KILLICK CREEK
ESTUARY PROCESSES STUDY

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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 Killick Creek at Crescent Head. 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 Killick Creek 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, 'Killick Creek Estuary Processes Study'.

Executive Summary

This estuary processes study has been prepared on behalf of Kempsey Shire Council 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 Killick 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

Killick Creek is located near the township of Crescent Head in the sub-tropical climate of the mid-north coast of NSW. The Killick Creek estuary entrance has been kept permanently open since the 1950s, but prior to this is understood to have closed periodically. The creek is approximately 2.75 km long with a waterway area of approximately 0.6 km^2. As part of flood mitigation works in the late 1950s a number of modifications to the Killick Creek entrance took place. The entrance to the lagoon was straightened, the sand dune system was stabilised and rock revetments were constructed around reclaimed land that is now the site of a caravan park. The creek is tidal while it is kept open to the ocean. The water level is also dependent on rainfall/runoff, groundwater flows, evapotranspiration and the operation of the Killick Cut floodgates upstream that allow freshwater flows from the upper Belmore area into Killick Creek during floods.

Catchment Characteristics

The catchment area of Killick Creek downstream of the floodgates is approximately 5 km^2. Its major tributaries are Muddy Arm to the west and the flood cutting to the north-west, with surface and stormwater drainage from the urban area of Crescent Head to the south also contributing flows near the entrance. Vegetation in the immediate catchment is comprised of moist *Eucalyptus* forest, disturbed coastal vegetation and cleared land. Hat Head National Park borders the creek to the north, and wetland areas to the north, east and west of the creek are protected under State Environmental Planning Policy No. 14 Coastal Wetlands.

Inflows to Killick Creek are complicated by the waterway connections constructed as part of the regional flood mitigation schemes. Killick Creek is formally connected to the Macleay Flood Mitigation Scheme via Scotts and Killick drains in the upper Belmore and the upper Maria River via Connection Creek. The upper Belmore catchment has an approximate area of 90 km^2 and the catchment of Connection Creek approximately 40 km^2. Both catchments are largely privately owned rural lands. All three catchments fall into the Macleay River catchment (a section of Connection Creek falls into the Hastings catchment), which occupies 11,385 km^2. The local Killick Creek catchment (downstream of the floodgates) is affected by processes operating in the Macleay catchment when significant rainfall events result in the discharge of water through the Killick floodgates and waters exit to the ocean via Killick Creek.

Climate

The prevailing climate of Killick Creek estuary is warm and temperate with a maritime influence. At South West Rocks, the meteorological station nearest to Killick Creek, mean daily maximum temperatures range from 18.5ºC in July to 26.7ºC in January and February. Mean annual rainfall at Smoky Cape to the north 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 has been wetter than average years. Wind directions show a strong seasonal pattern, with summer winds predominantly onshore from the north-east whereas autumn and winter show light winds from the west and south-west. 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

The geology and soils of the area show a range of influences associated with different geological development periods. Killick Creek estuary is located in the tectonic province of the New England Fold Belt which covers the north-east of NSW and extends into Queensland. It is composed of Late Palaeozoic (410-360 million years old) and remobilised older complexes intruded by extensive Permian (245-286 million years old) and Triassic (208-245 million years old) orogenic granites. Major faults and fractures divide the belt into distinct blocks. The belt was affected by deformation during the Middle Devonian (~380 million years ago) and the Middle to Late Carboniferous (~300 million years ago) and progressively stabilised from south to north following the Hunter-Bowen Orogeny (Middle Permian to Late Triassic). The types of rocks present are mostly sediments (sandstone, shale, conglomerate and glacial deposits) and volcanics (mostly tuffs and felsic lavas).

Soils

In the Early Pleistocene (~1.8 million years ago) the shoreline near Crescent Head was located at the foot of the Dulkoonghi Range with a string of seven offshore islands from Hat Head, through Crescent Head to Point Plomer. Rising sea levels in the Pleistocene brought sand from the continental shelf linking the islands with barrier dunes. This created a lagoonal environment inland of the sand that permitted tidal water interchange between the present Hastings and Macleay rivers systems. The barrier dune was quite narrow between Crescent Head and Richardsons Crossing. In the Holocene (11,000 years ago to present), the narrow lagoon to the west of the sand barrier filled with estuarine deltaic sediments and lagoonal muds, whilst to the east, young barrier sands formed a low barrier plain and foredunes. Killick Creek was an isolated coastal lagoon within this Holocene sand plain but was not connected to the swamp to the west that today drains to the Belmore River and Connection Creek. The soils in the Killick Creek area can be divided into three soil categories based on this history: sandy, swampy and bedrock soils. The Crescent Head hills to the south of Killick Creek and the footslopes to the Dulkoonghi Range in the west are comprised of shallow stony bedrock soils and poorly to moderately drained podzolic soils. The swampy plain to the east of Killick Creek contains acid sulphate lagoonal sediments, grading from silty sands to muds. The dune ridges immediately surrounding Killick Creek have deep well drained sandy soils.

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 Killick Creek. Land use in the immediate catchment is a mixture of bushland, rural and urban areas. Urban development has increased rapidly over the last 30 years, with accelerated growth over the past few years. A sewage treatment plant, located in the catchment near the Muddy Arm tributary, services the growing population. This plant discharges treated effluent to the sea via an ocean outfall south of Little Nobby headland. Stormwater runoff from the Crescent Head residential areas discharges directly to the creek, and a stormwater management plan is currently in preparation by Kempsey Shire Council in order to prevent and mitigate detrimental impacts of stormwater on the estuary.

Flood Mitigation Scheme

The formal connection of Killick Creek to the Macleay Flood Mitigation Scheme took place between 1957 and 1974. Up to the 1950s floodwaters were stored in the Belmore and Kinchela swamps and formed semi-permanent wetlands. Following floods in 1949 and 1950 the Macleay Valley Flood Mitigation Committee produced a report advising on flood mitigation works options. Resulting works included the construction of headworks in Belmore River and Connection Creek to prevent backwater flooding of the backswamps and drains in the backswamps to increase removal of floodwaters. Killick Creek, along with Korogoro Creek and Ryans Cut, were modified as ocean cuts to provide greater escape for floodwaters in time of flood, to provide greater storage for floodwater and to give drainage from the Belmore area between floods. During floods Killick Creek drain now takes a large proportion of the water from the southern sector of the upper Belmore via Scotts drain.

Flood Control

Floodplain management strategies have been developed for the lower Macleay and the upper Belmore. The Lower Macleay Floodplain Management Plan presents a 1-in-100-year flood level for the Killick Creek area of 2.30 m AHD. During non-flood times the Belmore floodway is kept closed. Historically the floodway is opened when flood levels reach 4.1 m at Kempsey traffic bridge. When the floodway opens water rapidly inundates the backswamp, increasing water depths and flooding pastures in the upper Belmore area. Council is currently raising the levees on the Belmore River and Kinchela Creek to allow the floodways to be kept closed longer. On occasions of high floods in the Hastings River, water will flow from that catchment into the upper reaches of the Belmore through Connection Creek. Flood waters in Connection Creek can be removed via ocean cuts at Ryans Cut, Killick Creek and Big Hill Cut.

Tides and Flushing

An assessment of the hydrodynamics of the estuary estimated that the tidal prism at mean neap and mean spring tides is of similar size or larger than the estuary volume of 95 x $10^3 m^3$, and hence in an overall sense the system should be well flushed. The depth decreases from the ocean to the confluence of Muddy Arm with the main arm and then increases upstream to the flood cutting. The mean tidal velocity decreases in the upstream reaches where the tidal prism diminishes and the depth increases, which suggests that the upstream reaches may be subject to lower mixing, with a possibility of persistent vertical stratification. The tidal excursion distance near the creek entrance is around 2 km (roughly the length of the estuary) and in the flood cutting reduces to around 300 m. This suggests that vigorous mixing and flushing occur near the mouth but upstream in the flood cutting the water may remain trapped for at least several tidal cycles. Bulk water flushing times are estimated to vary between about one day and four days at the upstream reach.

Water Balance

The major influences on water levels in the estuary are tidal conditions, freshwater inflows from the local catchment and water inflow via the floodgates during major regional flood events. Less significant influences include groundwater flow inputs, evaporation and groundwater flow through the coastal dune to the ocean. Estimates of the average monthly discharge entering the estuary from the local catchment indicate a range from 43 ML in September to 147 ML in March, with an average annual freshwater inflow volume of 1,128 ML. This equates to an average time for local runoff to replace the estuary volume of about 31 days, which is considerably longer than the estimated tidal flushing time of three days. In contrast a major event in the upper Belmore or Connection Creek areas could cause complete flushing of the estuary by the freshwater inflow in a few hours, highlighting the major effect that sporadic floods may have.

Circulation and Flushing

Water circulation in the estuary 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. Salty (and hence dense) water from the ocean intrudes into the estuary and flows 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. Stratification is broken down by turbulent mixing caused by wind and tidal exchange in deeper upstream areas. There are generally longer residence times in deeper areas of the creek, while reaches both upstream and downstream are characterised by shorter residence times. The flushing characteristics of Killick Creek are also complicated by the complex hydraulic processes associated with the operation of the floodgates and the formation of sand bars in the lower reach of Killick Creek that tends to occur in December-January. 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

Water quality in Killick Creek is influenced by inflows from the local catchment (Crescent Head township and areas downstream of the floodgates) and the super catchment (Belmore Swamp, Connection Creek catchment and greater Macleay catchment) during times of extreme rainfall events, from water exchange with the ocean and by bio-geochemical cycling within the estuary. Increased loads of sediments, nutrients and other pollutants can be attributed to a combination of urbanisation in the catchment, connection to the flood mitigation scheme and subsequent overdrainage effects, and inputs of nutrient-enriched water, marine vegetation and suspended sediments from the ocean. Water quality data provided by Kempsey Shire Council and measurements taken as part of this study indicate that there may be concerns regarding low levels of dissolved oxygen and high levels of chlorophyll-a, total phosphorus and faecal coliforms in the estuary and its tributaries when compared to ANZECC guidelines. It is strongly recommended that a regular water quality monitoring programme be established for sites in Killick Creek as part of the current monitoring being undertaken in the upper Belmore. This will provide baseline data, give insight into the influence of inflows from upstream of the floodgates, and improve understanding of the relationships between salinity, chlorophyll-a and pH and entrance behaviour and floodgate operation.

Acid Sulphate Soils

The majority of the local catchment surrounding Killick Creek is classified as low acid sulphate soil risk. However, the Belmore Swamp and Upper Maria River–Connection Creek areas have been identified as priority areas. In these priority areas land management decisions in relation to acid sulphate soils, such as drainage, can cause and/or contribute to severe soil acidification, poor water quality, reduction in agricultural productivity, loss of estuarine habitat and degraded vegetation and wildlife. These impacts may be transferred downstream when the floodgates are open, with consequences for the Killick Creek ecosystem.

