3. Hydrodynamics

3.1 Existing Hydrodynamic Data

3.1.1 Previous Studies

There are no previous studies of the hydrodynamics of the overall estuary. During the planning of the Killick flood drain hydraulic design calculations were made to assess the optimal depth, width and channel construction features. These calculations are reported in files and letters held at Council and by DLWC. The original channel was designed for a discharge capacity of 13,000 cusecs or 368 m^3s^{-1} (cubic metres per second). The constriction to the hydraulic capacity caused by the tidal stage at the entrance was recognised and it was recommended that the entrance area be maintained in a state that optimised as large a channel as possible to allow unimpeded discharge of flood waters. An interesting perspective on proposed modifications to the original design as presented to a meeting of the Belmore River branch of the PPU on 3 July 1957 is provided in the following extract from the files:

> **'Killick Creek Flood Cutting (1957)**
>
> **1. Operation of existing cutting during February-March floods, 1956**
>
> As you know, the cutting discharged water from the swamps for a considerable period during the floods of February and March, 1956, when valuable data was obtained as to its functioning. The results obtained indicated that the cutting operated more satisfactorily than was anticipated.
>
> Over a period of 16 days, from 20th February to 7th March, a total of 21,440 acre feet were discharged with a peak discharge of 1100 cusecs or 2200 acre feet in 24 hours.
>
> It has been calculated that for a 1950 type flood its peak discharge would be 6,000 cusecs or 12,000 acre feet in 24 hours.
>
> **2. Additional Works now to be undertaken**
>
> (a) Deepen and enlarge the cutting – extra depth 6 ft.
> (b) Clear and excavate a channel from Connection Creek to the Cutting.
> (c) Construct a combined culvert and floodgate structure near entrance to cutting.
> (d) Improve capacity of Killick Creek near entrance to Ocean.
> (e) Investigate, and if found necessary, provide protection against floodwater for Mosquito Flat.

3. Extra capacity due to proposed works

(a) Cutting will commence to function when swamp level is 2'6" to 3'0" lower than at present.
(b) Capacity will be at least quadrupled at low stages.
(c) Capacity will be at least trebled at intermediate stages.
(d) Capacity will be at least doubled at high stages.

4. Anticipated benefits due to proposed works

(a) Swamp will be maintained at a lower level than now prior to floods.
(b) Peak height of floodwater in Belmore Basin will be lowered – about 9" for a flood such as March, 1956.
(c) Time of inundation will be reduced – For the flood of March, 1956, the corduroy to Crescent Head would have been clear of water 5 days sooner and the swamp would have reached a level 1 foot lower than the corduroy 14 days sooner."

As part of this project MHL conducted a site inspection on 5 April 2001. During the inspection water quality data were collected using a Hydrolab multiprobe to record vertical profiles of temperature, salinity, dissolved oxygen, pH and turbidity at three sites within the estuary (Figure 3.1). On 1 May 2001 DLWC conducted a more detailed exercise using more sophisticated instruments. They also deployed water level recorders near the entrance and about two kilometres upstream for a two-month period. In addition DLWC conducted a detailed bathymetric survey of Killick Creek in early April. The collected data are described in MHL (2001) and sites are shown in Figure 3.1.

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

3.2 Tidal Characteristics of Killick Creek

3.2.1 Preliminary Volumetric Assessment

A simple volumetric analysis of the tidal hydraulics provides a useful preliminary understanding of the tidal effects. Using the bathymetric data (depths to Australian Height Datum or approximately mean water level) provided by DLWC (as uncontrolled data) and water level measurements, a range of variables that highlight the tidal characteristics may be derived (Figure 3.2). Typical tidal prisms have been calculated from best estimates using the available data.

Maximum depth, average depth and cross-section width at roughly 50 m intervals along the inlet and up to the floodgates were derived from the bathymetric data. The cross-section area at each location was calculated as depth multiplied by width and the inlet volume was estimated as average cross-section between adjacent locations multiplied by the downstream distance between the locations. Note the depth decreases from the ocean to the confluence of Muddy Arm with the main arm and then increases upstream in the flood cutting arm. This profile has implications for stratification and water exchange in the deeper upstream areas (see Section 3.5).

The tidal prism at mean neap and mean spring tides (see Section 3.2.5) is of similar size or larger than the inlet volume and hence in an overall sense the system should be well flushed. The mean tidal velocity (average cross-section velocity over the tidal period) decreases in the upstream reaches where the tidal prism diminishes and the depth increases. This suggests that the upstream reaches may be subject to lower mixing due to tidal-induced turbulence and hence a possibility of stratification.

The depth-averaged flushing time provides an estimate of the bulk water flushing and as indicated by the relatively large tidal prism suggests the system is well flushed.

This discussion is based on a knowledge of the bulk characteristics and as such provides a first order assessment. It must be remembered that other factors may cause deviations from this bulk behaviour. For example following a fresh event the vertical stratification in the deeper areas may lead to longer residence times within the deeper waters. Longer residence times in the deeper waters leads to deoxygenation of the deeper water by microbial consumption. This in turn affects the sediment/water fluxes of nutrients and may lead to increased nutrient concentrations in the deeper waters. During a mixing event these high nutrient/low dissolved oxygen waters mix to the surface and may have consequences for algal growth and survival of fauna, respectively.

3.2.2 Water Level Variability

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

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

3.2.3 Tidal Planes

Astronomic tides are the ocean's response to the gravitational attraction of the planets. Each of the planetary and lunar orbits and the earth's rotation occur at set frequencies that force oscillations of the oceans - the tides – at similar frequencies. The major tidal components along the NSW coast occur in response to the lunar and solar attractions interacting with the rotating earth. The tides in the region are dominated by the semi-diurnal (twice per day) constituents with a strong spring-neap cycle as shown in the water levels recorded near the entrance, upstream and in the ocean at Crowdy Head (Figure 3.3). The figure highlights the attenuation of the tides between the ocean and the entrance gauge near the footbridge but little attenuation between the footbridge and the floodgates. While the Killick cutting arm is tidal up to the floodgates the tidal range in the main arm presumably diminishes into low-lying areas adjacent to the waterway.

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

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

Table 3.1 Tidal Planes for Killick Creek Estuary

Tidal Plane	Ocean Crowdy Head	Killick Entrance	Killick Upstream
HHWSS	1.139	0.983	0.926
MHWS	0.693	0.611	0.572
MHW	0.577	0.535	0.503
MHWN	0.462	0.458	0.433
MSL	0.037	0.156	0.155
MLWN	-0.388	-0.146	-0.124
MLW	-0.504	-0.223	-0.193
MLWS	-0.620	-0.299	-0.263
ISLW	-0.938	-0.564	-0.516
HHW to ISLW	2.077	1.547	1.442
MSR	1.313	0.910	0.835
MNR	0.850	0.605	0.557

Note: Data relative to Australian Height Datum (AHD)

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

(See Appendix D for definitions of tidal planes)

3.2.4 Tidal Phasing

The tidal phasing relates to the rate of propagation of the tides into the estuary. Using the data collected at the ocean, inside the inlet near the footbridge and upstream near the floodgates provides a measure of the time lag between high tide in the ocean and high tide at these two inlet sites. The methodology for calculating the tidal phases is described in MHL (2001) and results are presented in Table 3.2.

Table 3.2 Time Lags Between High and Low Water in the Ocean and Two Sites in the Estuary

Site	Mean Lag	Mean High Water Lag	Mean Low Water Lag
Footbridge	42 minutes	21 minutes	62 minutes
Flood cutting	53 minutes	25 minutes	76 minutes

Notes: Footbridge site is about 500 m upstream of the entrance
Flood cutting site was about 2000 m upstream of the entrance

3.2.5 Tidal Prism

The tidal prism is shown in Figure 3.2 and for the whole estuary varies between about 90 x 10^3 m^3 at mean neaps and about 130 x 10^3 m^3 at mean springs. The estuary volume at mean sea level is approximately 95 x 10^3 m^3.

3.2.6 Tidal Excursion

The tidal excursion is the distance a water parcel travels during the ebb or flood flow. This distance assumes that the velocity at each point applies to the neighbouring locations. For the Killick Creek estuary the average tidal excursion is largest near the entrance and diminishes upstream. The excursion distance near the entrance is around 2 km (roughly the length of the estuary) and in the flood cutting reduces to around 300 m. These estimates suggest that vigorous mixing and flushing occur near the mouth but upstream in the flood cutting the water may remain trapped for several tidal cycles.

3.2.7 Flushing Times

The bulk water flushing times estimated using the kinematic assumption from conservation of volume principles vary between about one day and four days at the upstream reach. The flushing times may also be calculated from measurements of salinity and a knowledge of the freshwater inflow. These latter estimates provide more information on the spatial variability, particularly as to the importance of vertical stratification. Estimates derived from salinity and freshwater inflow are discussed in Section 3.3.

3.2.8 Low Frequency Sea Level Oscillations

Low frequency sea level oscillations include phenomena with periods greater than about four days such as the coastal trapped waves that propagate up the NSW coast causing ocean water level changes of around 0.1 to 0.5 m. These changes are transferred to the estuary and result in significant changes in the water volume within the estuary. As these oscillations are smaller than the tidal range throughout much of the estuary they are masked by the tidal oscillations in the water level measurements. The tidal residuals presented in Figure 3.3 highlight these oscillations during May 2001 when a significant increase in the average water level occurred between 6 and 8 May and then a gradual decrease ensued between 9 and 18 May.

While these oscillations are generally not important in the main part of the estuary they become a major component of the water level variability in the extremities where the tidal oscillations diminish. For example, the exchange of water between the wetland areas surrounding the upper part of the main arm are likely to be influenced by these longer period water level changes as the tidal influence is negligible in these areas.

3.3 Freshwater Inflows

Freshwater inflows to the estuary are derived from the local catchment at Crescent Head and low-lying areas to the north of Killick Creek, as well as the important sporadic inflows from the Belmore Swamp via the Killick flood cutting. Estimates of the inputs from the local catchment may be derived from a simple rainfall runoff relationship. Within the scope of this study it is not possible to derive estimates of the flows through the Killick floodgates but the available water level data may be used to provide qualitative information about when flows occur.

The average monthly discharge entering the estuary from the local catchment area (5 km^2) is estimated by assuming a runoff coefficient of 0.15 which is typical for these catchments and applying the average monthly rainfall statistics available for South West Rocks (the nearest station to Killick Creek). Dividing the estuary volume by the monthly inflow volume provides an estimate of the number of days required for the inflow to replace an equivalent estuary volume. Note the relatively long time for local runoff to replace the estuary volume is considerably longer than the estimated tidal flushing time of around three days. Although this low inflow may not be significant in terms of its volume for replacing the estuary volume it may be significant as a source of fresh water that influences the stratification (see Section 3.5).

Table 3.3 Monthly Freshwater Inflow Volume (,000 m^3) and Number of Days to Replace the Estuary Volume of 95 x 1000 m^3

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Runoff from Crescent Head	114	122	147	126	103	101	61	64	43	69	85	93	1128
Days to replace estuary volume	25	23	19	23	28	28	46	45	66	41	34	31	31

The influence of the inflow from Belmore Swamp via Killick flood cutting may be described by comparing the water levels upstream of the floodgates with the water levels in Killick Creek and the ocean (Figures 3.4 and 3.5). Unfortunately the Killick Creek estuary water level sites were established after the major floods of early March 2001, so a comparison of the Belmore Swamp level (Killick Creek floodgates U/S) with the ocean levels at Crowdy Head are shown in Figure 3.4. It is interesting to note that the water level in the Belmore Swamp shows a typical rise in response to the inflow of floodwater from the catchment as well as a tidal signal after the major flood level has receded (Figure 3.4).

While the data presented in Figure 3.4 indicate a major inflow event from both the local catchments (upper Belmore and Connection Creek) and Macleay River, smaller local events also cause a flow through tidal flap floodgates (Figure 3.5). The Killick cutting water levels are compared with the levels in Killick Creek at the footbridge. The situation shown in Figure 3.5 demonstrates the complex response of the water level in the Belmore Swamp to both the tidal regime in the estuary and the longer period oscillations (discussed in Section 3.2.6) and spring-neap cycle. Hence it is very difficult to gain a quantitative estimate of the flow within the flow gauging exercise that would lead to a relationship between water level and discharge. Assuming a discharge of around 100 m^3s^{-1} (8640 x 10^3 m^3day^{-1} or roughly 90 estuary volumes per day) during the major event suggests that the estuary would be completely flushed by the freshwater inflow and highlights the major effect that such sporadic floods may have.

3.4 Conceptual Water Balance Model

A conceptual water balance model is shown in Figure 3.6. The major water inputs and outputs are the tidal prism, water inflow via the Killick cutting during major regional events and inflow from the local catchment with significant local rainfall. Other less significant inputs include groundwater, and outputs include evaporation and groundwater flow through the coastal dune to the ocean. The catchment of Killick Creek extends north of the main arm towards Ryans Cut, but there is insufficient information to determine the extent and nature of inflows from this area.

