. The inflows into Saltwater Creek and lagoon come from small streams on the steep hills and the floodplain with surrounding minor ridges. Mounser's (1981) analysis used a range of pre-event water levels in the floodplain storage and corresponding inflow rates for storms of various durations. Several steady state backwater analyses were performed to determine the maximum 1-in-100-year flood level. Predicted 1-in-100-year peak flood heights for Saltwater Creek range from 2.25 m AHD at the ocean to 2.85 m in Saltwater Lagoon.

The entrance condition and in particular the height of the berm plays a very important role in controlling flood levels during a particular rainfall/runoff event. The maximum berm height, over previous years of artificial opening, according to Mounser (1981) is 1.45 m. For the purposes of flood modelling Mounser adopted a constant ocean water level of 2.0 m AHD, which is slightly less than the estimated maximum ocean level during a 1-in-100-year event of 2.25 m AHD. He concluded that since the maximum level of the berm (1.45 m) is considerably less than the assumed constant ocean level (2.0 m) the berm will be scoured before the peak of the 1-in-100-year flood and thus under these conditions the berm height does not affect maximum flood levels.

Recent surveys of the berm at the entrance to Saltwater Creek have been undertaken by Kempsey Shire Council. The lowest point of cross-sections through the entrance to the creek are plotted in Figure 2.13 and the highest point along this thalweg is hereafter referred to as the maximum berm height. Figure 2.13 shows the height of the thalweg, or lowest point, through the entrance on four survey dates, which were all under closed entrance conditions. On these four occasions the maximum berm height ranged from 1.53 to 1.81 m, which is higher than the 1.45 m level used by Mounser (1981). The tidal plane levels presented in the figure indicate that even at the highest tidal levels the berm would not be breached, although other factors such as storm surges and wave runup may allow overtopping to occur.

These recent measurements suggest that Mounser's assumptions regarding berm height were too low and thus the role of the berm in flooding may have been underestimated in his report. It is recommended that a comprehensive flood study, independent of development proposals and considering the whole Saltwater Creek and lagoon catchment, be carried out. This study should assess a variety of berm conditions, entrance management strategies, stormwater inputs and flood flows from the catchment.



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LOCALITY PLAN

MHL Report 1126

Figure 2.1

DRAWING 1126-02-01.CDR

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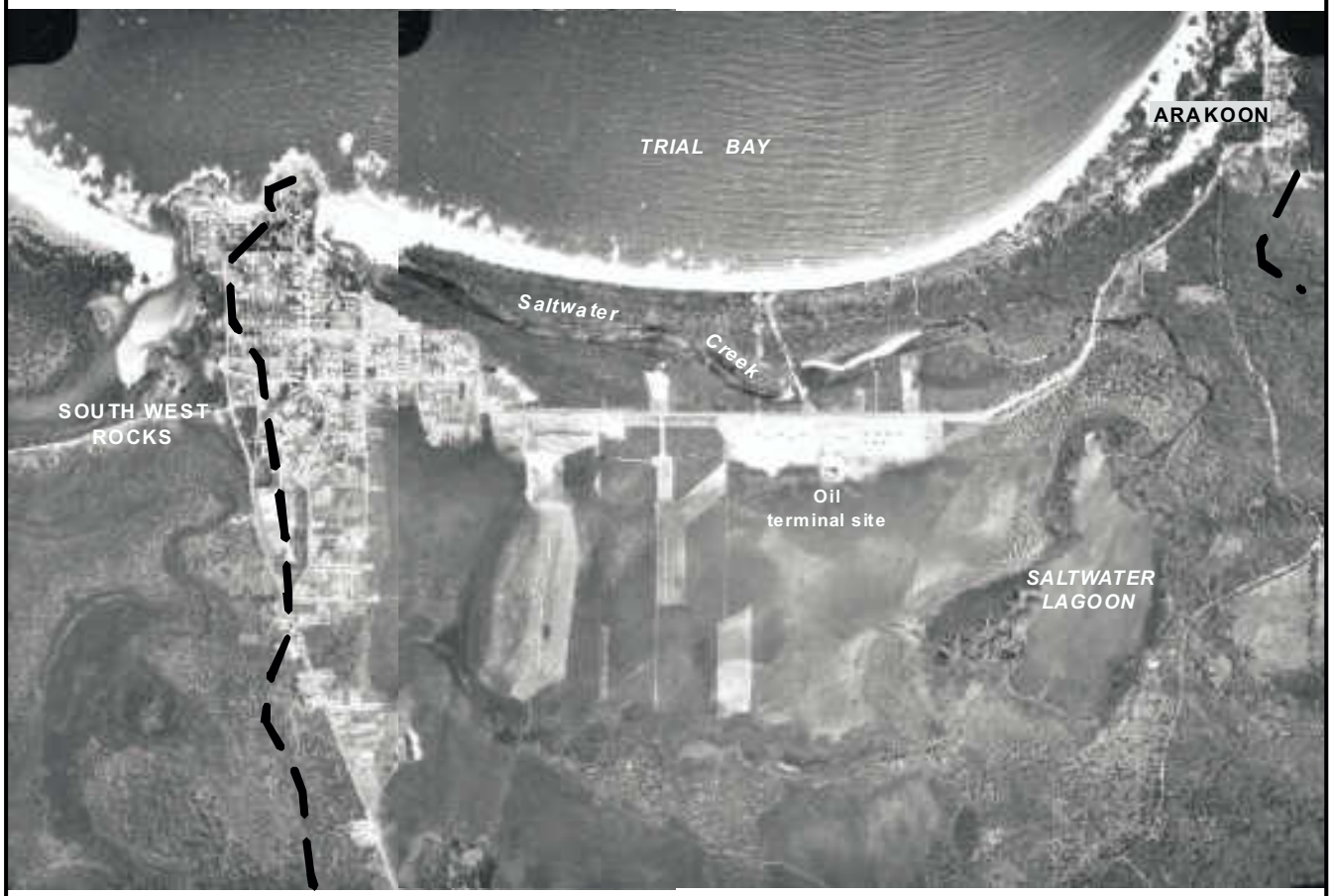
SALTWATER CREEK AND LAGOON
1956 AERIAL PHOTOGRAPH