Water Quality and Biota

Water quality is a critical issue for the management of aquatic ecosystems. A major concern in the study area is the large number of fish kills that has been observed in the Belmore River and Killick Creek in recent years. The cause of these fish kills is unclear but may relate to deoxygenation of the water column, acid sulphate soil pollution or stranding of fish in swamp areas after flooding. From the evidence to date it appears that low oxygen levels may be the primary cause, which may be attributed to the oxygen-consuming decomposition of either inundated pasture in the Belmore swamps during flooding or red marine algae trapped on shoals in the creek. There is little information on the impact of poor water quality on other biota of Killick Creek, but it is likely that the events that cause fish kills also have sub-lethal effects on fish and invertebrates. There is evidence that a viable benthic community exists in Killick Creek.

Vegetation

There are several wetlands adjacent to and surrounding Killick Creek that have been designated SEPP 14 Coastal Wetland. These include the wetland to the west of Killick Creek between Muddy Arm and the flood cutting, a narrow wetland behind the dunal system of Killick Beach that runs to the north of Killick Creek, and a larger wetland within the catchments of the upper Belmore River, Scotts Drain and Connection Creek. Previous studies of the area report that the major vegetation types in Killick Creek are bush, mangrove and seagrass, but also suggest that the areas of mangroves and seagrass have declined over time. However, field observations as part of this study suggest that mangrove areas are presently more extensive than areas mapped in the early 1980s. Unfortunately there are no detailed descriptions of the past or present vegetation available.

Fauna

Information on the estuarine fauna of Killick Creek is also limited. A fish survey carried out in 1993 found a total of 1,163 fish of 26 species and concluded that the relatively high numbers of fish caught and the diversity of species was indicative of fish populations and habitats that are generally in good condition. The broad range of size classes caught for each species also suggested that the fish populations were healthy. As part of the same study benthic biota was sampled and the biota was found to be typical of such habitats on the mid-north coast of NSW, including intertidal macro-algae, molluscs (limpets, gastropods, oysters, chitons) and other invertebrates (barnacles, anemones, seastars, cunjevoi, crabs, tube worms). Crabs and yabbies were abundant along the banks of the creek and soft sediment cores taken in summer found ten polychaete worm species, four gastropod species, seven bivalve species and five crustacean species. Of note, the sediments with the highest organic content contained little or no fauna.

Ecological Processes

Conceptual models of ecological processes, primarily based on studies done in other similar systems, illustrate the importance of the variety of habitats in Killick Creek and also the effect that permanent entrance opening has on the ecosystem. With the entrance kept open the passage is constantly maintained for recruiting fish in late winter to early summer and pre-spawning fish making their way out of the estuary in autumn and late winter. The permanent opening of the entrance has meant that Killick Creek is subject to more influxes of nutrient-rich ocean water derived from upwelling and greater frequency of red algae blooms from adjacent coastal waters. It has been suggested that these nutrient influxes and red algae blooms play a role in water quality and odour problems in the creek. While entrance conditions have a significant impact on ecological processes in the creek, there are a number of other processes, including flooding and the operation of the floodgates, recruitment and spawning patterns, and seasonal processes that interact to influence the biodiversity and abundance of fauna in Killick Creek.

Ecological Health

It is difficult to assess the health of the ecosystem in Killick Creek with the available data, but a number of features of the creek have important implications for water quality and ecological processes associated with water flow. It is clear that human-induced changes to the natural conditions, such as flood mitigation works, mechanical entrance opening and foreshore development, have altered processes in the creek but it is not possible to quantify the extent of the changes. The results of this study suggest that the health of Killick Creek is likely to be highly variable through time, the strongest evidence being the periodic fish kills that occur both above and below the floodgates. Further information is urgently required in order to understand the frequency, extent and causes of these fish kills. In addition, more detailed data on spatial and temporal patterns of abundance and distribution of faunal groups will assist in describing baseline conditions from which to identify principal factors that influence these components.

Estuary Sediments

A previous study of sediments in Killick Creek found that sediments were mostly fine sands with varying amounts of silt and pebble depending on the site. Areas where the creek deepens and widens have allowed the accumulation of substantial quantities of organic matter, and locations such as the junction of the creek with the flood cutting have high organic content and high oxidisable sulfur content in sediments. Organic-rich mud, known as black ooze, is found in depressions in the upper reaches of the estuary and act as a large store of nutrients as well as producing unpleasant odour when exposed to the air. The surrounding sandy soils are erodable and result in some infilling of the system. Anecdotal evidence suggests significant infilling has occurred since the 1950s, which could be attributed to a number of processes and activities, including clearing of dunes, realignment of the entrance and construction of roads and drainage channels. Marine sediment movement into the estuary is also a significant process and can result in shoaling or blocking of the entrance and shoaling further up the creek, such as near the entrance to Muddy Arm.

Conclusions and Recommendations

From the above discussion it is clear that the Killick Creek estuary has been impacted by a number of human-induced changes to the system, including flood mitigation works, mechanical and permanent opening of the entrance, and catchment development. The major concerns for the system include water quality and odour problems, floodgate management, sedimentation and entrance management, ecological health and recreational amenity. A number of important decisions and strategies regarding the management of the estuary will require further information through a range of studies such as those listed below.

- *Flooding* – Hydrological modelling of Killick Creek and drain, Ryans Cut and Big Hill Cut, to assess the potential for changes to Killick Creek's role in the flood mitigation scheme. This should be linked to studies on water quality and biota to improve understanding of the impact of the floodgates and incoming floodwaters on downstream estuary processes.
- *Land use practices* – Assessment of future options for land management in the upper Belmore area, as current land use practices are impacting on drainage and water quality. These impacts are likely to increase with sea level rise and climate change. The inputs of stormwater from urban land use should also be investigated to assess their contribution to the system in terms of flow and water quality.
- *Entrance surveys* – Detailed surveying of the entrance at regular intervals and immediately after flood and storm events to provide greater understanding of entrance behaviour and relationships between water level and entrance condition.
- *Biota* – Detailed surveys of flora/fauna communities along the foreshores of the creek including up to and beyond the north arm 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. An investigation into the role of marine red algae for water quality in the creek and odour issues should also be carried out.
- *Water quality* – installation of a water quality monitoring device capable of measuring chlorophyll-*a*, salinity, pH and flow, which in combination with the survey task described above will enhance understanding of the effects of changing entrance conditions and floodgate operation on water levels and water quality.

Summary Statistics

Killick Creek is located in the township of Crescent Head in the sub-tropical climate of the mid-north coast of NSW. Killick Creek estuary falls into the category of intermittently closed and open lakes and lagoons (ICOLLs). Killick Creek entrance has been kept permanently open since the 1950s.

Table S.1 Characteristics of Killick Creek Estuary

Catchment area downstream of floodgates	5 km^2
Waterway area	0.6 km^2
Length of creek	2.75 km
Major tributaries to Killick Creek	Killick drain, Connection Creek
Mean air temperature	19 C° (winter)–26 C° (summer)
Mean annual rainfall	1,500 mm (Smoky Cape)
Length to tidal limit	Floodgates 2 km upstream of entrance
Tidal prism	approx. 95 x 10^3 m^3

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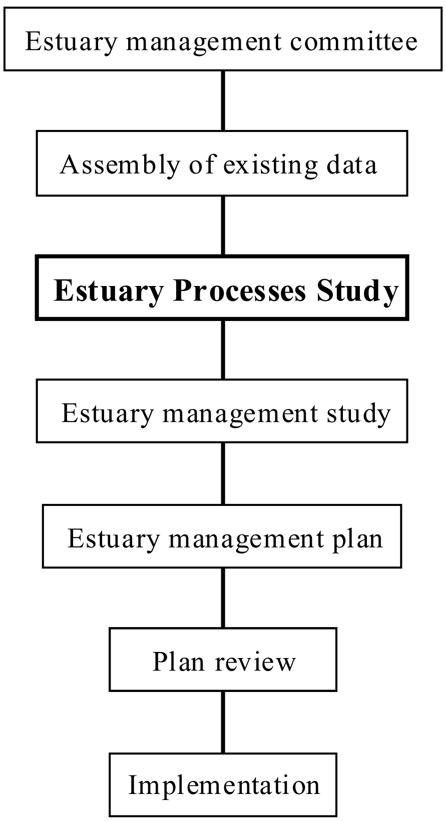
1. Introduction

1.1 Scope of Work

The Department of Public Works and Services' Manly Hydraulics Laboratory was commissioned by Kempsey Shire Council to undertake an Estuary Processes Study for Killick Creek at Crescent Head. MHL 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 Killick Creek with the Killick Creek Working Group and the Coastal and Estuary Management Committee
- one day of field investigations at Killick Creek (to be supplemented with limited further field work)
- community meeting to present conceptual diagrams and identify issues of importance, attended by interested Crescent Head residents, visitors and Killick Creek Working Group
- production of a report on the issues of importance to the community and presenting the conceptual diagrams of Killick Creek derived from similar studies
- assembly of existing literature on Killick Creek and similar systems
- review of collated literature and specific research culminating in a report 'Killick Creek Estuary Processes Study'.

1.2 Data Compilation

A literature search of a number of reference databases was 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 were sourced from Kempsey Shire Council, the Department of Land and Water Conservation and National Parks and Wildlife Service. The information was collated and used as a base for the development of conceptual models. Conceptual models were derived for Killick Creek based on information from previous studies both within Killick 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 community hall in Crescent Head on 5 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, which are summarised in Section 8.

Prior to the meeting, a letter requesting submissions of information on Killick Creek was sent to 40 contacts from the Killick Creek Working Group and the Coastal and Estuary Management Committee, whose details were supplied by Council. In addition, 15 local residents provided their contact details at the community meeting in order to make a submission. 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 and list of recipients is included in Appendix A. A list of people who made submissions is also included.

2. Catchment Characteristics and Processes

2.1 Introduction to Killick Creek

Killick Creek is located in the township of Crescent Head in the sub-tropical climate of the mid-north coast of NSW (see Figure 2.1). Killick Creek estuary falls into the category of intermittently closed and open lakes and lagoons (ICOLLs). 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. Killick Creek entrance has been kept permanently open since the 1950s. The 1942 aerial photograph in Figure 2.2 shows that the creek once operated as an ICOLL.

Killick Creek is open to the sea through a narrow channel at Crescent Head. As part of the flood mitigation works in the late 1950s a number of modifications to Killick Creek entrance took place. The entrance to the lagoon was straightened, the sand dune system was stabilised and reclaimed land was rock-stabilised and is now the site of a caravan park. These changes are highlighted on the aerial photo in Figure 2.3.