3.5 Stratification and Mixing Processes

Data collected in Killick Creek in January 1992 by University of New England (UNE 1993) showed that at the time of sampling water in the deeper parts of the creek was distinctly stratified into an upper layer that was well mixed with inflowing tidal water and a colder stagnant lower layer with a lower percent dissolved oxygen saturation. The percent dissolved oxygen saturation drops by about 5% over a few centimetres across the boundary between the two water bodies and continues to decline toward the sediment-water interface. This is the first reported evidence that the stratification may be a significant factor for water quality.

The recent vertical water quality profiler measurements collected by MHL on 5 April 2001 and DLWC on 1 May 2001 show also the presence of stratification in the upper deeper reaches of the estuary but generally well-mixed conditions in the lower reaches. This is typical of tidal estuaries after freshwater inflow events, such as occurred in March 2001. The freshwater inflow from the catchment continued for several weeks after the event. While the presence of stratification is of interest the significant factor is how long the stratification persists and hence affects the water residence time. If the stratification persists and inhibits vertical exchange between surface and deeper water layers then the dissolved oxygen in the lower layer will decrease due to consumption by microbial activity.

The data presented in Figure 3.7 indicate a complex pattern of mixing, with the different variables suggesting different processes. While the salinity data suggest a typical saline intrusion of dense salty ocean water along the bottom, the temperature and dissolved oxygen indicate a different water age at different locations. Inspection of the floodgates suggested that at the time of sampling freshwater inflow only was occurring via the floodgates and the character of this inflow is influencing the upstream Site 3 (Figure 3.7), with vertically well-mixed, cold, low salinity water. Unfortunately the dissolved oxygen (DO) data is not reliable at this site as the sensor was not allowed to stabilise before the profile was collected resulting in very low DO near the bottom which occurs as the sensor equilibrates to its surroundings. It is likely that the DO was relatively low throughout the water column and probably lower than at the other two sites.

Further downstream at the deeper Site 2 near the confluence of the flood cutting with the Killick Creek main arm the water is warmer and saltier with a strong stratified layer in the bottom 0.2 m. Interestingly the surface water is low in DO, 50%, and the deeper water is high in DO, indicating the presence of warm, salty and well-oxygenated oceanic water that recently penetrated to this depth. At Site 1 the salt stratification is well developed with a gradient of around 10 ppt over the 1 m depth. Surface pH values are frequently below pH 5, while deeper sections show values generally above pH 7, reflecting intrusion of saline oceanic water (pers. comm. Peter Haskins, DLWC).

The emergent picture for this day is that the water, although stratified, is undergoing vigorous mixing between the low DO inflow and the high DO oceanic water. This is in contrast to the situation described by the UNE sampling in January 1992 when presumably the conditions were more stagnant, with little freshwater input, and the lower DO water was observed in the deeper layer. These two situations highlight the difficulties of interpreting limited data that is affected by the antecedent processes. For similar observed stratification the actual mechanisms are quite different, leading to the different DO signals.

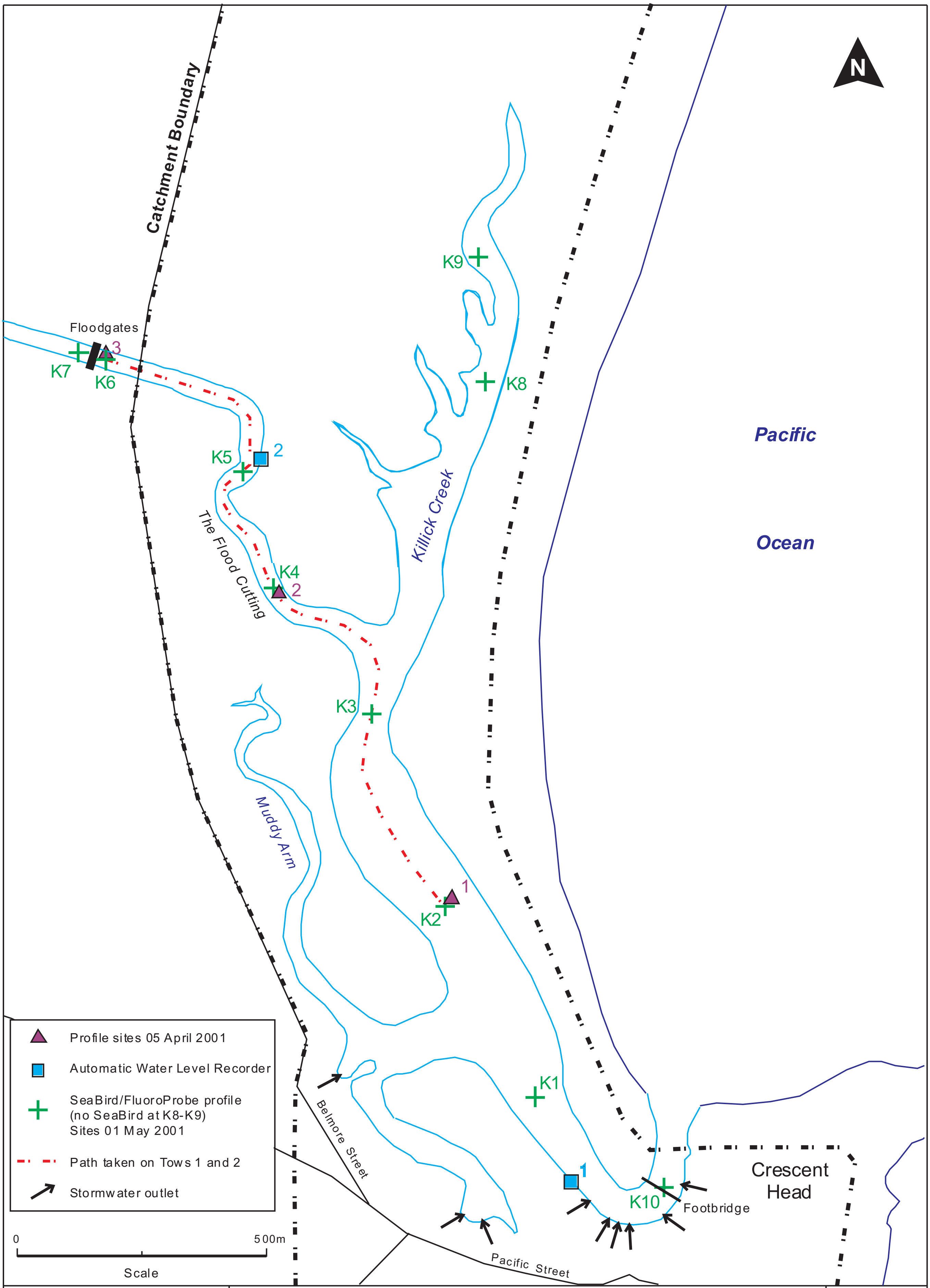
Council is presently maintaining a water quality monitoring station immediately above the floodgates. The data provides an insight into blackwater (high pH, low DO) events associated with significant flooding and pasture inundation (pers. comm. Peter Haskins, DLWC). These instruments need to be maintained to ensure the quality of the data collected so that our understanding of processes can be improved.

3.6 Conceptual Model of Circulation and Flushing

Water circulation is dominated by tidal flows and superimposed over these daily variations is a long-term salt wedge-like exchange flow driven by the freshwater inputs to the creek (Figure 3.8). 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.

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

The flushing characteristics of Killick Creek are complicated by the complex hydraulic processes caused by the floodgates in Killick flood cutting. The floodgates open due to water pressure from behind allowing drainage of the Belmore Swamp areas through Killick Creek. These inflows occur during storm events with recurrence intervals of greater than 1:5 to 1:10 years and local heavy or continuous rainfalls. They have significant impact on circulation during the larger events but may also be significant for water quality during the smaller local events. During the larger events significant volumes of generally poor quality water, low in dissolved oxygen and high in organic material, are delivered to the estuary. Although their impact on circulation and mixing is relatively short-lived the longer-term effects of the material loads are unclear. Sand bar formation in the lower reach of Killick Creek tends to occur in association with December–January storms. The bar acts as a barrier that inhibits water exchange and has decreased flushing of deeper waters upstream.



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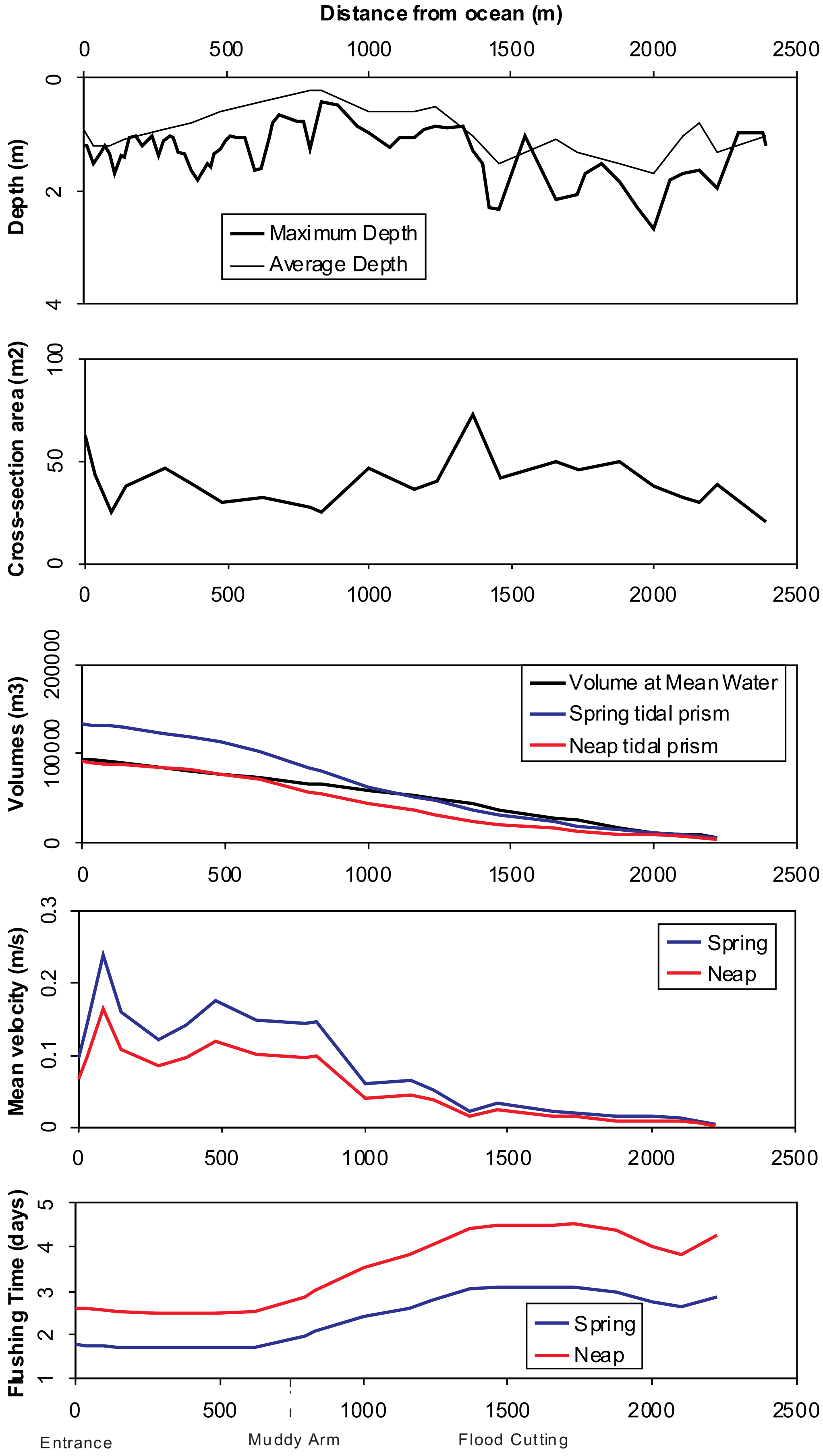
KILLICK CREEK WATER QUALITY SAMPLING SITES
AND STORMWATER INPUTS