MHL Report 1126
Figure 2.2a
DRAWING 1126-02-02ACDR



NOTE: Full extent of available photograph is shown

0 500m
Scale (approx)

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SALTWATER CREEK AND LAGOON
1966 AERIAL PHOTOGRAPH

MHL Report 1126
Figure 2.2b
DRAWING 1126-02-02A.CDR

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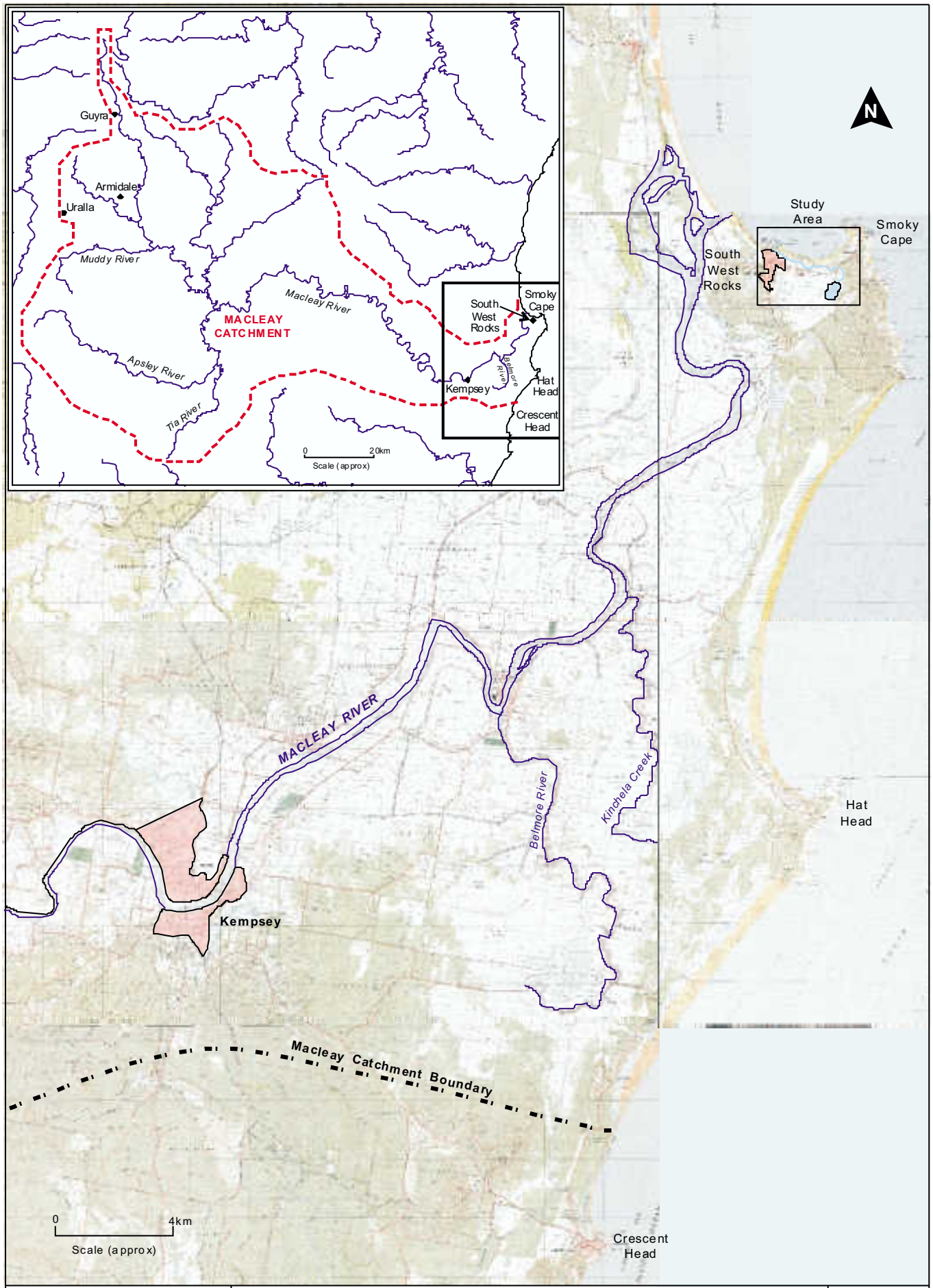
SALTWATER CREEK - 1997 AERIAL PHOTOGRAPH