The creek is approximately 2.75 km long with a waterway area of approximately 0.6 km^2. The creek is tidal while it is kept open to the ocean. The major tributaries are known locally as Muddy Arm and the flood cutting. Killick Creek is formally connected to the Macleay Flood Mitigation Scheme via Scotts and Killick drains in the upper Belmore and the upper Maria River via Connection Creek. Floodgates have been installed at Scotts drain, Killick flood cutting and upper Connection Creek. The catchment area downstream of the floodgates is approximately 5 km^2 and is comprised of coastal complex, moist eucalyptus forest, disturbed coastal complex vegetation and cleared land. Hat Head National Park borders the creek to the north. Urban and semi-rural developments exist in areas to the south and east of the creek including a caravan park.

The upper Belmore catchment has an approximate area of 90 km^2 and the catchment of Connection Creek approximately 40 km^2. Both catchments are largely privately owned rural lands. All three catchments fall into the Macleay River catchment (a section of Connection Creek falls into the Hastings catchment) or 'super' catchment as referred to here. The super catchment occupies 11,385 km^2 (Bucher and Saengar 1989) and is presented in Figure 2.4. The local Killick Creek catchment (downstream of the floodgates) is affected by processes operating in the super catchment when significant rainfall events result in the discharge of water through the Killick floodgates and waters exit to the ocean via Killick Creek. Therefore, this study will also refer to the Macleay River catchment where it is considered relevant to Killick Creek.

2.2 Climate

2.2.1 Introduction

The prevailing climate of Killick Creek estuary is warm and temperate with a maritime influence. Weather and climate variables are measured at a number of sites around Killick Creek and in the Macleay catchment by the Bureau of Meteorology (BoM), MHL and DLWC.

Weather and climate impact upon hydrodynamic processes, geology, 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)).

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 Killick Creek estuary, while Armidale is in the upper area of the Macleay catchment.

Table 2.1 Mean Daily Maximum Temperature (°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 values 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 and 1996-97 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

Killick Creek estuary is located in the tectonic province of the New England Fold Belt which covers the north-east of NSW and extends into Queensland. It is composed of Late Palaeozoic (410-360 million years old) and remobilised older complexes intruded by extensive Permian (248-286 million years old) and Triassic orogenic granites. Major faults and fractures divide the belt into distinct blocks. The belt was affected by deformation during the Middle Devonian and the Middle to Late Carboniferous and progressively stabilised from south to north following the Hunter-Bowen Orogeny (Middle Permian to Late Triassic). The types of rocks present are mostly sediments (sandstone, shale, conglomerate and glacial deposits) and volcanics (mostly tuffs and felsic lavas).

The creek is located in a Pleistocene (~100,000 to 10,000 years ago) sand dune ridge swale system formed when the Pleistocene barrier was eroded by a storm surge to form the creek basin and subsequent deposition of the Holocene outer barrier partially blocked the eastern boundary of the basin. Rising sea level and the associated rise in regional groundwater then led to flooding of the depression forming a coastal lagoon. Figure 2.9 presents a geological map for the area surrounding Killick Creek estuary.

2.4 Topography

The Killick landscape is part of the Aeolian/Barrier landscapes. It is part of the larger Limeburners Barrier Dunefields which extend along the coastal strip from Port Macquarie to north of Hat Head and include Pleistocene backbarrier plains, low barrier beach ridge systems, high transgressive dunes as well as Holocene beach, foredune and backbarrier sandplain system (Atkinson 1999). The Killick Creek area shows low relief (9-70 m, usually <30 m). Elevation is <70 m and there are slopes of 10-50% in the dune areas (Atkinson 1999). The swamp areas behind the dunes have low relief and low elevation. Up in the hills elevation and relief rises to 250 m and slopes range from 10-30%.

2.5 Soils and Physiography of the Killick Creek Area

In the Early Pleistocene the shoreline near Crescent Head was located at the foot of the Dulkoonghi Range with a string of seven offshore islands from Hat Head, through Crescent Head to Point Plomer. Rising sea levels in the Pleistocene brought sand from the continental shelf linking the islands with barrier dunes. This created a lagoonal environment inland of the sand that permitted tidal water interchange between the present Hastings and Macleay rivers systems. The barrier dune was quite narrow between Crescent Head and Richardsons Crossing. In the Holocene, the narrow lagoon to the west of the sand barrier filled with estuarine deltaic sediments and lagoonal muds whilst to the east, young barrier sands formed a low barrier plain and foredunes. Killick Creek was an isolated coastal lagoon within this Holocene sand plain not connected to the swamp to the west.

Soil distribution in the area is related to these physiographic features (Figure 2.10). The soil landscapes were mapped by Atkinson (1999). The hills are Crescent Head Soil Landscape (ch, chs, chl) formed on Permian conglomerates and lithic sandstones of the Kempsey Beds. Soils are shallow stony Lithosols (Um2.12) on crests and sideslopes with Soloths (Dy2.41) and Yellow Podzolic Soils (Dy2.21) on lower slopes. Footslopes to the Dulkoonghi Range are the Beranghi Soil Landscape which have Red Podzolic Soils (Dr2.21) on crests and Yellow Podzolic Soils (Dy3.21) on footslopes.

Behind the paleo-offshore islands, wave refraction resulted in the deposition of sand plains of the Limeburners Soil Landscape which have deep, well-drained Podzol Soils (Uc4.24, Uc3.26). Windblown sands mantled some of the lower bedrock slopes forming the O'Connors Soil Landscape that also has deep, rapidly drained Podzols (Uc2.31). The main barrier dune ridge linking Crescent Head and Richardsons Crossing also has sand Podzol Soils (Uc2.32) and Siliceous Sands (Uc2.21) forming the Killick Soil Landscape. These soils have a hard pan layer at the watertable about 5 m below the dune crest. The Holocene sand plain to the east of this dune is mapped as the Plomer Road Soil Landscape. It is of 1-2 m elevation and consists of Podzols (Uc2.21) without pans. Acid sulfate soil conditions occur below the watertable.

The foredune is loose, windblown sand with immature Siliceous Sands (Uc1.21) and Calcareous Sands (Uc1.11) of the Goolwah Soil Landscape. Where these sands are stabilised and some topsoil has formed they are mapped as North Shore Soil Landscape.

Behind the dunes is a swampy plain of less than 1.0 m elevation which is differentiated into four soil landscapes. Delicate and Belmore Soil Landscapes are acid sulfate lagoonal sediments. In the Belmore Soil Landscape sediments grade from silty sands to muds forming Humic Gley Soils (Uf6.51) and Acid Peats (O). In the Delicate Soil Landscape they have a thin layer of peaty alluvium overlying muddy sands forming Humus Podzols (Uc5.11). Gladstone Soil Landscape is estuarine delta bars and levees formed near a previous river mouth and range from sandy to clayey alluvium adjacent to the Connection Creek Soil landscape which delineates the paleo-channel features of prior stream locations now forming low swampy linear depressions.

A schematic east-west cross-section from the ocean through Killick Creek to the Dulkoonghi Range is shown in Figure 2.11. This illustrates the relationships between soil types, physiographic features and vegetation types

2.6 Foreshore Features

Killick Creek enters the sea through a narrow channel at Crescent Head. There is a caravan park near the mouth along the rock-stabilised training wall. Other local features include a surf club, footbridge and a boat ramp. Some of the major foreshore features are presented on photographs in Figure 2.12 and 2.13.

2.7 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 Killick Creek.

The catchment characteristics, including land zonings and prominent features, are shown in Figure 2.14. 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 near the Muddy Arm tributary, services the growing population. This plant discharges treated effluent to the sea via an ocean outfall south of Little Nobby headland. Stormwater runoff from the Crescent Head residential areas discharges directly to the creek.

2.8 Stormwater Management

The Kempsey Shire Urban Stormwater Management Plan 2001-2005 (KSC in prep.) states that stormwater runoff from the Crescent Head urban area presents a number of threats and pressures to the lower reaches of Killick Creek. Stormwater from the urban residential area on the hillside, CBD, caravan park, recreation area and golf course drain untreated to the creek, which is popular for swimming and other holiday recreation.

The urban runoff poses nuisance and health hazards from litter, dog faeces and sewage contamination, which is especially likely from the caravan park. Nutrients, litter, fuels, oils and sediments are also likely to cause minor impacts to aquatic ecosystems in the creek, with the golf course likely to be a nutrient source.

The overall objective of actions listed in the Stormwater Management Plan is to minimise pollutants transported to Killick Creek using a range of strategies in the sub-catchment, including behavioural and other source controls supported by judicious local treatment at discharges (KSC in prep.).

2.9 Interaction of Belmore Swamp, Connection Creek and Killick Creek

Killick Creek is formally connected to the Macleay Flood Mitigation Scheme via Scotts and Killick drains and to the upper Maria River via Connection Creek. The Lower Macleay River floodplains are drained by Belmore River and Kinchela Creek. The connections between the Belmore River, Connection Creek and Killick Creek are presented in Figure 2.15. Flood cuttings to Killick Creek were first proposed at the end of the 19th century. In January of 1890 floods had opened a drain previously dug by landholders connecting the Belmore Swamp to Killick Creek to 21.3 m in width. It was not maintained and became overgrown. In the period 1930s to mid-1950s there were strong pleas for the cutting to be reopened, especially from the Crescent Head Progress Association.

Up to the 1950s floodwaters were stored in the Belmore and Kinchela swamps and formed semi-permanent wetlands. After the 1949 and 1950 floods the Macleay Valley Flood Mitigation Committee was established. The committee resulted in the Jacka Report in 1953 advising on options for flood mitigation works. As a result of this report headworks were constructed in Belmore River and Kinchela Creek to prevent backwater flooding of the backswamps. Drains with non-return floodgates were constructed in the backswamps to increase removal of floodwaters. Ocean outfalls were constructed at Korogoro Creek, Ryans Cut and Killick Creek (Webb McKeown 2000). The original concept of the Killick Creek ocean cut was to provide greater escape for floodwaters in time of flood and so reduce the time of inundation, and further to give drainage from the Belmore area between floods and provide for greater storage of floodwater when floods do occur and so reduce flood heights.

Floodgates have been installed at Scotts drain, Killick flood cutting and upper Connection Creek. The Killick Creek headworks were established in 1957. Figure 2.16 shows the works proposed for the Killick Creek flood cutting augmentation. It includes construction of the floodgates, deepening and widening of Killick Creek, establishment of a training wall to straighten the entrance and the dune system to be stabilised. The Belmore to Killick drain was established in 1964 (see Figure 2.17) and the connection to Scotts drain in 1974. Killick Creek drain now takes a large proportion of the water from the southern sector of the upper Belmore via Scotts drain (Webb McKeown 2000). A major impediment to the removal of floodwaters is the size of the single floodgate at Scotts drain (1.5 m in diameter) compared to the five substantial floodgates at Killick Creek. The Scotts drain floodgate has been modified to allow controlled flows from the Belmore River to enter. These flows (fresh) have been used successfully to restore large areas of salt-scalded pasture (pers. comm. Peter Haskins, DLWC).