MHL
Report 1125

Figure
3.1

DRAWING 1125-03-01.CDR



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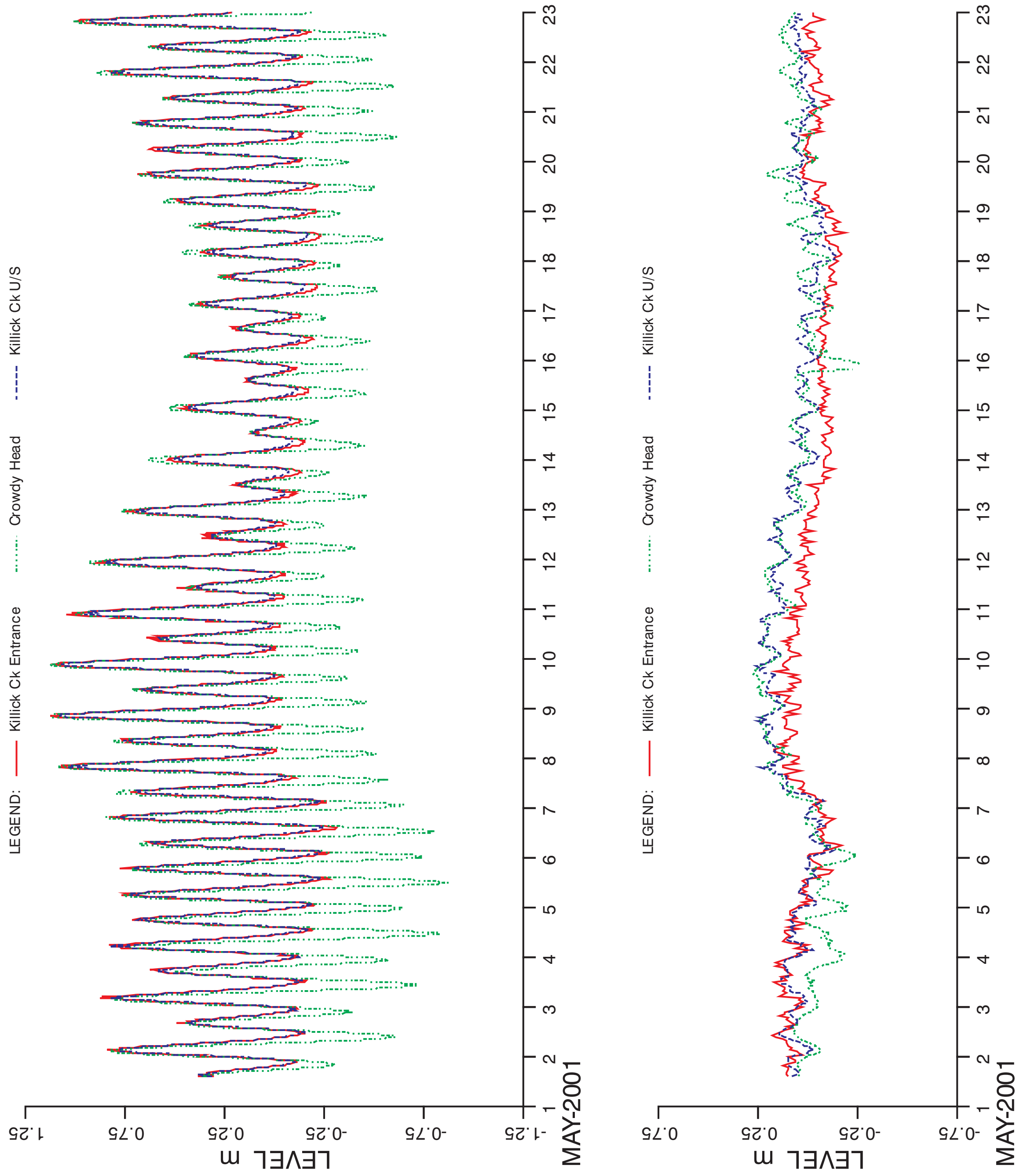
TIDAL CHARACTERISTICS DERIVED FROM
VOLUMETRIC ANALYSIS

MHL
Report 1125

Figure
3.2

DRAWING 1125-03-02.CDR



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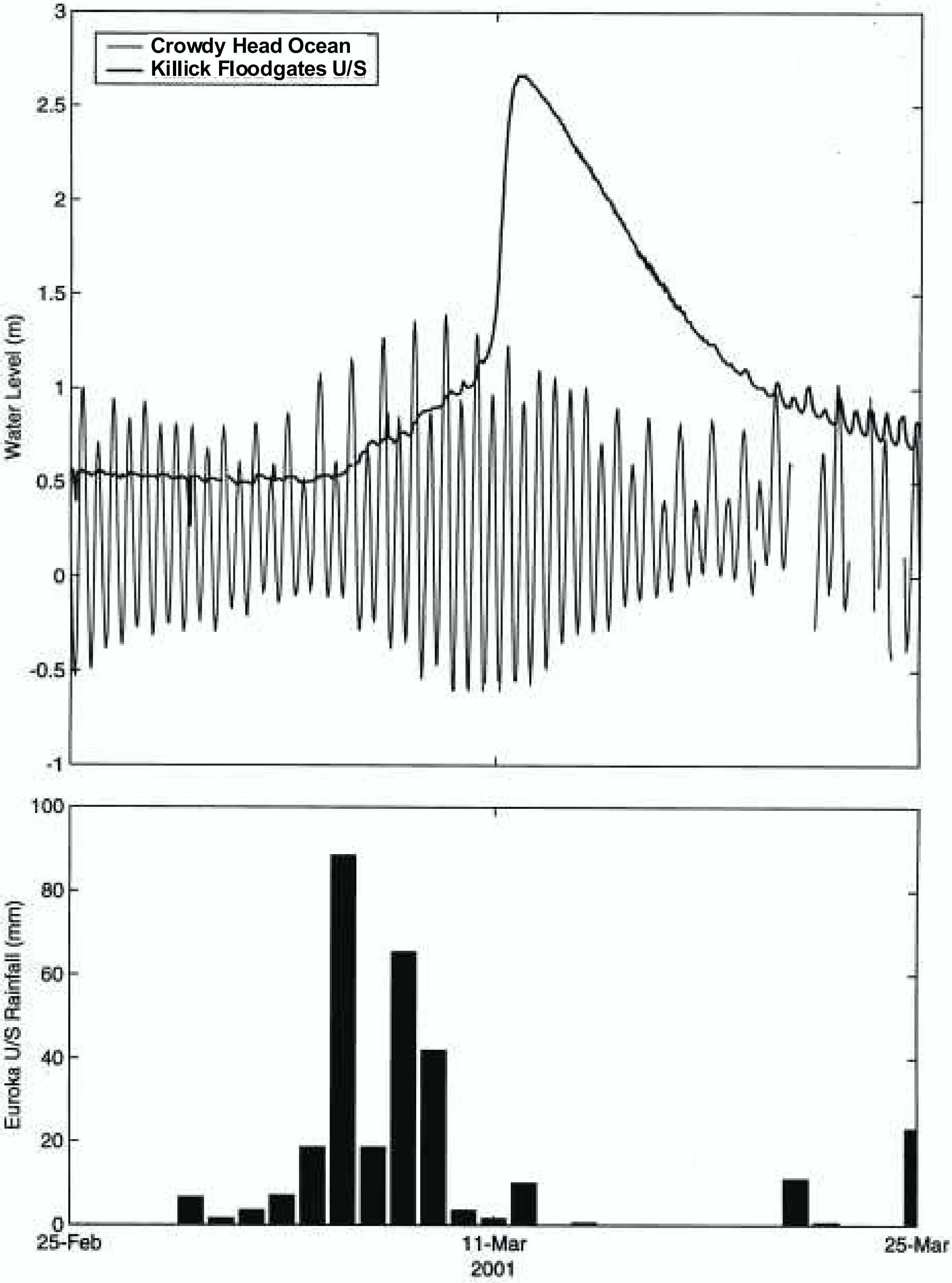
WATER LEVELS AND RESIDUALS FOR KILLICK CREEK
FROM 1 MAY 2001 TO 22 MAY 2001

MHL
Report 1125

Figure
3.3

DRAWING 1125-03-03.CDR



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WATER LEVELS AT KILLICK FLOODGATES UPSTREAM AND CROWDY HEAD OCEAN

MHL
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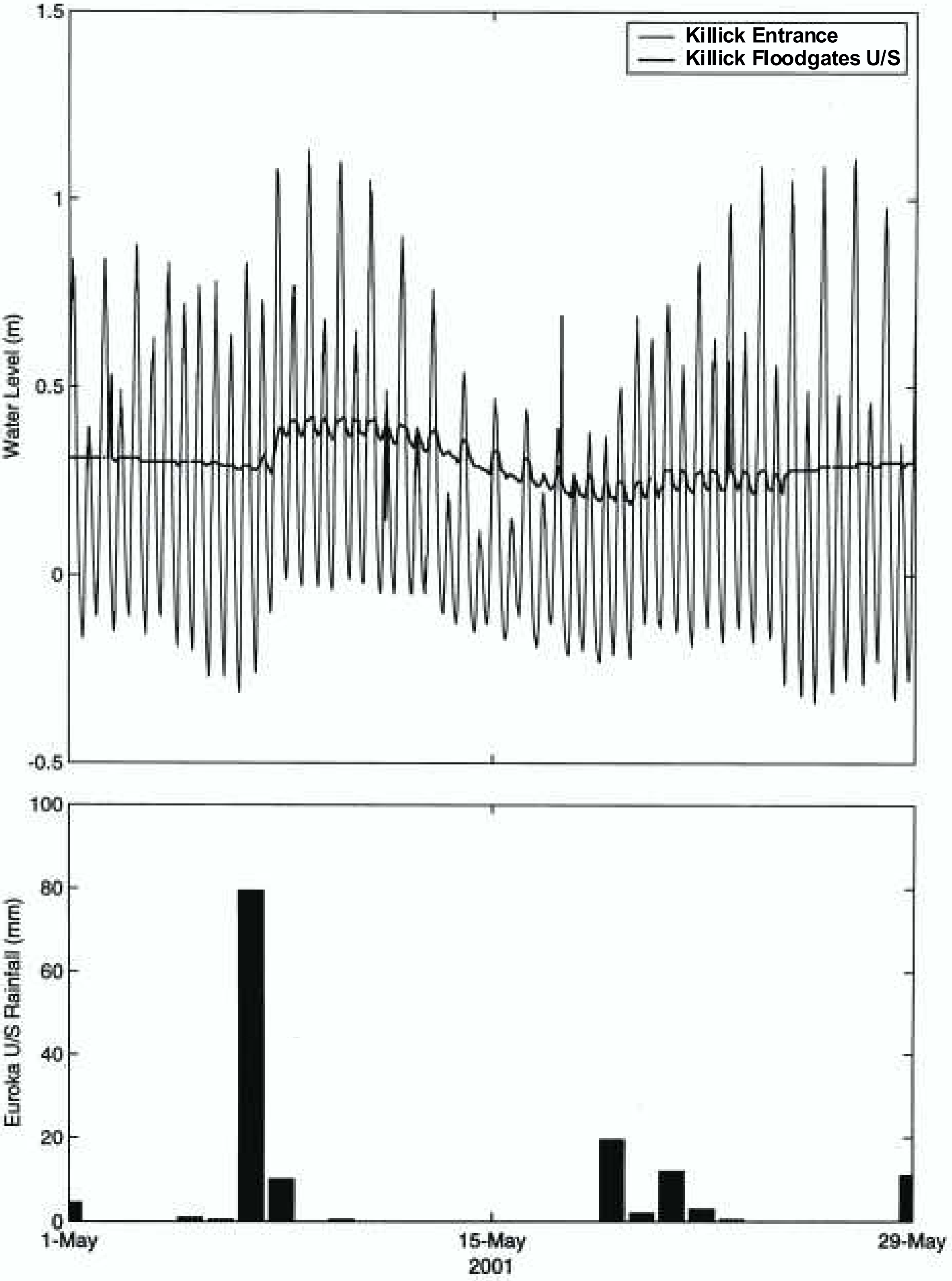
Figure
3.4