MHL Report 1126

Figure 2.3

DRAWING 1126-02-03.CDR



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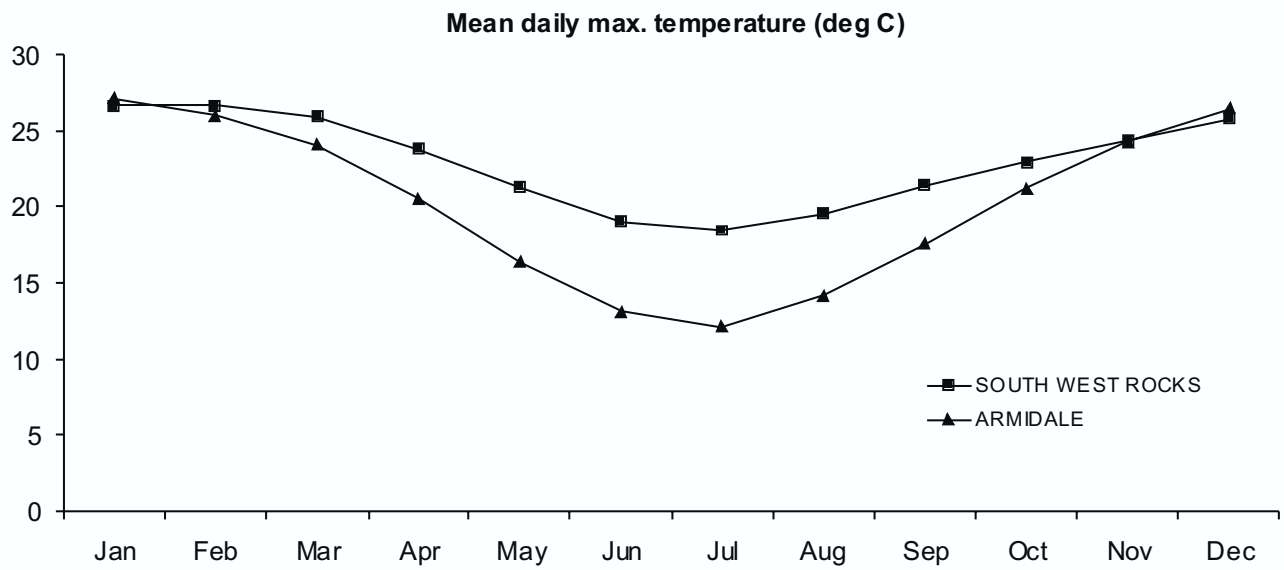
MACLEAY VALLEY CATCHMENT

MHL Report 1126
Figure 2.4
DRAWING 1125-02-06.CDR



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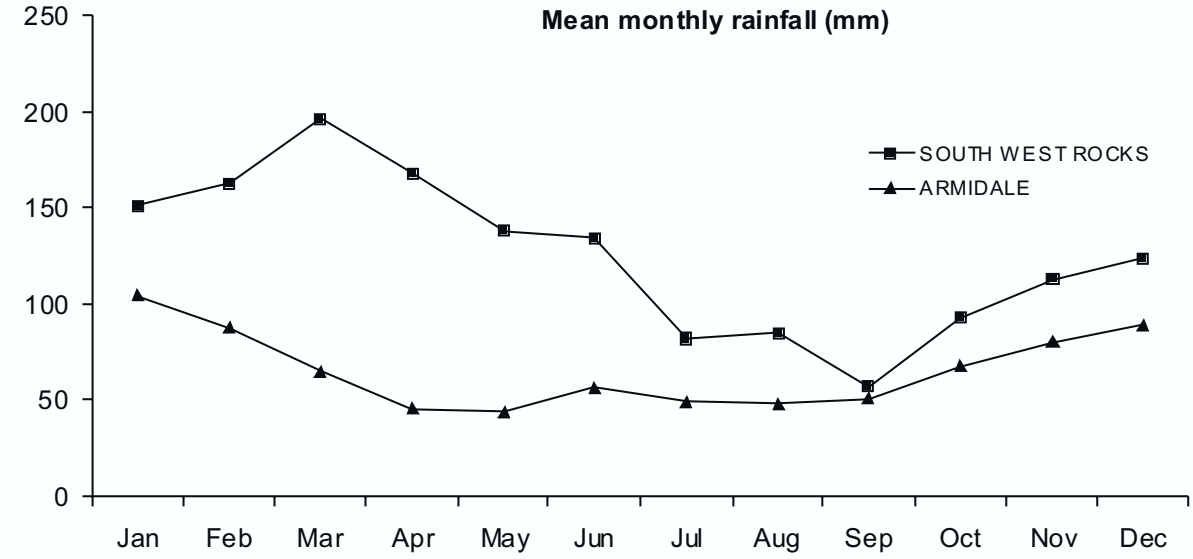
MEAN DAILY MAXIMUM TEMPERATURE (degC)