The extent of flood mitigation drainage networks in the upper Belmore results in poor quality water from the Belmore floodplain flowing into the lower Macleay River and Killick Creek. Excessive drainage of low-lying lands results in longer water residence times and associated deteriorating water quality. The Killick Creek floodgates are hinged and open automatically when the water level above the headworks is higher than that below the headworks. The only way the outflow can be stopped is through the insertion of dropboards. In the period 1958-1972 Council inserted the dropboards on three occasions (letter from Council to the Minister for Environment Control 1972). All occasions were during school holidays when Council was sympathetic to pleas of local residents in light of tourist activity during that time. There is no accurate record of the use of dropboards since the 1970s, but Council is known to install them during school holidays (pers. comm. KSC). Currently dropboards are actively managed in consultation with upriver landholders.

The problem of saltwater intrusion onto low-lying land along Scotts drain is of particular concern to landholders and raises concerns regarding the Killick Creek floodgates. The major cause of salt intrusion was through failed subordinate floodgates which were located under the road approach to the headworks. Council has now cemented in these structures and has installed a permanent water quality monitor to alert for future saline ingression.

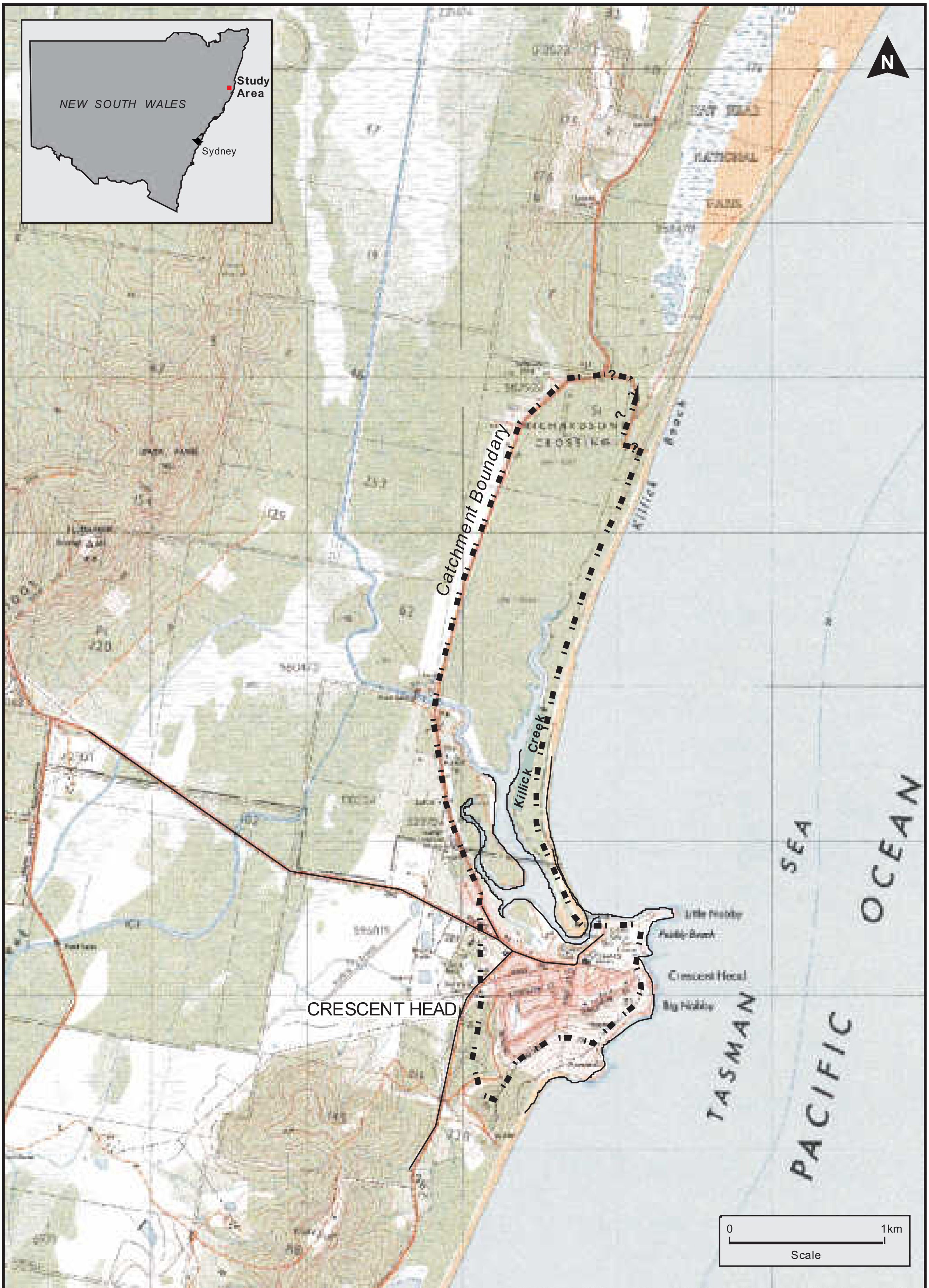
2.10 Flood Control

Floodplain management strategies have been developed for the lower Macleay (Webb McKeown 1999) and the upper Belmore (Webb McKeown 2000). The Lower Macleay Floodplain Management Plan recommends establishing 12 drainage management areas, including the upper Belmore. Within the Upper Belmore Floodplain Management Strategy Scotts and Killick drains form one of the management groups.

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 two largest historical events, 1949 and 1950, approach the 1-in-100-year flood. Figure 2.18 presents the 1-in-100-year flood levels for the lower Macleay floodplain including Killick Creek.

During non-flood times the Belmore floodway is kept closed. Historically the floodway is opened when flood levels reach 4.1 m at Kempsey traffic bridge (Webb McKeown 2000). When the floodway opens water rapidly inundates the backswamp, increasing water depths and flooding pastures in the upper Belmore area. Council is currently raising the levees on the Belmore River and Kinchela Creek in order for the floodways to be kept closed longer (Webb McKeown 1999).

On occasions of high floods in the Hastings River, catchment water will flow from that catchment into the upper reaches of the Belmore through Connection Creek. Flood waters in Connection Creek can be removed via ocean outfalls at Ryans Cut, Killick Creek and Big Hill Cut (Figure 2.15).



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LOCALITY PLAN

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Figure 2.1

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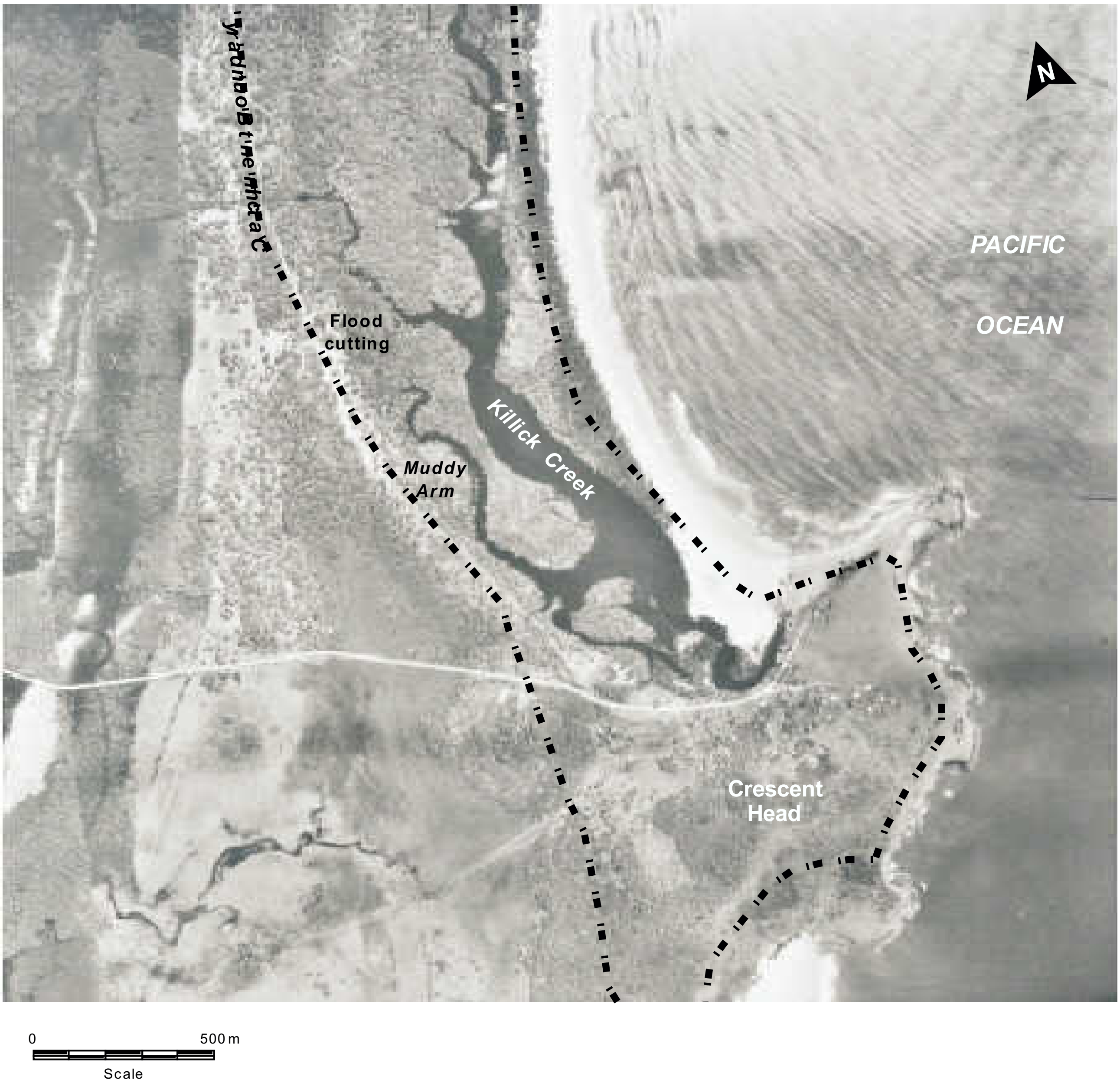

Source: Department of Land and Water Conservation

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KILLICK CREEK - 1942 AERIAL PHOTOGRAPH
CLOSED ENTRANCE CONDITIONS

MHL
Report 1125

Figure
2.2

DRAWING 1125-02-02.CDR

Source: Department of Land and Water Conservation

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KILLICK CREEK - 2000 AERIAL PHOTOGRAPH