DRAWING 1125-03-04.CDR



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WATER LEVELS AT KILLICK FLOODGATES UPSTREAM AND KILLICK ENTRANCE

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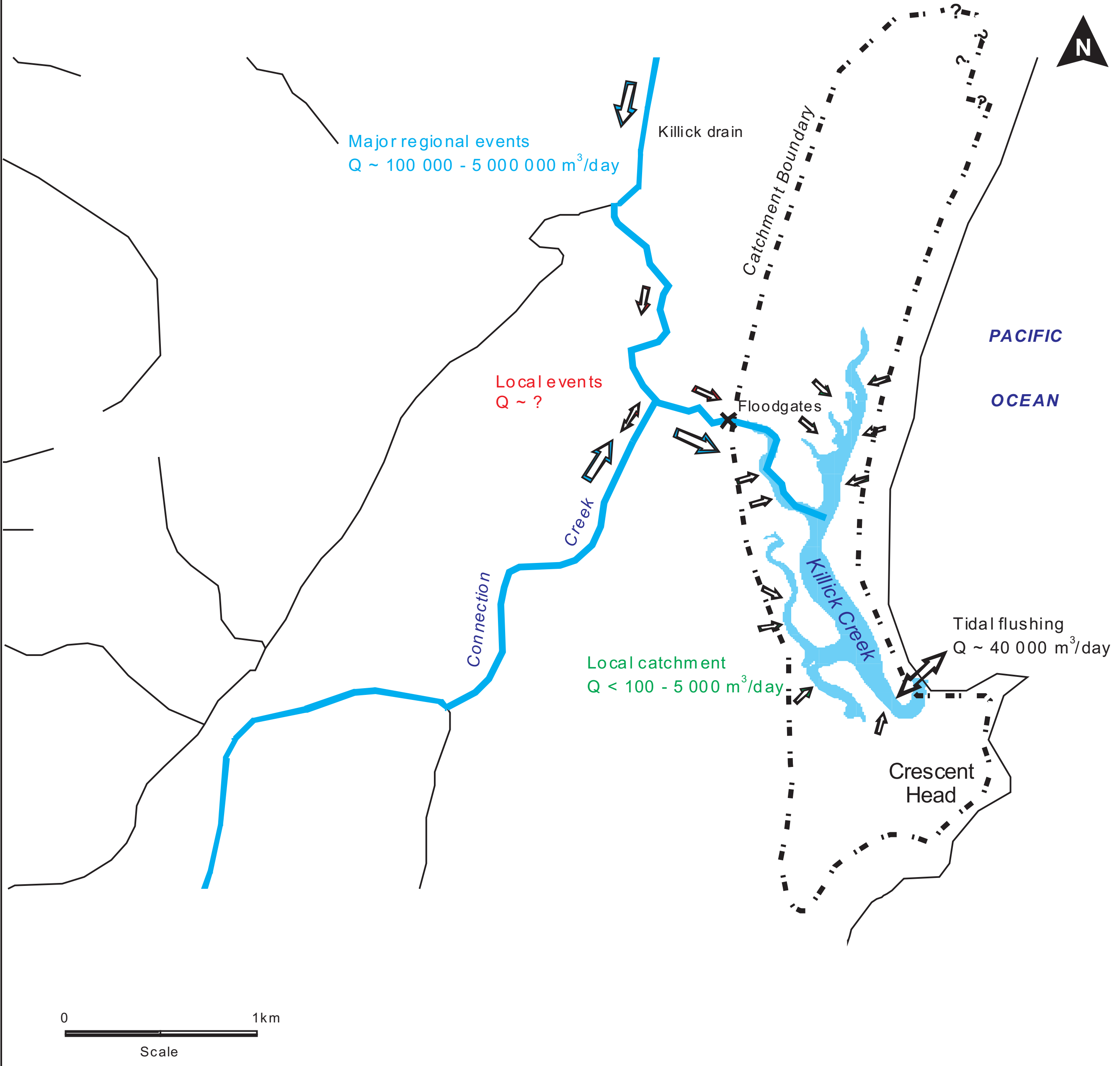
Figure
3.5

DRAWING 1125-03-05.CDR



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CONCEPTUAL WATER BALANCE MODEL

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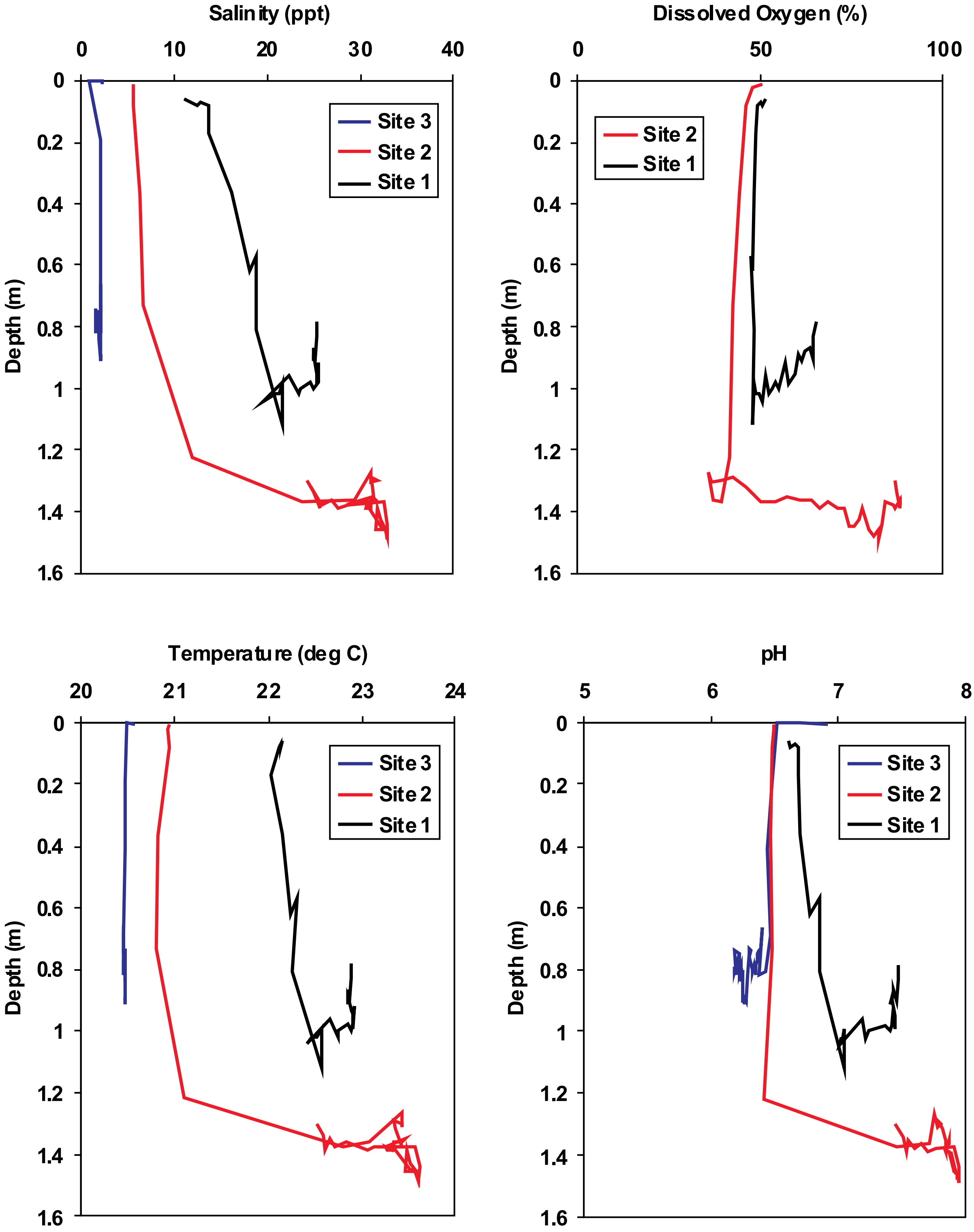
Figure
3.6

DRAWING 1125-03-06.CDR



See Figure 3.1 for site locations

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WATER QUALITY PROFILES ON 5 APRIL 2001

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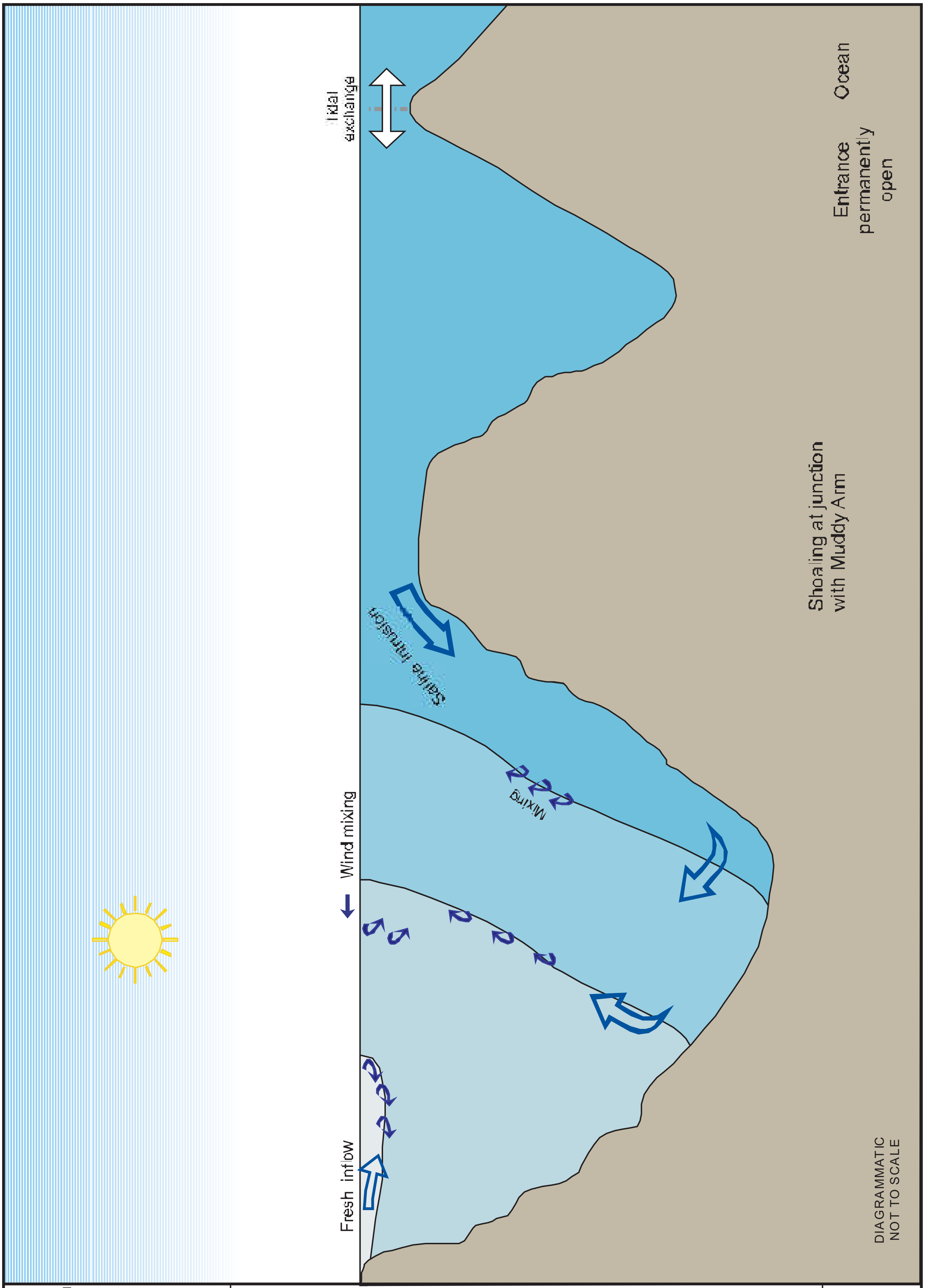
Figure
3.7

DRAWING 1125-03-07.CDR



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CIRCULATION AND FLUSHING

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Figure
3.8

DRAWING 1112-03-08.CDR

4. Water Quality

4.1 Introduction

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.

Urbanisation of the catchment has led to an increase in sediment and nutrient loads to the estuary. During rainfall events pollutants are washed into the creek from diffuse sources such as Crescent Head urban area and rural areas. They may also be discharged directly into the creek from point sources such as stormwater within the catchment (stormwater outlets are shown in Figure 3.1). In the past the sewerage treatment plant has overflowed to the west of the catchment into the wetlands area, but controls have now been put in place to prevent this happening. The connection of Killick Creek to the flood mitigation scheme through the flood cutting (late 1950s) has also led to increased loads of sediments and nutrients as well as other pollutants through the floodgates.

Overdrainage may be caused by drains (including secondary drains constructed by landholders) that continue to remove water from the backswamps. The Belmore area has a potential acid sulphate soil problem (see Section 4.6) which makes drainage a particular concern (Webb McKeown 2000).

The lower reaches of the creek receive nutrient-enriched water from the ocean due to upwelling during summer, which can include entrained marine vegetation (red algae, commonly known as ‘cornflake weed’), as well as suspended sediments resulting from wave motion.

These water quality impacts also influence the estuarine processes within Killick Creek.

Pollutant and hydraulic loads affect the bioavailable nutrients, which are consumed by and therefore affect the macroalgae, phytoplankton and zooplankton communities. Phytoplankton, as well as being dependent on bioavailable nutrients, are also affected by environmental factors such as light and temperature.

4.2 Existing Water Quality Data

A number of studies have been conducted concerning water quality of Killick Creek. In 1980 a study (Yates 1980) was prepared by the State Pollution Control Commission (now EPA) to identify the cause of fish kills. The conclusion from that report was that the cause of the fish kills was anoxia resulting from rapid depletion of oxygen in the water by oxygen-demanding substances.

A study was commissioned by Kempsey Shire Council to assess the condition of Killick Creek and possible solutions to the oxygen depletion phenomena. In January 1992 17 sites were sampled and at each site width and depth measurements were taken and the water quality parameters of temperature, pH, salinity, dissolved oxygen, Eh(water) and Eh(sediment) were recorded (UNE 1993).

Dissolved oxygen concentrations of within 20% of saturation concentrations found in the UNE (1993) study were similar to those found by Yates (1980) for the incoming tidal water, water in Muddy Arm and water in the lower 800 m of the estuary. In the remainder of Killick Creek the dissolved oxygen concentrations were much higher in 1993 than in 1980 after a major fish kill.

The pH values measured by UNE (1993) show little variation in the estuary and are essentially normal. Salinity values reveal a small regular decrease up the estuary.

Eh values for water samples in the lower part of the estuary are typical of well-aerated natural estuarine waters. Eh data for sediment show that the upper reaches of the estuary are characterised by a moderate to locally high reduction potential.