MHL Report 1126
Figure 2.5
DRAWING 1126-02-05.CDR



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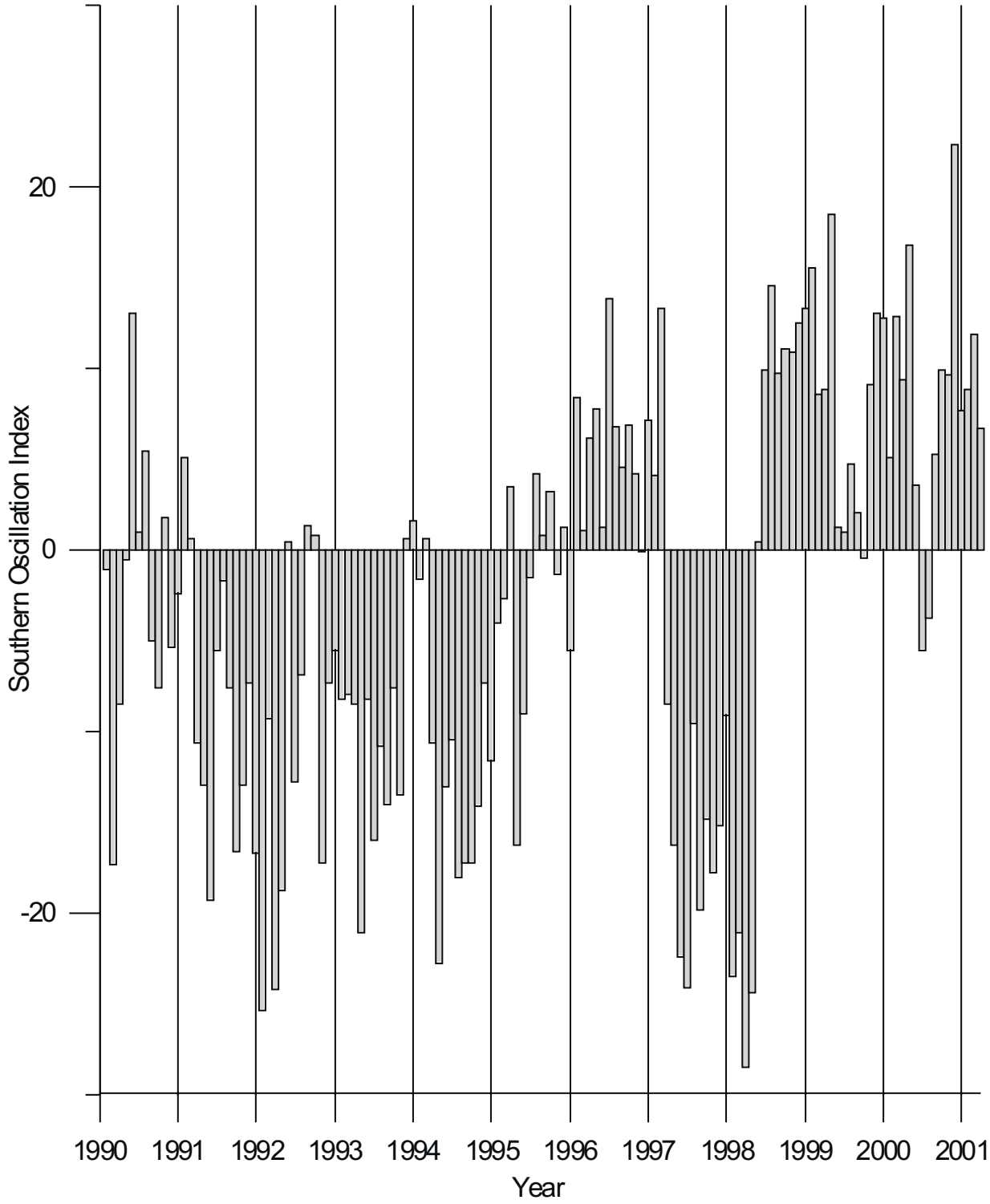
MEAN MONTHLY RAINFALL (mm)