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Figure 2.3

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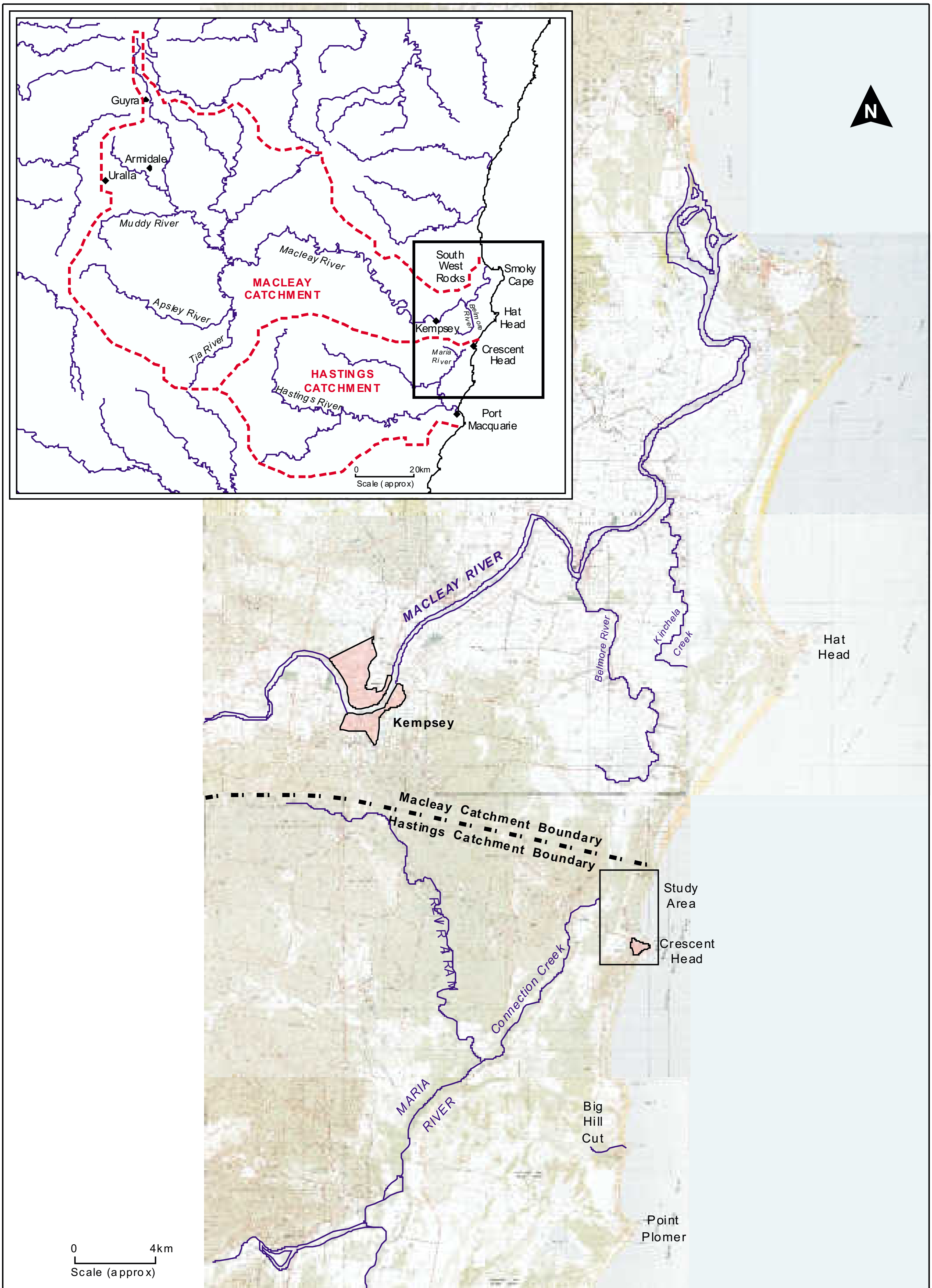

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MACLEAY VALLEY CATCHMENT

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Figure
2.4

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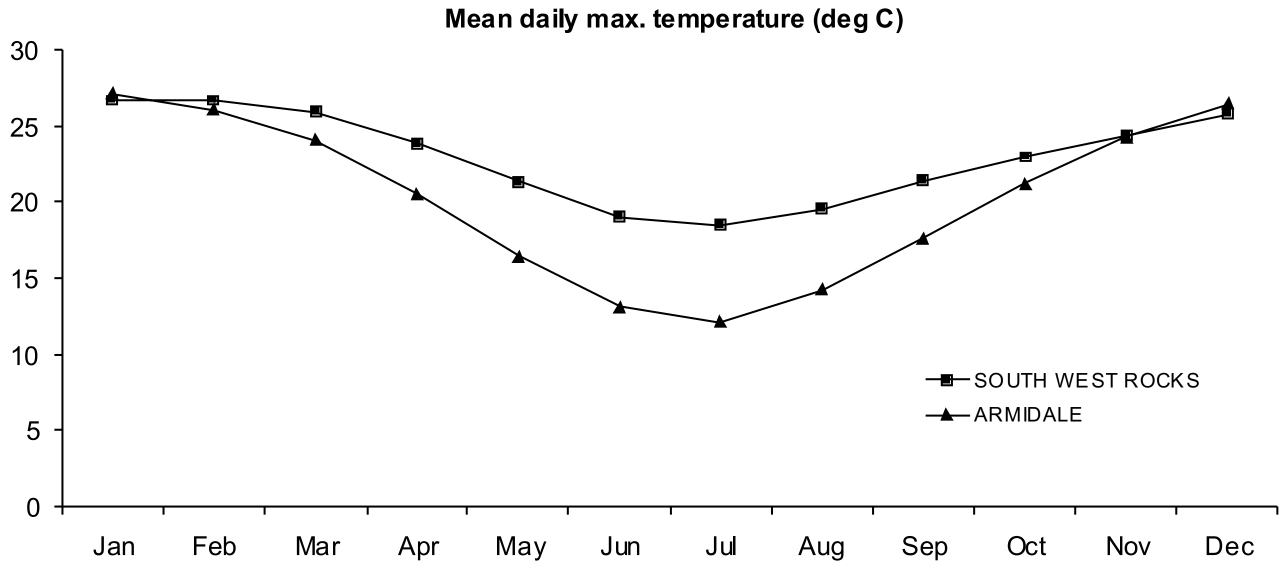
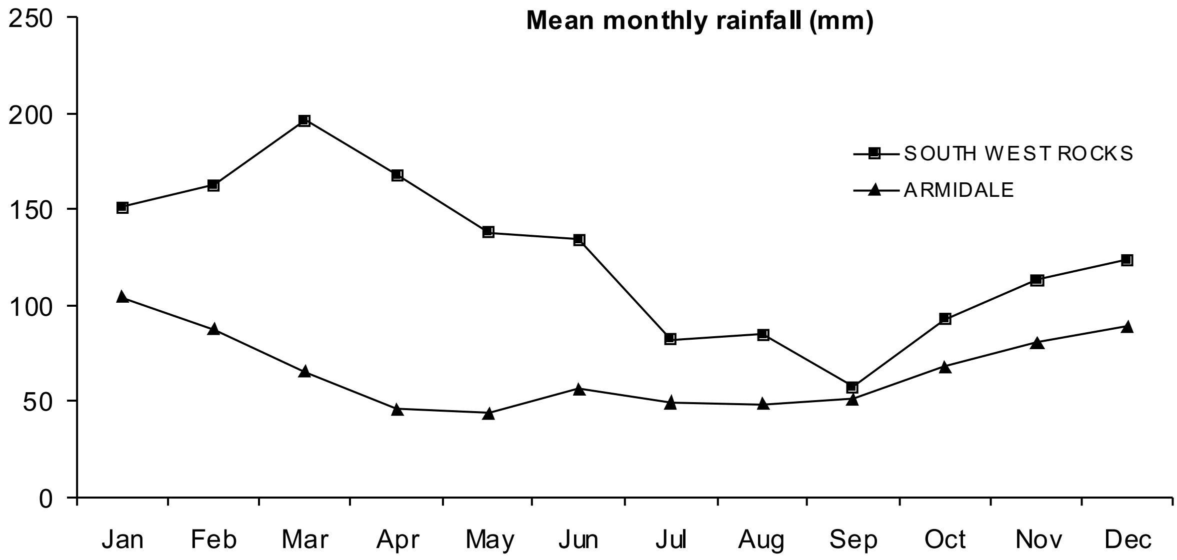


NSW DEPARTMENT OF PUBLIC WORKS AND SERVICES MANLY HYDRAULICS LABORATORY	MEAN DAILY MAXIMUM TEMPERATURE (degC)	MHL Report 1125 Figure 2.5 DRAWING 1125-02-05.CDR



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MEAN MONTHLY RAINFALL (mm)

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Figure 2.6

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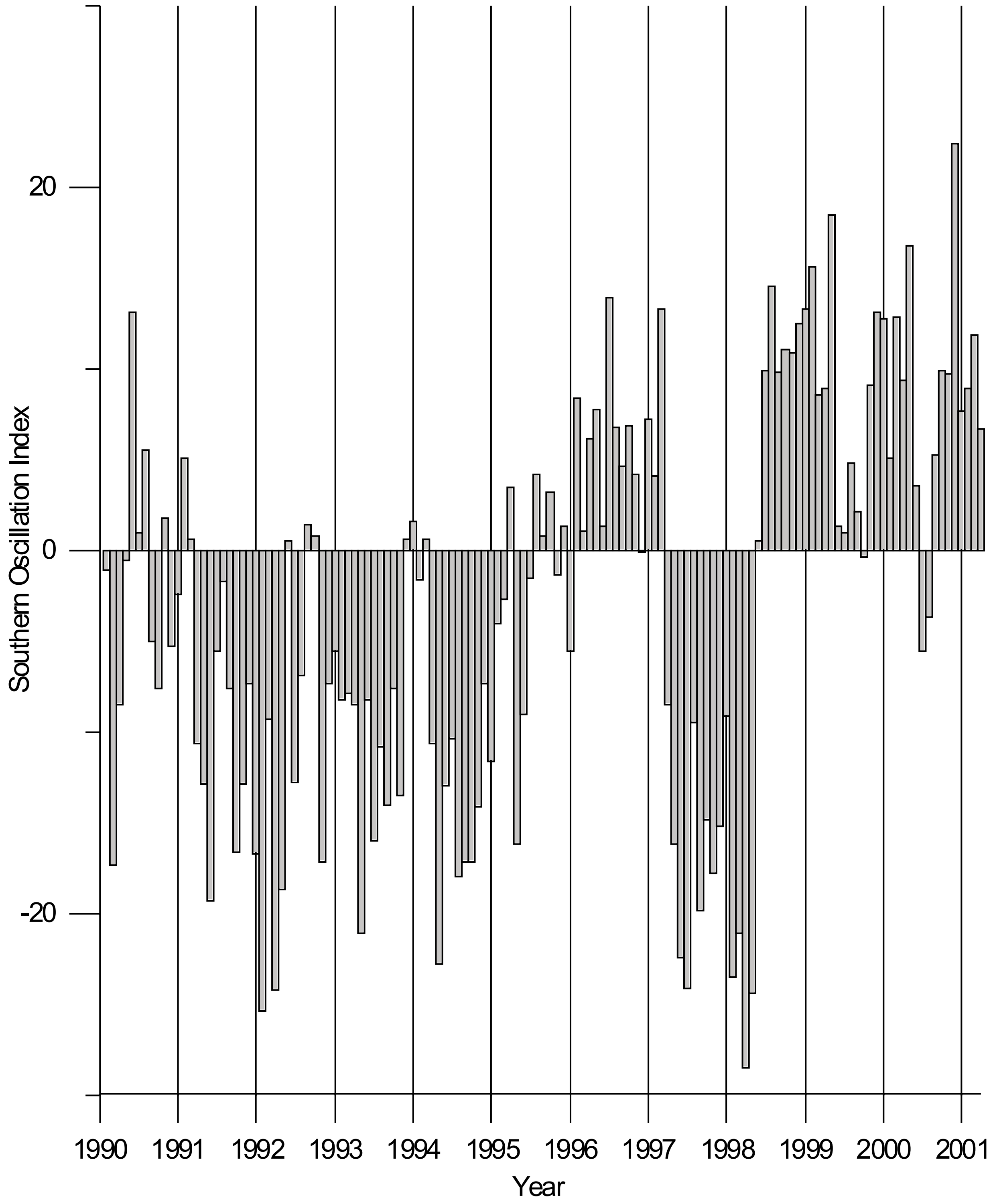