The free sulphate content of sediment taken at four sites is consistent with variations in the retention of sulphate from sea water and is not considered to be environmentally significant. In contrast the high oxidisable sulphur content of sediments in the upper estuary reflects the dominantly low Eh condition of the sediment, accounts for the sulphuric odour and provides a reservoir of material with a high potential oxygen demand.

The pH in oceanic waters is typically around 8.1, while the freshwater inflows will generally vary between low acidic values in acid sulphate soil regions and more neutral (pH = 7) conditions on natural catchments. The pH values in January 1992 varied between 5 and 8.1, with most samples in the high range indicating the predominance of oceanic waters, as was evidenced by the corresponding high salinity concentrations.

The data from the UNE (1993) study and Yates (1980) are tabulated in Appendix B.

Council data was available for the period February to June 2001. The water quality logger deployed in the Killick flood cutting upstream of the floodgates shows a range of interesting features in relation to the different variables measured (Figure 4.1). Interpretation of the data presented in Figure 4.1 must be undertaken with caution because the various water quality sensors are subject to problems with drift and, in the case of dissolved oxygen, chemical decay. In general the water level, temperature, conductivity and pH are fairly robust sensors and provide reliable measurements, while the dissolved oxygen sensor which uses chemical transfer across a membrane technology is highly suspect after a period of a few days to a week.

Water level upstream of the floodgates shows the response to rainfall and the occasional tidal influence.

A number of mechanisms may be invoked to explain the water quality signals illustrated in Figure 4.1. In general it is expected that some correlation exists between rainfall, runoff and water quality. For example the pH decreases in February during the dry period and increases following the major inflow of flood waters in March.

A more detailed investigation of the data in terms of the possible mechanisms that may explain these signals is required. These data provide qualitative indication of the basic mechanisms while a detailed understanding would require extensive studies such as being conducted over a five-year period in Moreton Bay (Abal et al. 2001) or in San Francisco Bay (Jassby et al. 1995).

4.3 Field Observations

Field data collected on 5 April and 2 May 2001 included profiles of chlorophyll-a and physico-chemical variables (physico-chemical profiles collected on 5 April 2001 are shown in Figure 3.7).

On 5 April the dissolved oxygen concentration was generally low, approximately 50% saturation, throughout the estuary, while on 2 May it had increased to around 70%. This difference indicates the larger volume of freshwater inflow with low DO that occurred in April following the large floods, while in May only a small inflow was affecting the system.

The pH signal on 5 April indicated the mixing gradient between the low pH (6.5) freshwater inflow waters and the high pH oceanic water (pH 8.1). On 2 May the pH had generally increased to around 8 again confirming the greater presence of the saline oceanic waters.

Chlorophyll-a data were also collected on both these occasions and provide some useful insights into primary production and its spatial variability. On 5 April only three sites were sampled between the footbridge and the floodgates (Figure 3.1) while on 2 May profiles were collected at eight sites and the instrument was towed at 0.5 m depth over a distance of about 1 km between the main arm and up the flood cutting. On 5 April the chlorophyll-a varied between 2 and 6 µg/L while on 2 May the values varied between 0 and 6 µg/L, indicating the presence of an algal bloom (MHL 2001). The bloom was confined to the surface layer of about 0.3 to 0.5 m depth and occupied a relatively small area of some 200 m along the flood cutting arm.

The existence of phytoplankton is typical in such systems where the inflow of organic and nutrient-rich waters provides a ready source of nutrients. Further, the presence of substantial organic material, both dissolved and particulate, causes poor water clarity and a shallow photic zone – the zone within which there is sufficient light for photosynthesis. Hence future sampling would need to be cognisant of the very shallow layers (<0.3 m depth) where considerable primary production may occur.

4.4 Comparison of Water Quality Data to ANZECC Guidelines

Kempsey Shire Council has provided water quality data from a range of sites on Killick Creek and its tributary creeks and drains sampled irregularly between April 1994 and February 2002. These data, along with data collected on 5 April and 2 May 2001, were compared to the ANZECC (2000) guidelines. They should be interpreted with caution as there is no record of sampling and analytical methods, exact locations of sampling or quality control.

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

Table 4.1 ANZECC (2000) Guidelines for Water Quality Variables

Water quality variable	Aquatic ecosystem trigger value	Recreational guideline
Dissolved oxygen	80 – 110 % saturation	
pH	7 – 8.5	
Total phosphorus	30 μg PL^{-1}	
Ammonia		10 μg N L^{-1}
Chlorophyll-*a*	4 μg/L	
Faecal coliforms (cfu/100mL)		1° contact < 150 2° contact < 1000

The chlorophyll-*a* data collected during field observations indicate the presence of algal blooms. The ANZECC (2000) aquatic ecosystem guidelines suggest that in a healthy system the typical chlorophyll-*a* levels should not exceed 4 μg/L. On the two days of data collection in Killick Creek chlorophyll-*a* concentrations of around 6 μg/L on 5 April and up to 22 μg/L on 2 May were in exceedance of the guideline level. It must be remembered that two samples do not provide a good indication of general ecosystem health. The conditions during the period of sampling were somewhat extraordinary, occurring after an extreme flood event in early March.

Dissolved oxygen levels on the two field observation days showed some low levels that are below the ANZECC (2000) aquatic ecosystem trigger value of 80% saturation. Dissolved oxygen measurements were not provided with the Council data.

Total phosphorus data collected by Kempsey Council indicate that levels frequently exceed the guideline value of 30 μgL^{-1}, with values ranging from 10 to 680 μgL^{-1}. The phosphorus measurements were all taken from drains discharging near the mouth of Killick Creek, indicating that stormwater inputs may contribute high levels of nutrients to the creek. Similarly, ammonia measurements taken from the drains indicate frequent exceedance of the 10 μgL^{-1} guideline value, although it appears that 10 μgL^{-1} may be the lowest possible detection level with the methods used, so it is difficult to interpret these results.

Concerning faecal coliforms ANZECC guidelines stipulate that for primary contact, such as swimming, median counts should not exceed 150 cfu/100 mL and for secondary contact, such as watersports, median counts should not exceed 1000 cfu/100 mL. The faecal coliform data provided by Council were collected from a range of sites including upstream and downstream of the floodgates and in drains discharging near the mouth of Killick Creek. The drain data frequently exceeds the secondary contact guideline, again indicating that stormwater inputs from the nearby urban area may be a significant pollution source. However, without further information on the conditions and activities on the days of sampling it is difficult to interpret this result further. Samples from Killick Creek near the floodgates are lower, with values occasionally exceeding the primary contact guideline. Faecal coliforms provide a measure of pathogens derived from warm-blooded animals and without additional information it is not possible to speculate further on the source of the measured values.

The limited spatial and temporal range of data available does not enable analysis of trends in water quality parameters.

4.5 Conceptual Model of Water Quality

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

The concentrations of phytoplankton have an effect on small zooplankton which respond to changes in food availability. Increased zooplankton abundance can result in grazing pressure (top down control) of phytoplankton.

4.6 Acid Sulphate Soils

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

Priority areas for management of acid sulphate soils in the lower Macleay floodplain have been mapped by DLWC (DLWC 1999). Priority areas are areas where land management decisions in relation to acid sulphate soils cause and/or contribute to severe soil acidification, poor water quality, reduction in agricultural productivity, loss of estuarine habitat and degraded vegetation and wildlife. One of the priority areas in the lower Macleay is Belmore Swamp which drains into Killick Creek via Killick drain. Acid sulphate soils in the Belmore area have been exposed after removal of floodwaters and continued drainage. Low pH and aluminium toxicity can lead to fish kills such as those reported in Killick Creek.

The Belmore Swamp and Upper Maria River-Connection Creek Acid Sulphate Soil Priority Areas are presented in Figure 4.3 and total approximately 3,510 ha and 4,495 ha respectively. Acid sulphate soils have been known to occur in the Belmore area since the late 1950s and since then the area has been sampled several times (DLWC 1999a). Sampling of soils in the Upper Maria area indicate that there are significant quantities of actual and potential acidity within high risk landscapes, which include the Connection Creek soil landscapes (DLWC 1999b). Figure 4.4 presents a map of acid sulphate soils risks around Killick Creek.

4.7 Implications of Poor Quality Water on Biota of Killick Creek

Water quality is a critical issue for the management of aquatic ecosystems. Except for short-term periods of oxygen deficiency and/or low pH, the water quality in Killick Creek is typical of small sized estuaries on the NSW coast without major pollutant inputs. However, there have been many human-induced changes to the natural flows of the system, which have implications for water quality. In particular, the construction of floodgates and the cut has increased the organic load to the creek. Also the shoaling allows the gradual accumulation of organic sediments (predominantly the red marine alga *Spuridia filamentosa*) that utilise high amounts of oxygen in the deeper parts of the stream. Under normal flow and temperature conditions, the oxygen-requiring sediments exert little effect on the overlying water as oxygen transfer between the sediment-water interface is limited. However, during turbulent flow when the sediments are resuspended, when organically enriched floodwaters are flowing through the system, or when summer temperatures and floating weed reduce the atmospheric reoxygenation of the waters, rapid deoxygenation of the entire water column can occur. This can, in turn, lead to fish kills and sulphurous odours (UNE and SCU 1993).

Deoxygenation also occurs above the floodgates in the Belmore River due to the decomposition of pasture species that are not able to withstand inundation. Prior to flood mitigation works, semi-permanent swamps were vegetated with water-tolerant plants that are less prone to death and decay from inundation (NSW Fisheries and Agriculture 1989).

There are also extensive acid sulphate soils in the swamplands of the Macleay, especially in the Belmore area (NSW Agriculture and Fisheries 1989). The production of acidic conditions and low dissolved oxygen concentrations are increased in areas where the water table has been lowered by flood mitigation practices, exposing acid sulphate soils to the atmosphere. These conditions promote the oxidation of the pyritic material in the clays that leach out when inundated by floodwaters (SPCC 1987). Further, acid water has been found to contain high levels of aluminium that is also toxic to fish (NSW Fisheries and Agriculture 1989). Water clarity and nutrient concentrations were also elevated in the Belmore River (SPCC 1987). Release of floodwaters into Killick Creek may therefore introduce acid water high in aluminium and contribute further to the depletion of oxygen (UNE and SCU 1993).

Fish kills have been reported within several parts of the lower Macleay floodplain including the Belmore River and Killick Creek. Richardson (1980) reported fish kills in the Belmore River in March in 1977 and 1978, and Yates and Brown (1980) recorded kills in 1976, 1979 and 1980. Since then, there have also been fish kills in Killick Creek in 1982, 1987, 1990 and 1993 and in the Belmore River in March 1995 and February 1996 (UNE and SCU 1993, TEL 1996). The NSW Fisheries Fish Kills Database has records of fish kills occurring in the Belmore River in 1977, 1978, 1988, 1989, 1990 and 1992, and in Killick Creek in January 1993 (Webb McKeown & Associates 2000). The Crescent Head Progress Association advises that they have no evidence of fish kills occurring prior to 1975.