MHL Report 1126
Figure 2.6
DRAWING 1126-02-06.CDR



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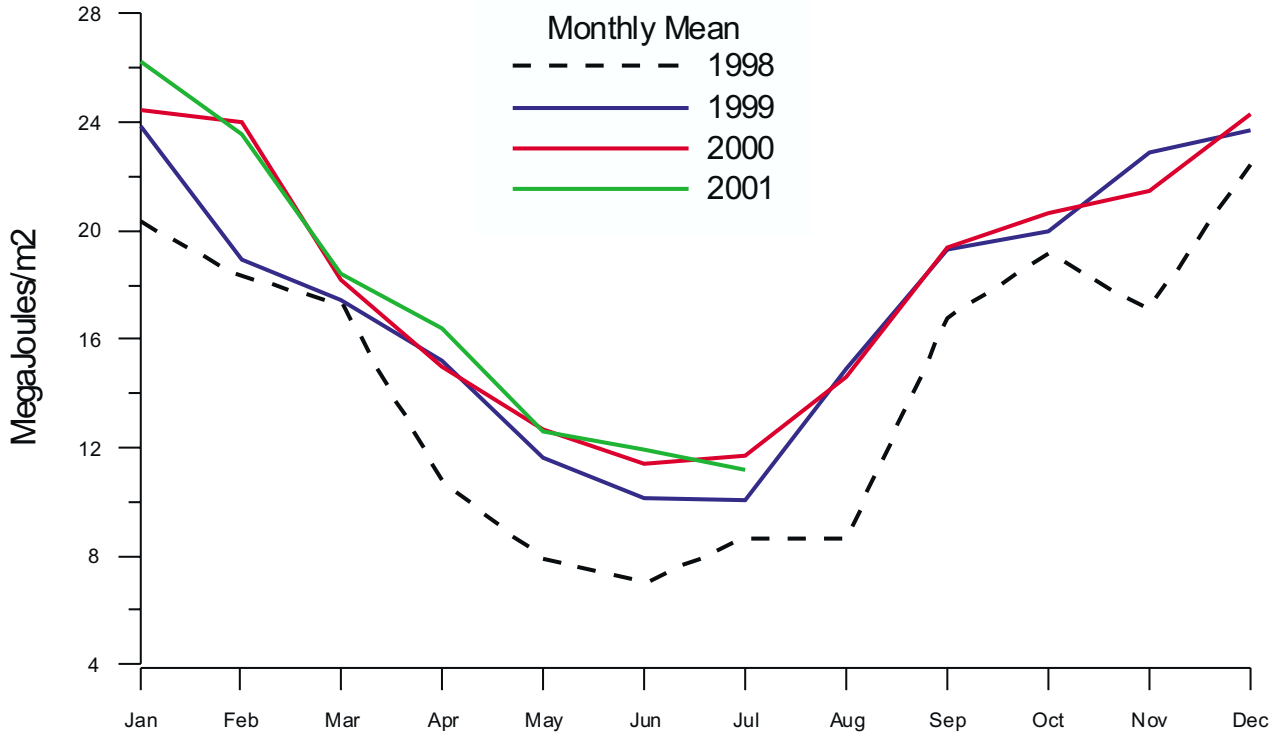
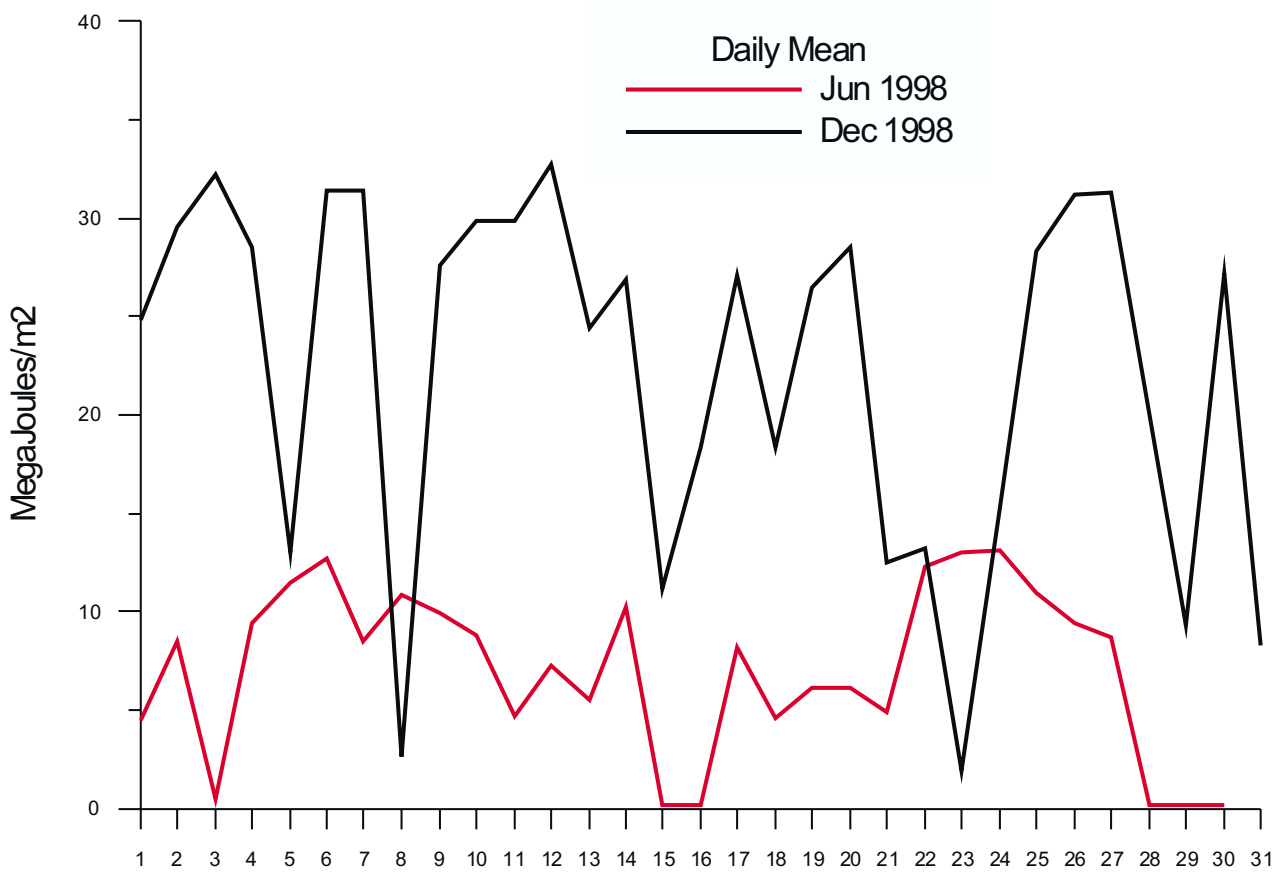
SOUTHERN OSCILLATION INDEX
1990 - 2001

MHL Report 1126
Figure 2.7
DRAWING 1126-02-07.CDR





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GLOBAL SOLAR EXPOSURE - SOUTH WEST ROCKS