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SOUTHERN OSCILLATION INDEX
1990 - 2001

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Figure 2.7

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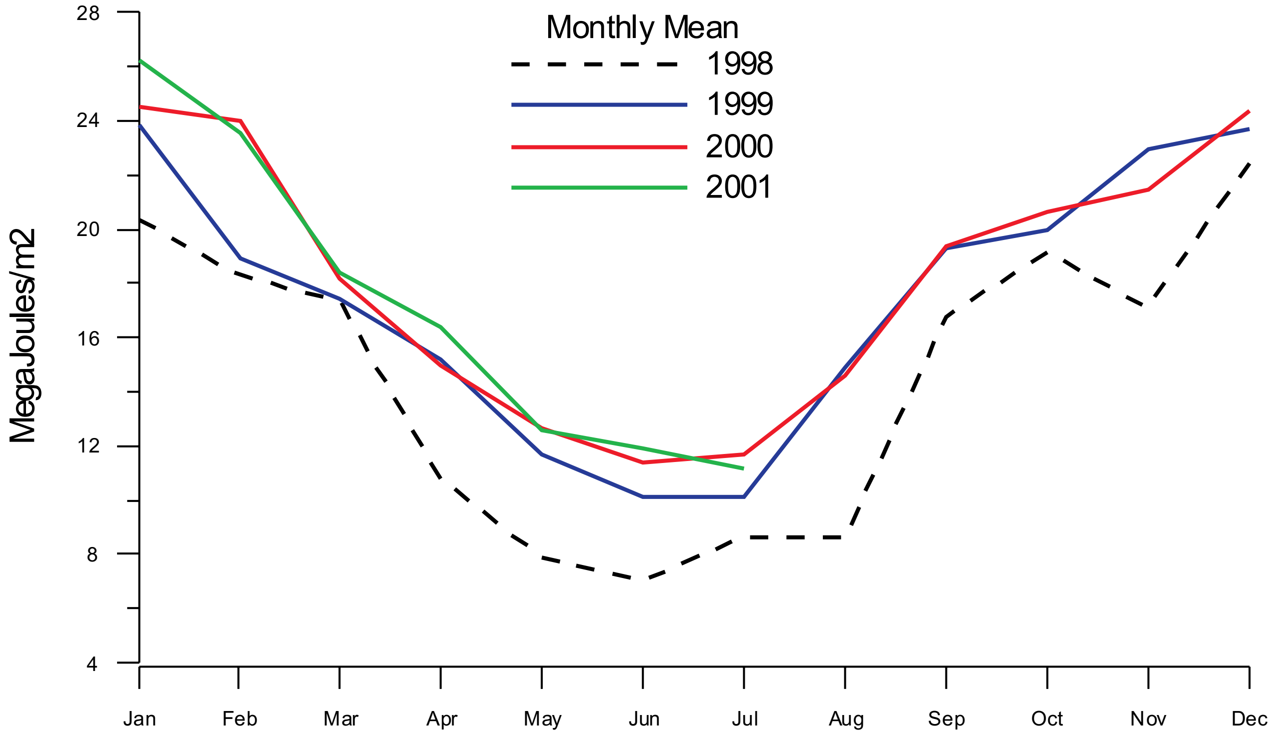

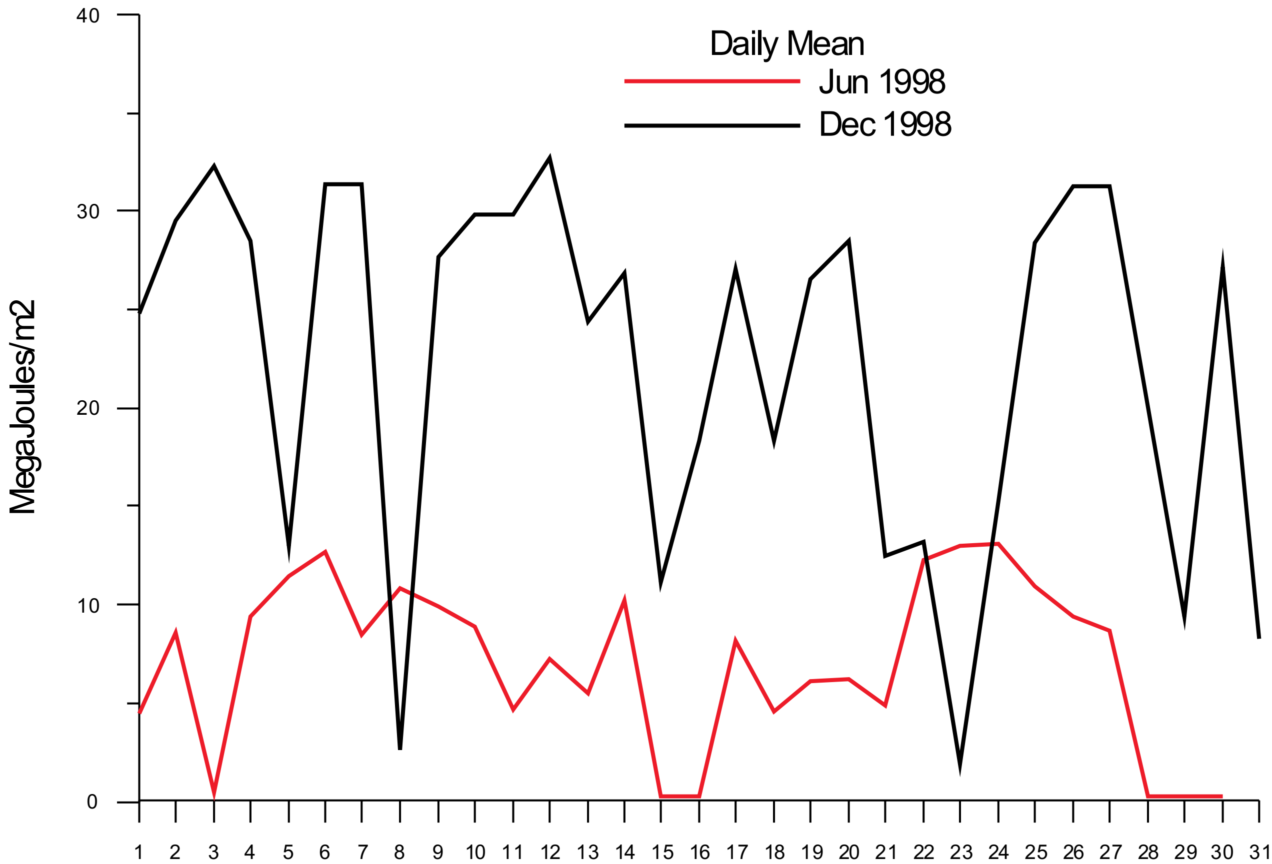

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GLOBAL SOLAR EXPOSURE - SOUTH WEST ROCKS

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Figure 2.8

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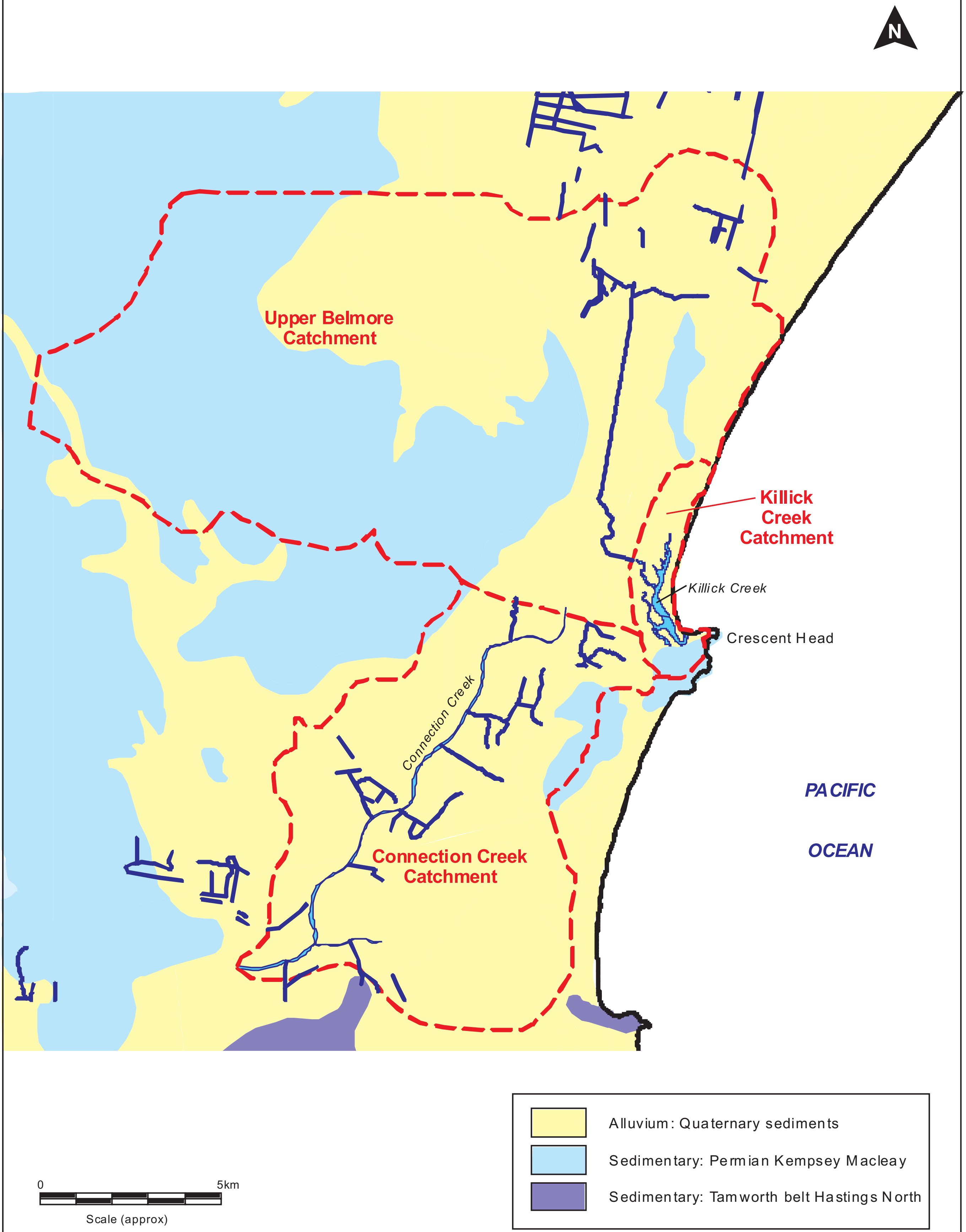