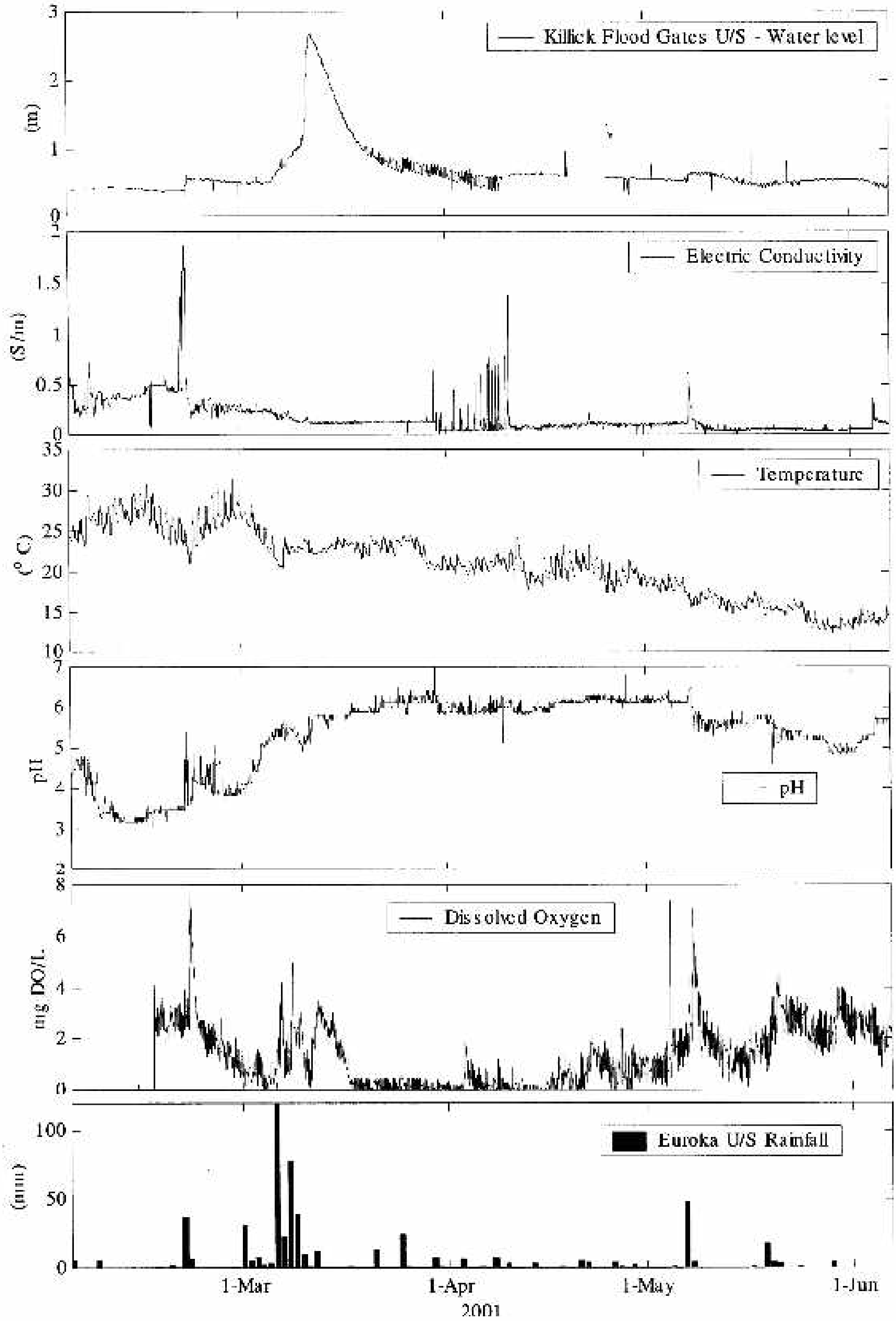
The exact cause of each fish kill is unclear and may be due to either deoxygenation, acid sulphate soils, the toxic effects of aluminium or stranding of fish in swamp areas after flooding. However, most authors agree that deoxygenation has been the primary cause of fish kills in the Macleay River and Killick Creek to date (Yates 1980, Simpson and Saenger 1991, UNE and SCU 1993, NSW Fisheries and Agriculture 1989). This is further supported by a study by the Department of Conservation and Land Management (1992) into the relationship between the presence of acid sulphate soils, rainfall events, various chemical parameters of water and fish kills. Despite both acidity and aluminium concentrations exceeding toxic levels during the period of the study, there were no fish kills. However, oxygen levels were almost always adequate for fish survival.

Observations during March 2001 and more recently in a local event in March/April 2002 suggest that many fish kills may be traced to blackwater conditions. This black water results from breakdown of vegetated material, is often accompanied by algal blooms and is frequently associated with adverse skin reaction in human contact. Black water has a demonstrable capacity to reduce DO content of water it mixes with in excess of the dilution ratio (pers. comm. Peter Haskins, DLWC).

A major fish kill was also reported for the upper Maria River near the confluence with Connection Creek in 1992 (Johnston 1995). In contrast to the Belmore River and Killick Creek fish kills, the available evidence suggests this kill was due to low pH levels caused by acid sulphate soils following significant rainfall.

It is also important to recognise that sub-lethal effects to fish and invertebrates can also occur. Acidic waters have been reported to cause numerous physiological effects, including reduced growth rates, visual and olfactory impairment and bone disorders (TEL 1996). Acid waters have also been implicated in the occurrence of epizootic ulcerative syndrome (EUS) – also known as red spot disease – in fish (TEL 1996). Further, Sammut et al. (1994) noted that avoidance behaviour by fish has been reported in waterways and in controlled tank experiments. He also pointed out that fish kills reported upstream of closed floodgates were probably more severe than had the gates been open or absent, as many of the fish have been unable to move away from the acid (or deoxygenated) water.

Despite the records of fish kills, there is little information on the impact of poor water quality on other biota of Killick Creek. A report by UNE and SCU (1993) into the biological and hydrological status of the creek suggests that there is a viable benthic community, indicating a healthy system. It is likely that the man-made interferences to Killick Creek have brought about some changes to the community but, despite oxygen depletion events, the creek has been able to sustain an estuarine community (UNE and SCU 1993). Therefore, whatever the extent of organisms killed during an oxygen depletion event, survivors and/or recruitment re-establishes populations.



Data supplied by Kempsey Shire Council and Manly Hydraulics Laboratory

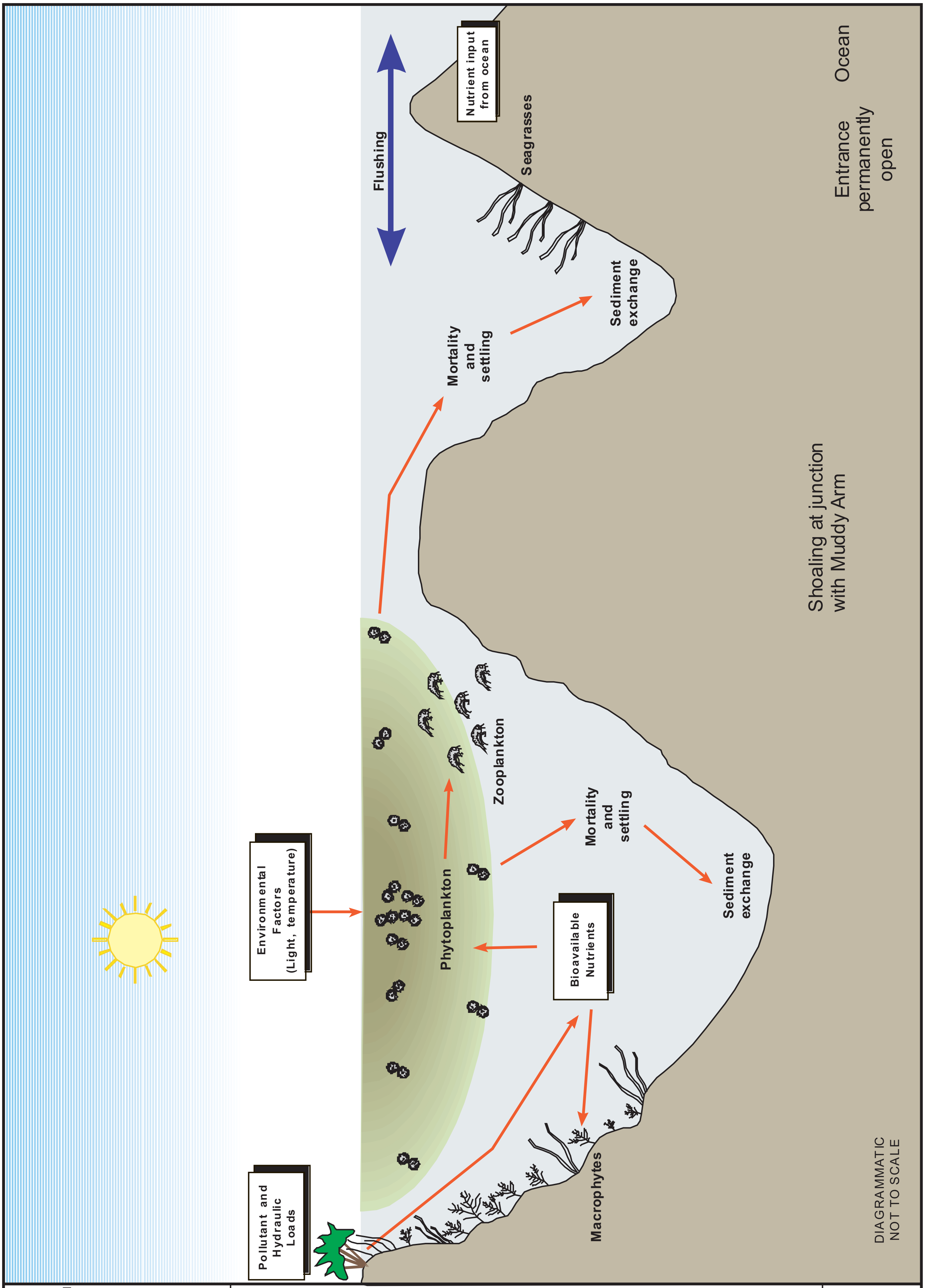
NSW DEPARTMENT
OF PUBLIC WORKS
AND SERVICES
MANLY HYDRAULICS LABORATORY

KILLICK CREEK WATER QUALITY DATA

MHL
Report 1125

Figure
4.1

DRAWING 1125-04-01.CDR



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MANLY HYDRAULICS LABORATORY

NUTRIENT CYCLING

MHL
Report 1125

Figure
4.2

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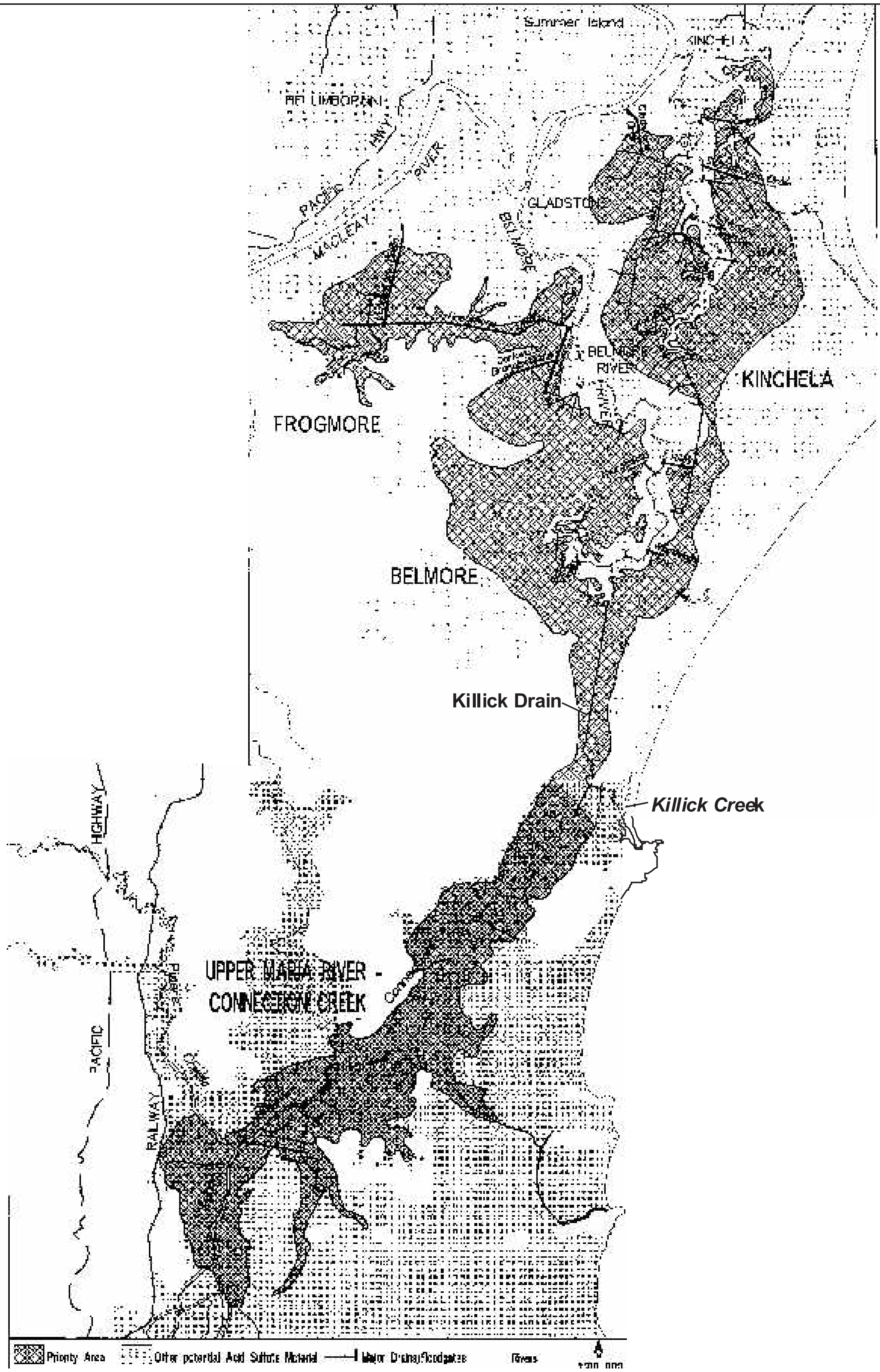