MHL Report 1126
Figure 2.8
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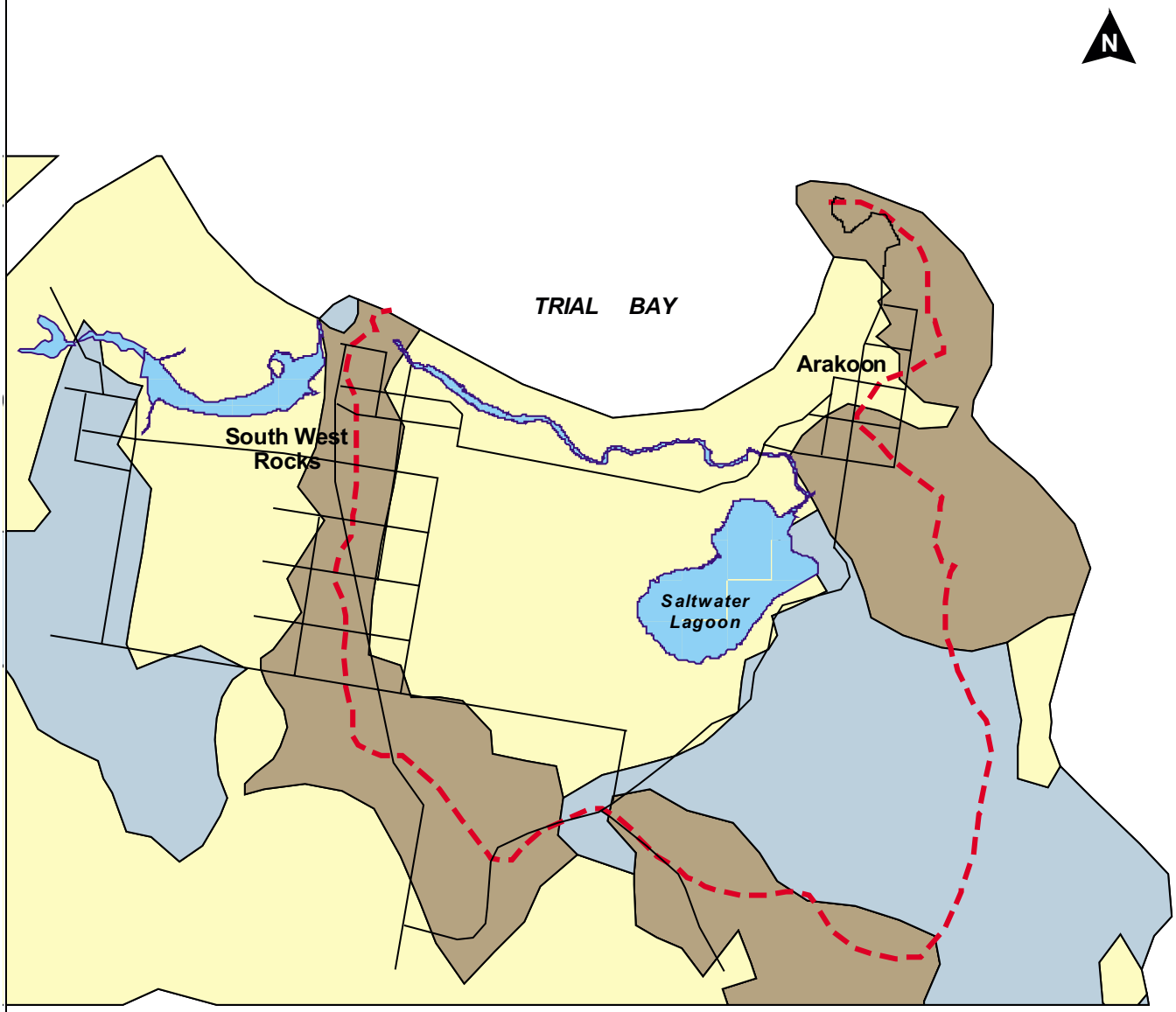