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GEOLOGY

MHL Report 1125

Figure 2.9

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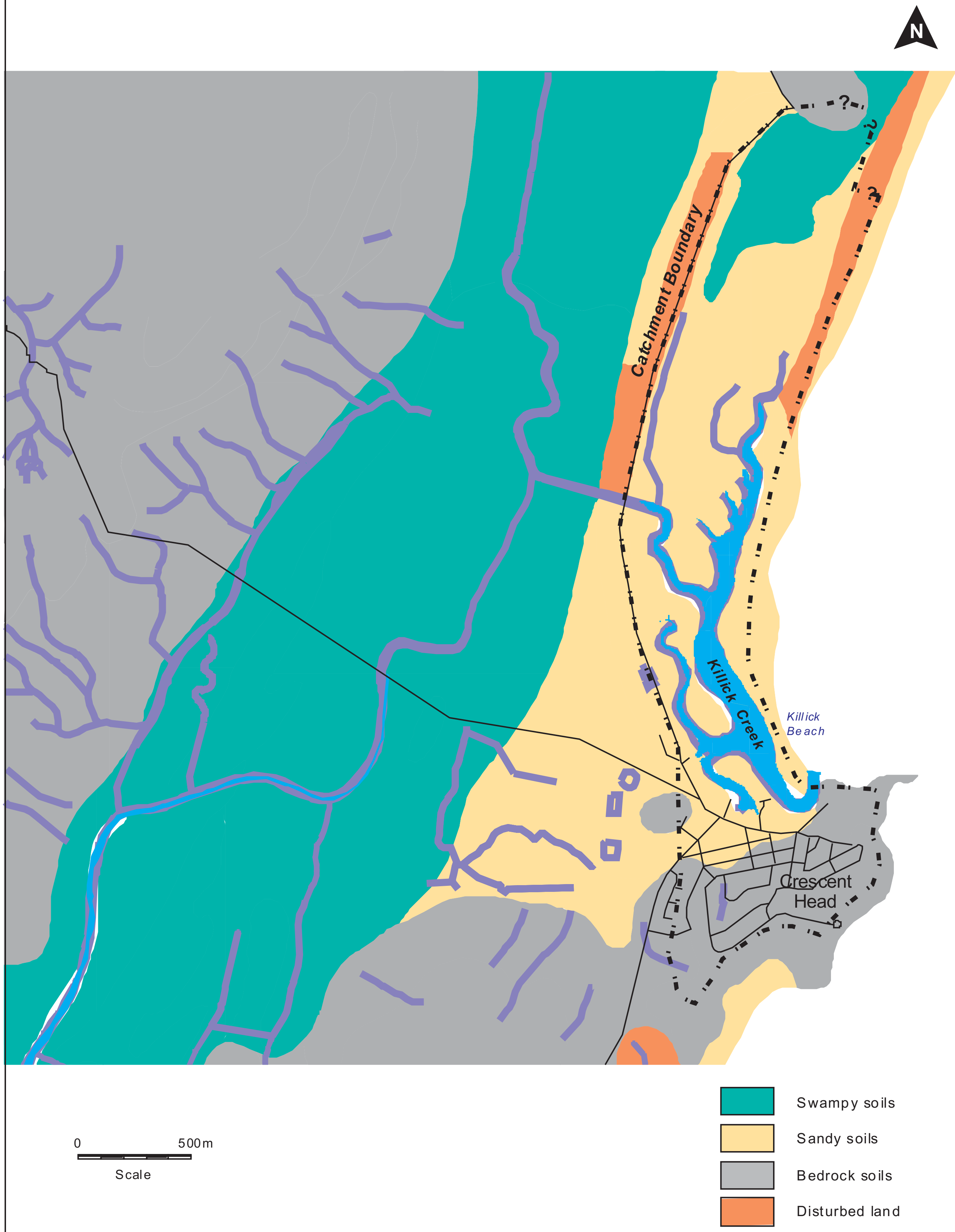

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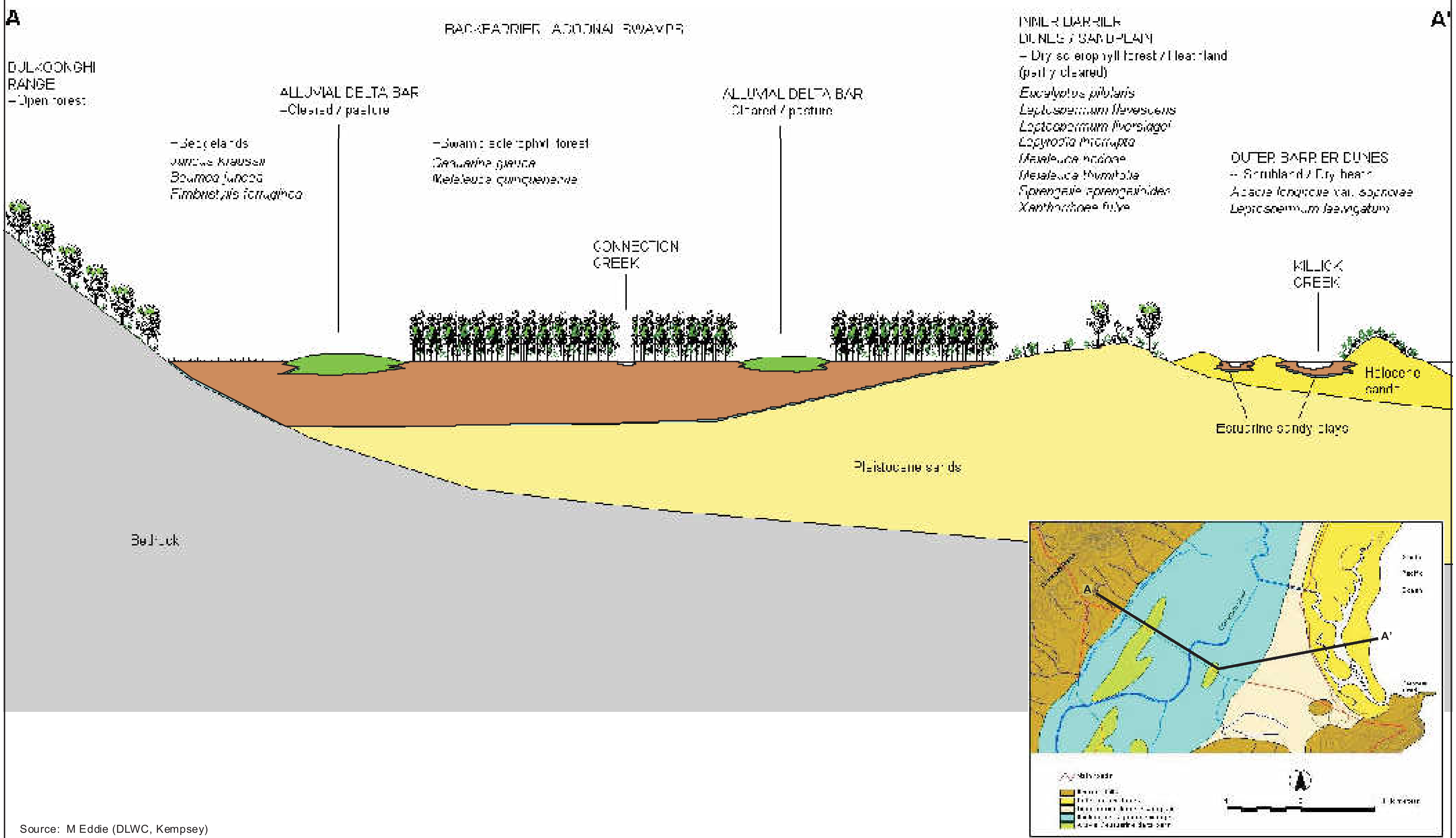
SOIL DISTRIBUTION

MHL Report 1125

Figure 2.10

DRAWING 1125-02-10.CDR



Source: M Eddie (DLWC, Kempsey)