Source: Department of Land and Water Conservation, 1999

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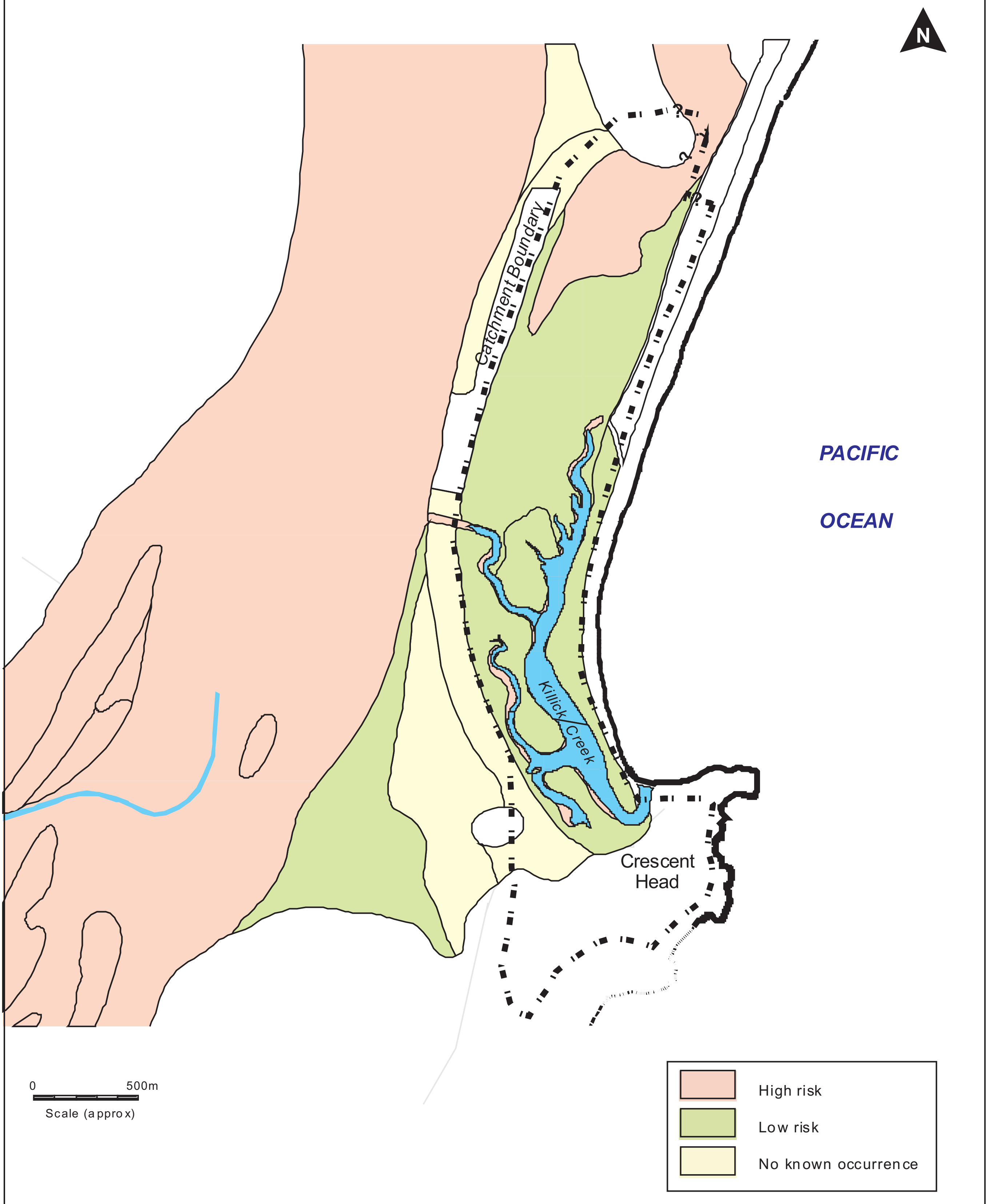
MANLY HYDRAULICS LABORATORY

BELMORE AND UPPER MARIA ACID SULPHATE SOIL MANAGEMENT PRIORITY AREAS

MHL
Report 1125

Figure
4.3

DRAWING 1125-04-03.CDR



Source: Department of Land and Water Conservation

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ACID SULPHATE SOILS

MHL
Report 1125

Figure
4.4

DRAWING 1125-04-04.CDR

5. Ecological Processes

5.1 Existing Ecological Data

5.1.1 Introduction

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

5.1.2 Flora

There are several wetlands adjacent to and surrounding Killick Creek that have been designated as SEPP 14 Coastal Wetland. These wetlands were originally mapped and numbered by Adam et al. (1985) and have since been amended by DUAP (1998). SEPP 14 Wetland No. 482a encompasses the wetland to the west of Killick Creek between Muddy Arm and the flood cutting. A much larger wetland (No. 479) is located within the catchments of the upper Belmore River, Scotts Drain and Connection Creek. Finally, a long, narrow wetland (No. 476) is formed behind the dunal system of Killick Beach and runs to the north of Killick Creek (Figure 5.1).

Three studies provide some information on the riparian and aquatic flora of Killick Creek. West et al. (1985) mapped estuarine habitats in NSW, including Killick Creek, using a combination of aerial photography (taken in 1976) and field surveys (done in May 1981). They reported that Killick Creek is an intermittently open estuary kept open mechanically and it has a 'map water area' of 0.198 km^2. They also reported that Killick Creek has areas of seagrasses (Zosteraceae) and saltmarshes of 1.1 ha and 0.8 ha, respectively. Mangroves were also reported to occur in Killick Creek, but they formed stands that were too small to map at a scale of 1:25,000. Species included grey mangroves (*Avicennia marina*) and river mangroves (*Aegeceris corniculatum*).

The area of mangroves in the Macleay River in 1956 was mapped and compared with distribution in 1976 using aerial photographs and personal field surveys in 1981 (Middleton et al. 1985). They concluded that there had been a 35% loss of mangroves in the whole estuary over that time. This report also determined that many areas that were formerly seagrass (*Zostera capricorni*) beds are now largely vegetated with rushes (*Juncus* sp.).

A later study by the University of New England and Southern Cross University (1993) included a general assessment of the instream and riparian habitats of the creek. Substratum types included mud, sand and rocks/rubble and the major vegetation types identified were bush, mangrove and seagrass. Details from this map have been reproduced in Figure 5.2. Unfortunately, there are no earlier published maps to use for comparison. However, the map indicates that mangroves lined large areas of the banks of Killick Creek and seagrasses were present at the head of the creek.

5.1.3 Fauna

Information on the estuarine fauna of the creek is very limited. Richardson (1980) sampled fish in the Belmore River in February, June and August 1978 as part of an investigation of the effects of a flood on the water quality and fish of the river. The fish sampled are listed in Table C.1 in Appendix C. During March 1978, fish species affected by a fish kill in the river were identified and the total numbers estimated (included in Table C.1, Appendix C).

Fish were also sampled in Killick Creek as part of a study into the biological and hydrological characteristics of the creek (UNE and SCU 1993). Hand nets, gill nets and seine nets were used in a range of habitats. A total of 1,163 fish were caught representing 26 species. A list of the species caught is included in Table C.1 in Appendix C. The authors 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. Further, the broad range of size classes caught for each species suggested that the fish populations were healthy, without any obvious signs of poor habitat, poor water quality or frequent fish kill events likely to wipe out year-classes or to affect recruitment.

UNE and SCU (1993) also sampled the benthic biota of Killick Creek in 1992. The study investigated: 1) the flora and fauna living on and around the rock wall and bridge at the entrance to the creek; 2) the fauna present along each bank of the creek (including arms); and 3) the fauna within the sediment at selected sampling sites along the creek – including the benthic fauna present in the middle of the creek bed (this also included measurements of organic matter and sediment grain size).

The fauna of the creek entrance was typical of such habitats on the mid-north coast of NSW and included intertidal macro-algae, molluscs (limpets, gastropods, oysters, chitons) and other invertebrates (barnacles, anemones, seastars, cunjevoi, crabs, tube worms) (UNE and SCU 1993). Crabs and yabbies common to NSW estuaries were abundant in the sand and mud along the banks of the creek. Species identified included soldier crabs (*Myctiris longicarpus*), sand-bubbler crabs (*Scopimera inflata*), ghost crabs (*Ocopode*), and grapsid crabs (*Sesarma erytrodactyla*). Naticid molluscs (*Conuber melastomum*) were evident near the entrance and yabbies (*Callianassa australiensis*) were extremely abundant along Muddy Arm (UNE and SCU 1993).

Benthic cores were taken of the soft sediment in winter and summer at each of seven sites along the creek. Ten species of polychaete worms, four gastropod species, seven bivalve species and five crustacean species were collected in cores in summer. There were variable patterns of abundance and species richness among the sites and between cores taken along the bank and in the middle of the creek bed. Seasonal differences were also detected between the winter and summer samples at many of the sites. Pie graphs were presented to illustrate the dominant taxa at each site but no statistical analysis of data were presented. Notably, the sediments with the highest organic content contained little or no fauna (UNE and SCU 1993). Most of the sediment was fine sand with varying amounts of pebble and silt depending on the site.

5.1.4 Catchment Flora and Fauna

An indication of the flora and fauna in the catchment of Killick Creek was obtained through a search of the Wildlife Atlas of National Parks and Wildlife. It should be noted, however, that these lists are indicative only and cannot be considered comprehensive. The searches cover an area within approximately 20 km of Crescent Head. The results of these searches are presented in Tables C.2 and C.3 in Appendix C.

5.1.5 Rare or Endangered Species and Communities in Killick Creek

In NSW, the *Threatened Species Conservation Act 1995* (TSC Act) is aimed at protecting animals and plants considered vulnerable and endangered by human activities. The legislation provides for the listing of threatened species, populations and ecological communities and has replaced the endangered fauna list known as Schedule 12 of the *National Parks and Wildlife Act 1974*. 'Threatened' species are now listed in Schedules 1 and 2, endangered and vulnerable species respectively. New Commonwealth legislation, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) also lists threatened species. Threatened species identified under each of these pieces of legislation within approximately 20 km of Killick Creek are highlighted in Tables C.2, C.3 and C.4 in Appendix C.

Five species of endangered fauna, one endangered plant, 36 vulnerable species and two plant species identified under the TSC Act have been recorded within 20 km of Killick Creek. A search of the EPBC Act database found 10 endangered and 23 vulnerable plant flora and fauna. The search also detected a number of animals protected under other sections of the EPBC Act including 13 marine birds, six marine species, seven terrestrial species and two wetland bird species covered by the migratory provisions of the Act; and 23 birds; 19 fish and four reptiles covered by the marine provisions of the Act.

The *Fisheries Management Act 1994* protects fish species listed as endangered or vulnerable. None of the species on this list is likely to be found in Killick Creek. However, two species of protected fish, the Australian bass (*Macquaria novemeaculata*) and the eel-tailed catfish (*Tandanus tandanus*) may occur in the area. As protected fish, they have set bag limits and must be considered in environmental assessments. The Fisheries Management Act also provides protection for estuarine habitats including seagrass and mangroves, both of which occur in Killick Creek.

5.1.6 Pathogens

No evidence has been found for the presence of pathogens in Killick Creek. The only suggestion that the creek has caused human illness is a letter by a local pharmacist which suggests that certain ailments evident in the community (conjunctivitis, unusual headaches, ear nose and throat infections, diarrhoea, vomiting and nausea) may be due to hydrogen sulphide gas. This possibility is not mentioned in any of the literature and cannot be confirmed.

5.2 Field Investigations

Staff from The Ecology Lab visited the creek on 5 April 2001 for a brief site inspection using a small boat. Photographs were taken of the dominant habitats and of any evidence of degradation (e.g. erosion, dead mangroves etc). The visit began at approximately 9.30 a.m. and was concluded by low tide (12.30 p.m.). Around the time of the visit there had been recent rains and the water in Killick Creek was extremely turbid. Hence, it was not possible to observe any creek bed features, including seagrasses.

Along the western bank of the creek near the entrance is a long rocky breakwall covered in oysters and stained red. The water here was too turbid to identify the presence of seagrass beds. A few small mangrove trees grow out of the breakwater and along the muddy bank upstream of Muddy Arm. The mangroves were more extensive along the eastern bank and there were two large stands downstream of the flood cutting (Figures 2.3 and 5.3). These mangroves were either absent or too small in area to map in 1981 (West et al. 1985) and hence potentially represent a major change in the ecology of Killick Creek over the past two decades. Along both sides of the creek there were clusters of paperbark (*Melaleuca* sp.), rushes (*Juncus* sp.), and swamp she-oaks (*Casuarina glauca*) (Figure 5.3).

Rubble banks extended from the floodgate to the road bridge. Further downstream there were natural rocky outcrops ('coffee rock'), which graded into paperbark and she-oak stands (Figure 5.4). There are also occasional mangroves, which became more common downstream. Erosion was evident on the bank downstream of the road bridge (Figure 5.4).

Killick Creek was very shallow at the confluence of the flood cutting and was not navigable. The surface of the mud here was covered in an iron precipitate, below which the mud was very black and highly anaerobic (Figure 5.5). Some dead mangrove seedlings were evident along the shore but older trees in the area appeared healthy (Figure 5.5). Many small fish were observed in the water: these fish appeared to be mullet (Mugilidae) but the water was too turbid to make a confident identification.

During the site inspection two sea eagles (*Haliaeetus leucogaster*) and two wedge-tail eagles (*Aquila audax*) were seen in flight and three white-faced herons (*Egretta novaehollandiae*), two white egrets (*Ardea alba*) and approximately 20 silver gulls (*Larus novaehollandiae*) were feeding on the mud flats at low tide.