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GEOLOGY

MHL Report 1126
Figure 2.9
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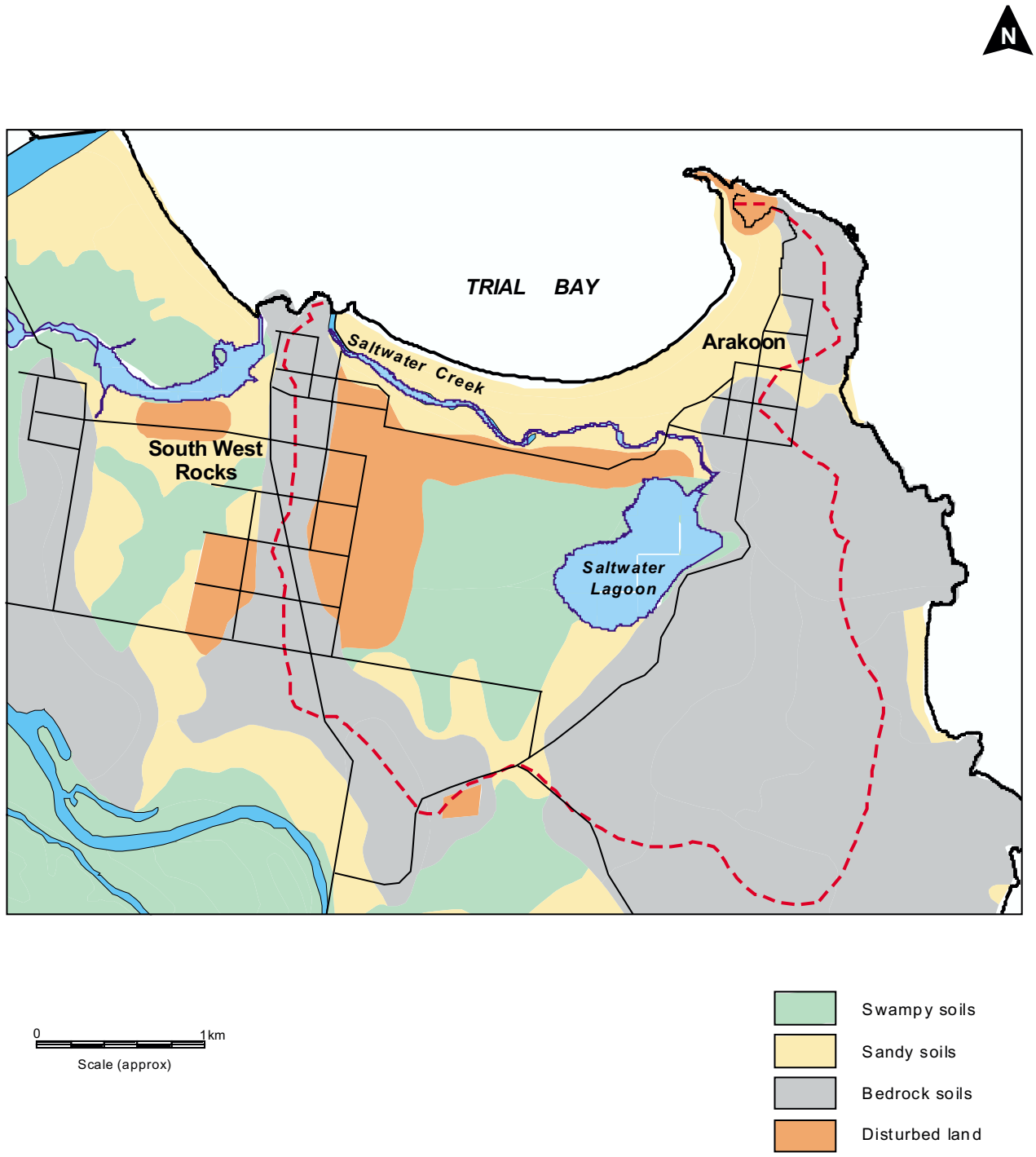

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SOIL DISTRIBUTION

MHL Report 1126
Figure 2.10
DRAWING 1126-02-10.CDR

Saltwater Creek entrance - open conditions (17 January 2001)

Saltwater Creek entrance - closed conditions (18 July 2001)

Downstream view from footbridge (18 July 2001)

Upstream view from entrance (18 July 2001)

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FORESHORE FEATURES

MHL Report 1126
Figure 2.11b
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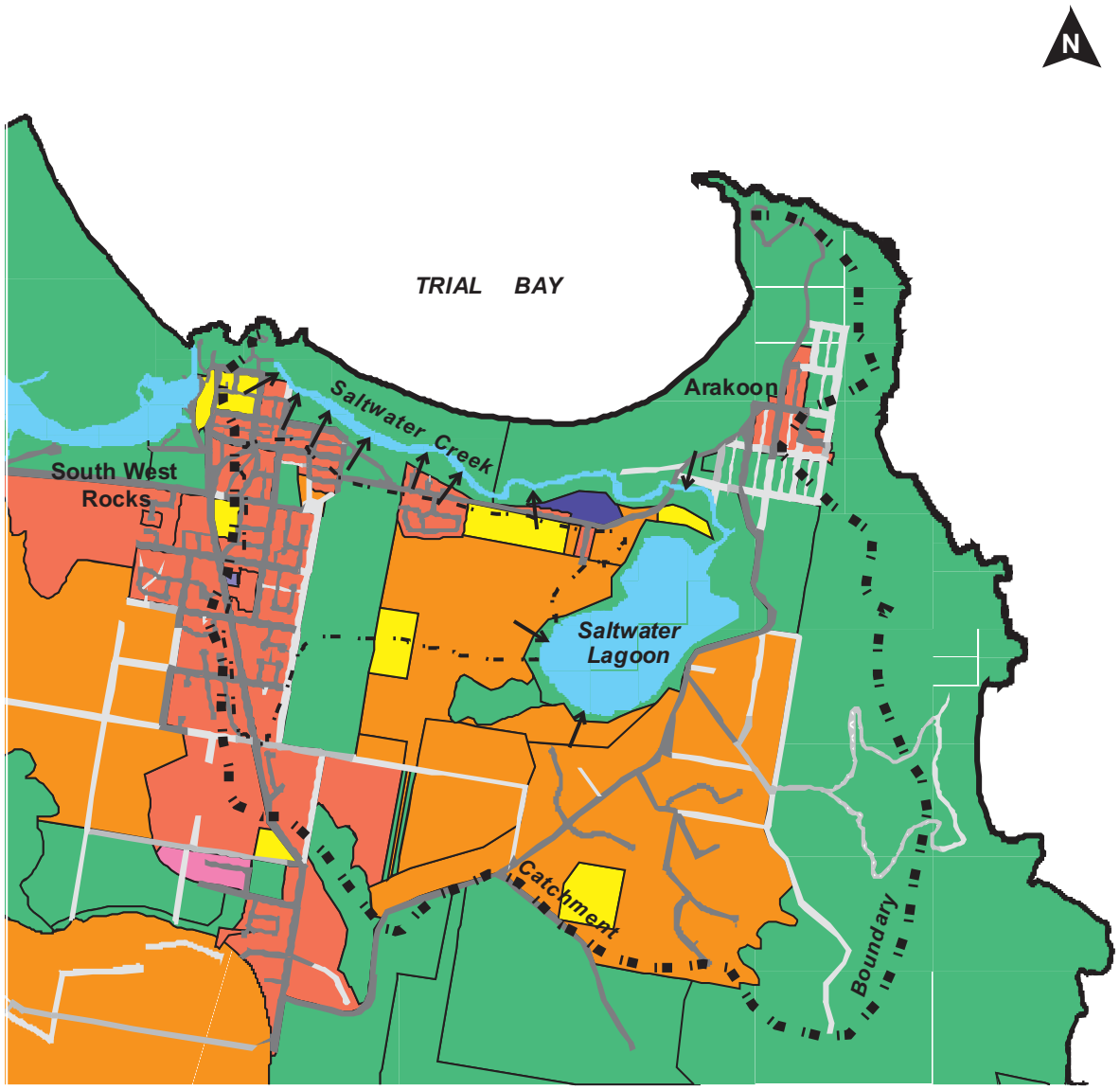