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SCHEMATIC CROSS SECTION OF KILLICK CREEK CATCHMENT

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Figure 2.11

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FORESHORE FEATURES

MHL Report 1125

Figure 2.12

DRAWING 1125-02-12.CDR

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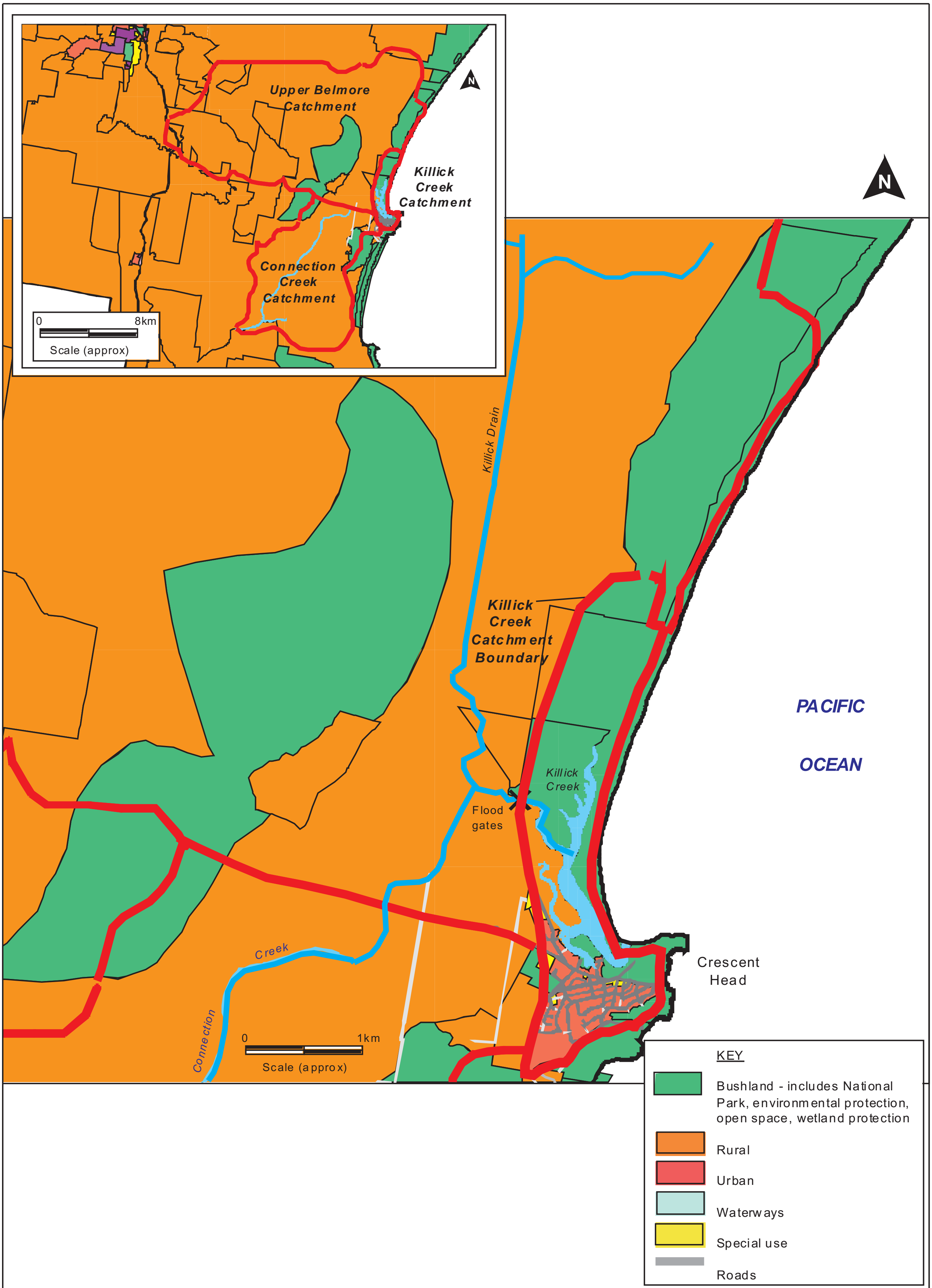
FORESHORE FEATURES

MHL Report 1125

Figure 2.13

DRAWING 1125-02-13.CDR



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LAND USE

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Figure 2.14

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INTERACTION OF BELMORE RIVER, CONNECTION CREEK AND KILLICK CREEK

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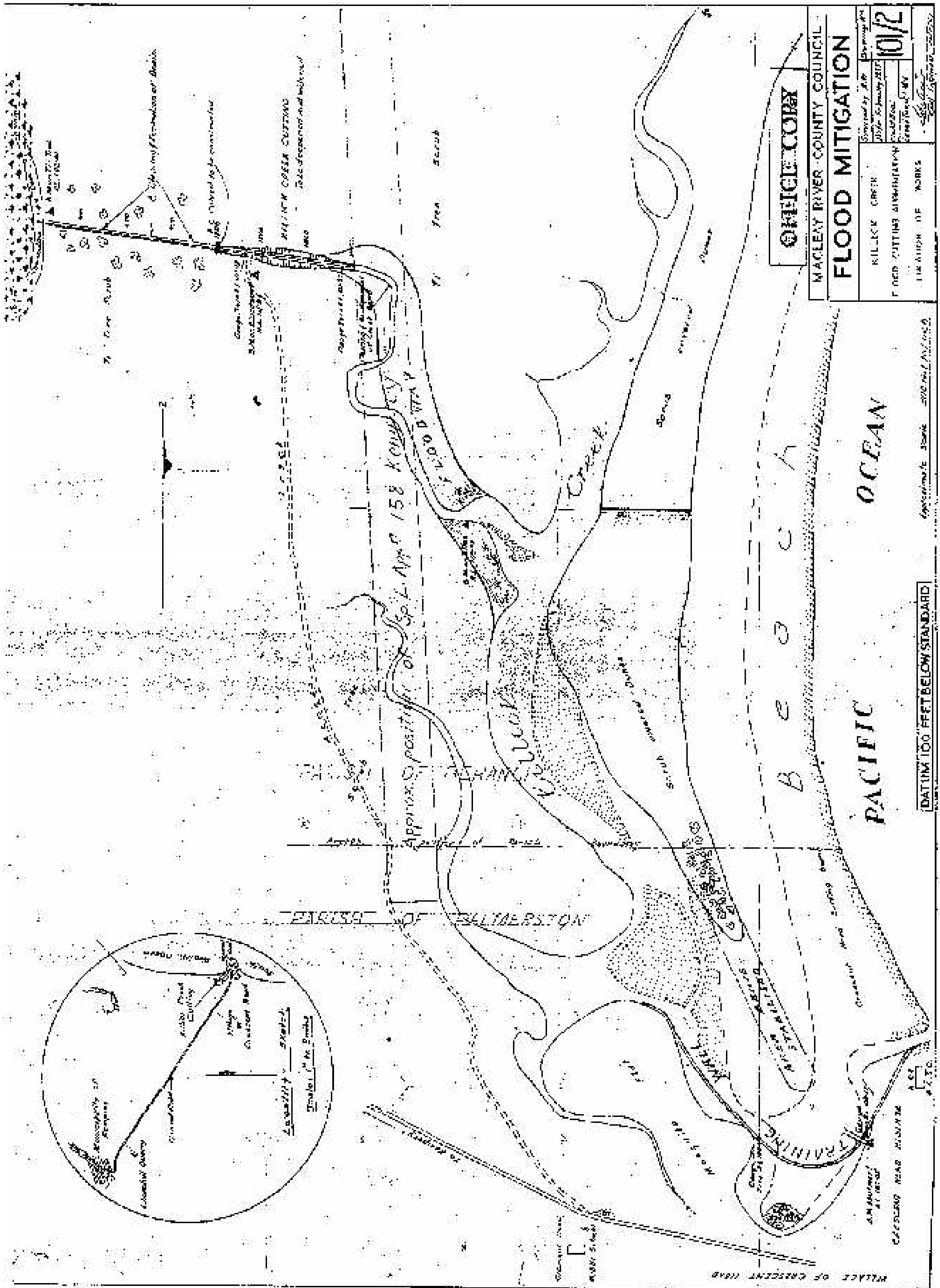
Figure 2.15

DRAWING 1125-02-15.CDR



Source: Macleay River County Council, February 1957

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LOCATION OF WORKS
KILLICK CREEK FLOOD CUTTING AUGMENTATION

MHL Report 1125

Figure 2.16

DRAWING 1125-02-16.CDR

Clearing and excavating waterway through ti-tree jungle

Aerial view of completed waterway

Source: Macleay River County Council, October 1966

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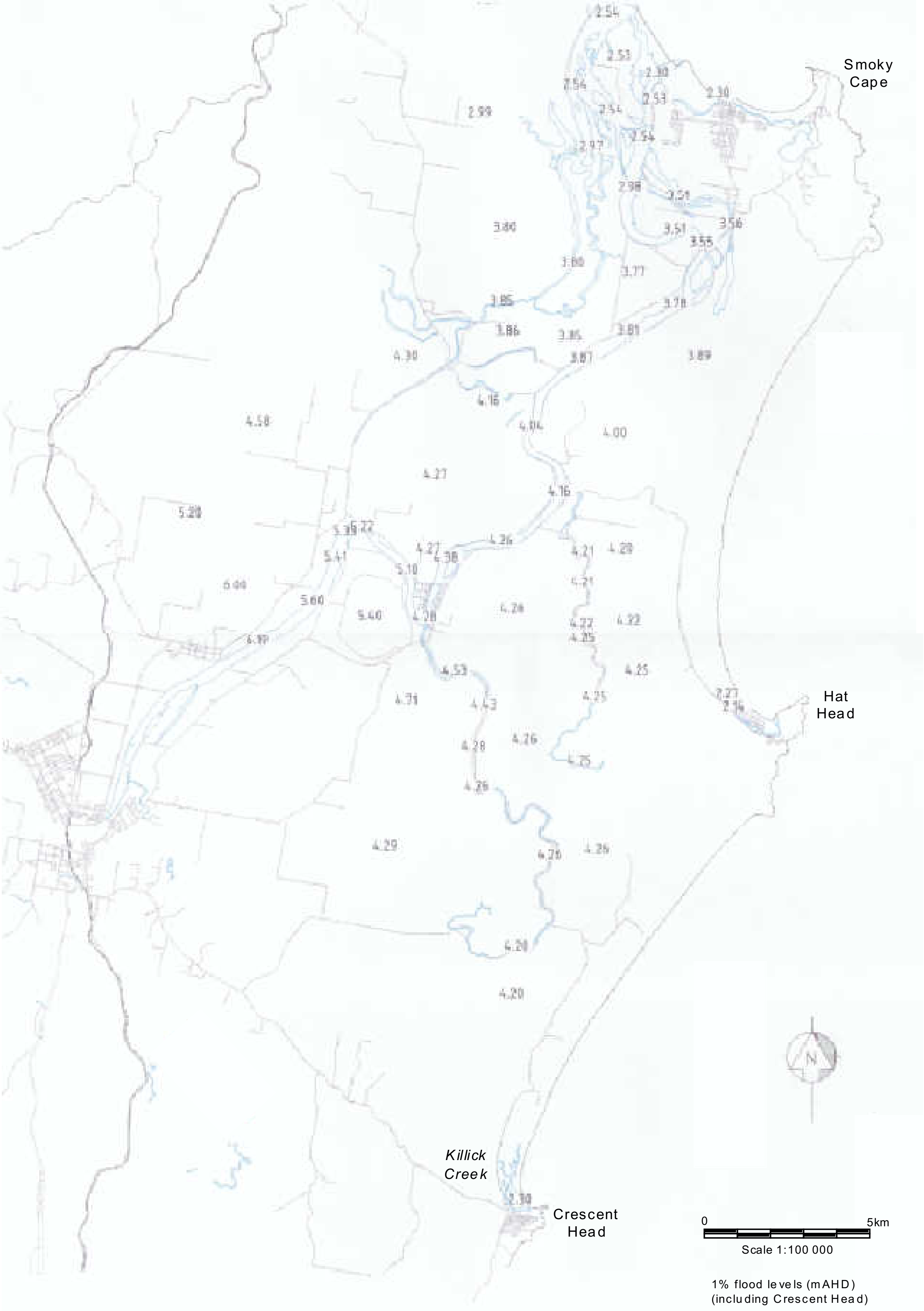
BELMORE RIVER TO KILLICK CREEK WATERWAY

MHL Report 1125

Figure 2.17

DRAWING 1125-02-17.CDR



Source: Webb McKeown, 1999

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1-IN-100-YEAR FLOOD LEVELS

MHL Report 1125

Figure 2.18

DRAWING 1125-02-18.CDR