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LAND USE AND STORMWATER INPUTS

MHL Report 1126
Figure 2.12
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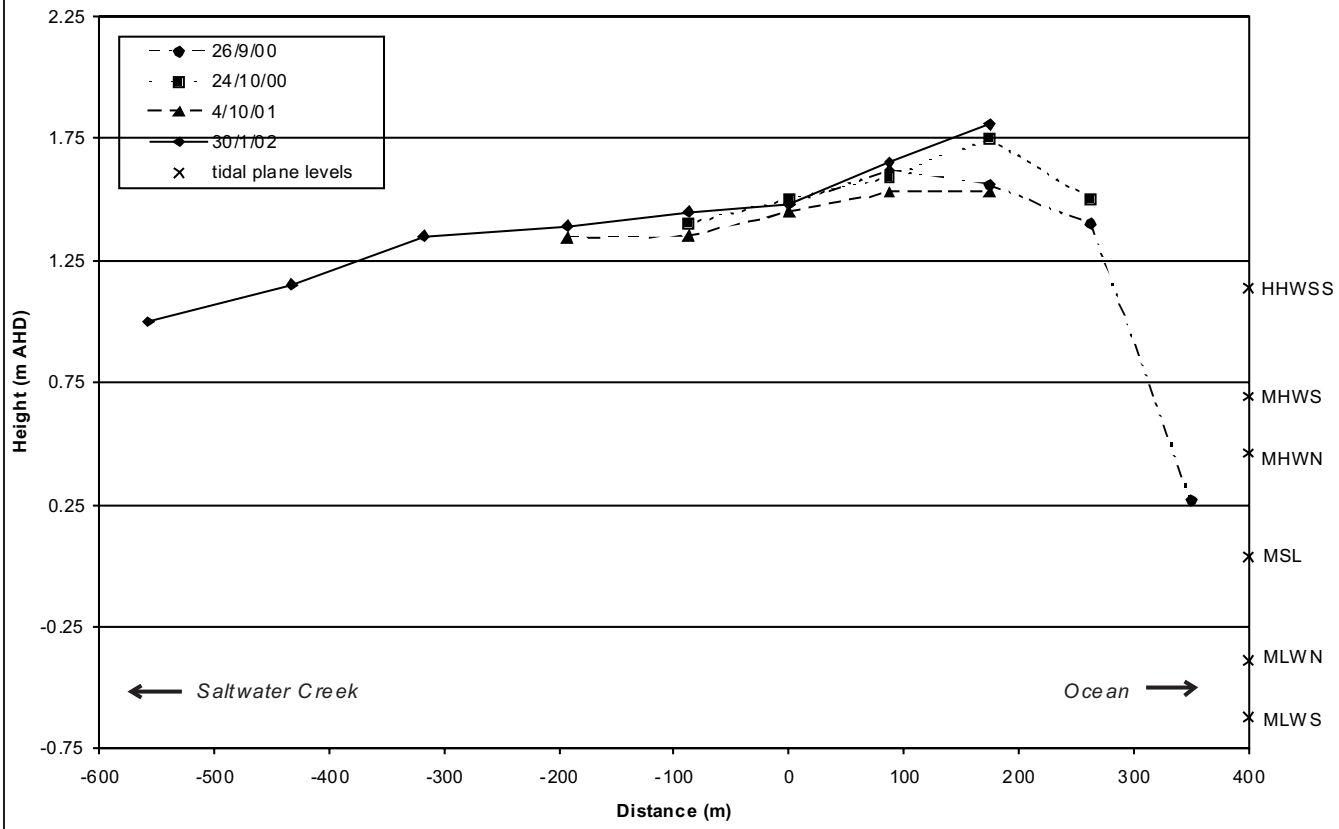

Source: Kempsey Shire Council

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BERM SURVEY

MHL Report 1126
Figure 2.13
DRAWING 1126-02-13.CDR