5.3 Conceptual Models of Ecological Processes

To illustrate the ecological processes operating within Killick Creek, three conceptual models have been developed and are presented in Figures 5.6, 5.7 and 5.8. These models are based on the graphical interpretation of very limited existing information on the system as well as background knowledge of other similar systems. The text below provides a brief explanation of each of the models to aid understanding of the processes that have been illustrated.

Figure 5.6 illustrates some of the important physical and biotic characteristics of the creek and their relationships to ecological processes. It should be noted that the distribution of aquatic habitats is based on mapping constructed from aerial photos taken in 1976 and field surveys done in May 1981 by West et al. (1985) because more recent, accurate mapping is not available. In particular, TEL's investigations suggest that there has been a large increase in the extent of mangroves within the creek (see Figure 2.3 for observed mangrove locations). This could be a long term consequence of human manipulation of the entrance conditions by altering tidal levels and maintaining relatively high salinity. Also included on the model is a list of the data gaps that are considered to be of major importance to ecological processes within Killick Creek.

Figures 5.7 and 5.8 illustrate the processes of spawning, recruitment and dispersal that would be expected to operate in the estuary during open and closed entrance conditions. The latter model represents the system prior to constant maintenance of an open entrance by mechanical means and might represent the system if the entrance reverts to its original behaviour. In general, seasonal effects are not likely to be very strong and the influences of entrance condition and flooding are likely to be the major natural structuring processes. There are three exceptions to this. First, many fish species and some invertebrates typically recruit to estuarine habitats in the period from late winter to early summer (SPCC 1981b). Thus, because the entrance is kept open, there may be a large recruitment at that time for coastal waters during this period. Conversely, if the estuary were allowed to close naturally, diversity and abundance of fish derived from coastal waters may be relatively small in Killick Creek through summer. In this case, a lower diversity of fish could not be considered as an indicator of poor ecosystem health, but rather an indicator of a natural process (see also Sections 5.4 and 6.5).

Second, the NSW coast is often subject to a large influx of nutrients from upwelling events in spring and summer. Because Killick Creek is kept permanently open, it is subject to more influxes of nutrient-rich water derived from upwelling and there would also be a greater frequency of blooms of red algae from adjacent coastal waters.

The third exception is that pre-spawning fish often make their way out of estuaries in autumn and late winter. A good example of this is sea mullet, which migrate out of estuaries and northward from autumn into winter (Section 6.5). Because the creek entrance is kept open, fish will be able to move out of the creek, but if it were closed they become trapped for extended periods.

Superimposed on these seasonal processes are the effects of human activities, including increased usage during holidays and manipulation of flood waters from the coastal floodplain. Thus, the timing of various estuary conditions can have a large effect on the biodiversity and abundance of fauna in Killick Creek. Moreover, several major processes can interact (e.g. estuary condition, recruitment) to affect the ecology of the creek.

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

5.4 Estuarine Processes and Ecological Health

As outlined in the sections above, the data available on the aquatic ecology of Killick Creek is very limited. In particular there is a lack of information in space and time that would help us to understand how the system fluctuates from one part of the creek to another. This limits our ability to accurately define the processes operating within the creek and restricts the potential to adequately model these processes. As a working hypothesis, ecological processes in Killick Creek are fundamentally similar to those in other estuaries along the NSW coast. The system, however, has features that make some of these processes of particular importance to the community and the managers responsible. These include the morphological behaviour of the entrance channel (which necessitates that mechanical means must be used if the creek is to be kept open) and the flood mitigation works at the head of the creek and along Scotts drain, the Belmore River and Connection Creek. These features have important implications for water quality and the ecological processes mediated by water flow such as the recruitment and migration of fishes and invertebrates, discussed as follows and in Section 6.5.

The background conditions of Killick Creek are that of a small coastal creek with inputs of fresh water, nutrients and sediments and an entrance kept open by mechanical means. These conditions favour the presence of certain habitats and the growth of particular species of macrophytes and macroalgae. For example, if the creek were closed for extended periods of time, we predict that there would be fewer mangroves due to a lack of tidal range, while *Zostera* might be replaced by *Ruppia* and saltmarshes by brackish wetland plants (e.g. *Phragmites*). Human-induced changes to these conditions (flood mitigation works, mechanical entrance opening and foreshore development) are likely to result in corresponding changes to the distribution and dominance of species. Determining the relative contributions to temporal variability in the system attributable to natural and human-induced causes is impossible at this stage. Thus, although it is clear that catchment development and anthropogenic uses of the catchment and the creek itself have altered the inputs to the creek, it is not possible to quantify the extent of the changes.

It is difficult to assess the status of the faunal assemblages of the creek, due to a limited amount of information available. Data on spatial and temporal patterns of abundance and distribution of most faunal groups are lacking, and further work is required to provide an adequate description of baseline conditions from which to identify principal factors that influence these components.

The results of this study suggest that the health of Killick Creek is likely to be highly variable through time. Clearly, the strongest evidence of a poor ecosystem health of Killick Creek is the periodic fish kills that occur both above and below the floodgates. These kills occur primarily in summer and are considered to be caused by deoxygenation of the water after flooding, although acid water, toxic levels of aluminium or iron and the rapid influx of fresh water may also contribute. There is an urgent need to understand the frequency, extent and causes of these fish kills – particularly in seeking to determine which may be natural and which caused by human activities or manipulation. In addition, the influx of red weed and/or nutrients from the adjacent coast may cause eutrophication in parts of the creek.

Table 5.1 summarises one way of assessing the ecosystem health of Killick Creek by using six biotic indicators. The table is based on a report card system used in the State of the Marine Environment Report (SOMER, Zann 1995) and expanded upon by Tony Roper of the Department of Land and Water Conservation. The table includes the current value of the indicator, comparison of the current value with a reference value, the trend in the status of the indicator and the pressures and their trends causing deterioration in the indicator. Clearly, there are many information gaps which prevent a detailed analysis of the health of Killick Creek, particularly using this method. Moreover, the report can also be misleading because it uses information that is collected for completely different purposes. For example, assigning as a current 'value' of fish distribution and abundance 38 species assumes that the work on which this number was based set out to determine the taxonomic richness of fishes in Killick Creek. Specifying this number in the context of ecosystem health then implies that this number should not change except in response to changes in health. Thus, a downward trend would be interpreted as a decrease in health while an upward trend would be explained as an increase in health. Clearly, far more information would be required to understand the mechanisms and parameters of natural change to allow us to then infer what 'un-natural' change might be.

Table 5.1 Summary of Killick Creek's Ecosystem Health Using Six Biotic Indicators

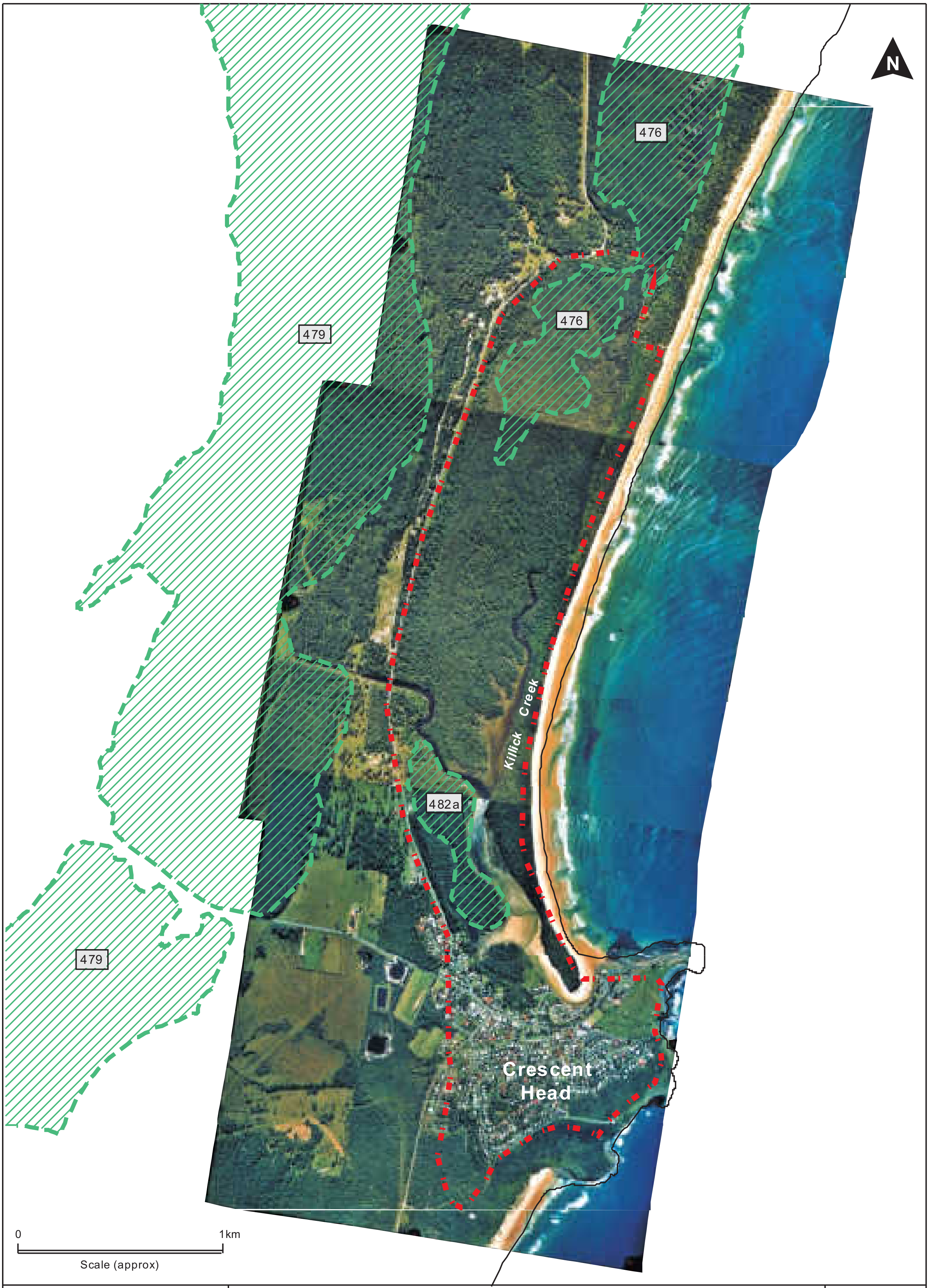
Based on a report card system used in State of the Marine Environment Report (SOMER, Zann 1995) and expanded upon by Tony Roper of DLWC). Trends have been given using one of the following four values:

⇔ = stable, ↑↓ = variable 👍 = improving, 👎 = worsening, ? = insufficient data.

(Source: The Ecology Lab report to Manly Hydraulics Laboratory on Killick Creek EPS Aquatic Ecology)

	State				**Pressure**	
Indicator	**Current Value**	**Reference value**	**Status**	**Trend**	**Sources**	**Trend**
Aquatic and riparian flora						
Seagrass area, composition and distribution	Area = 0.011 km^2 [1] Species composition = Zosteraceae	No specific criteria	?	?	Probable variable distribution due to temporal changes in entrance and floodgate conditions, oxygen concentrations, water quality, nutrients loads and epiphytic and macroalgae reducing light penetration	?
Saltmarsh area and distribution	Area = 0.008 km^2 [1] Includes 2 SEPP 14 Wetlands	No specific criteria	?	?	Draining of wetlands above floodgates has led to decrease in area of wetlands in Belmore River/Swamps. Wetlands also likely to be affected by poor water quality and acid sulphate soil pollution	?
Vegetation distribution and condition along tidal foreshores	?	No specific criteria	?	?	Clearing/grazing pressures.	?
Aquatic fauna						
Macroinvertebrate distribution and abundance	Typical of habitats on mid north coast of NSW [2]	No specific criteria	?	?	Frequent flooding/deoxygenated water/acid water may have impact on abundances and distributions	?
Fish distribution and abundance	38 species	No specific criteria	↑↓	↑↓	Periodic fish kills probably caused by deoxygenation of water, fish passage limited by floodgates and entrance conditions	↑↓
Exotic fauna distribution and abundance (*known or likely to occur*)	14 species recorded within approx. 20 km of Crescent Head [3]	No specific criteria	?	?	Almost all are unintentionally introduced species with the potential to compete/replace/exclude native species, damage local fisheries and aquaculture	?

In summary, there are currently insufficient data to be able to define what the ecosystem health of Killick Creek might mean, let alone whether the creek is healthy. It is clear, however, that the creek is very different to its pre-development state due to manipulation of the entrance conditions, use as a channel for dispersing flood waters and urban and agricultural development in its catchment. One obvious sign of poor health is the occurrence of fish kills and this should be given a priority in terms of future work. Another sign is the occurrence of red algae (*Spuridia filamentosa*) which may be problematic, and which may be affected by both natural and anthropogenic factors. More subtle signs are the apparent increase in mangrove growth (suggesting a shift in the ecology of the creek) and the presence of very fine flocculates observed during the site inspection. These issues should be considered in the context of the current manipulation of the entrance and use of the creek as part of the floodplain management.



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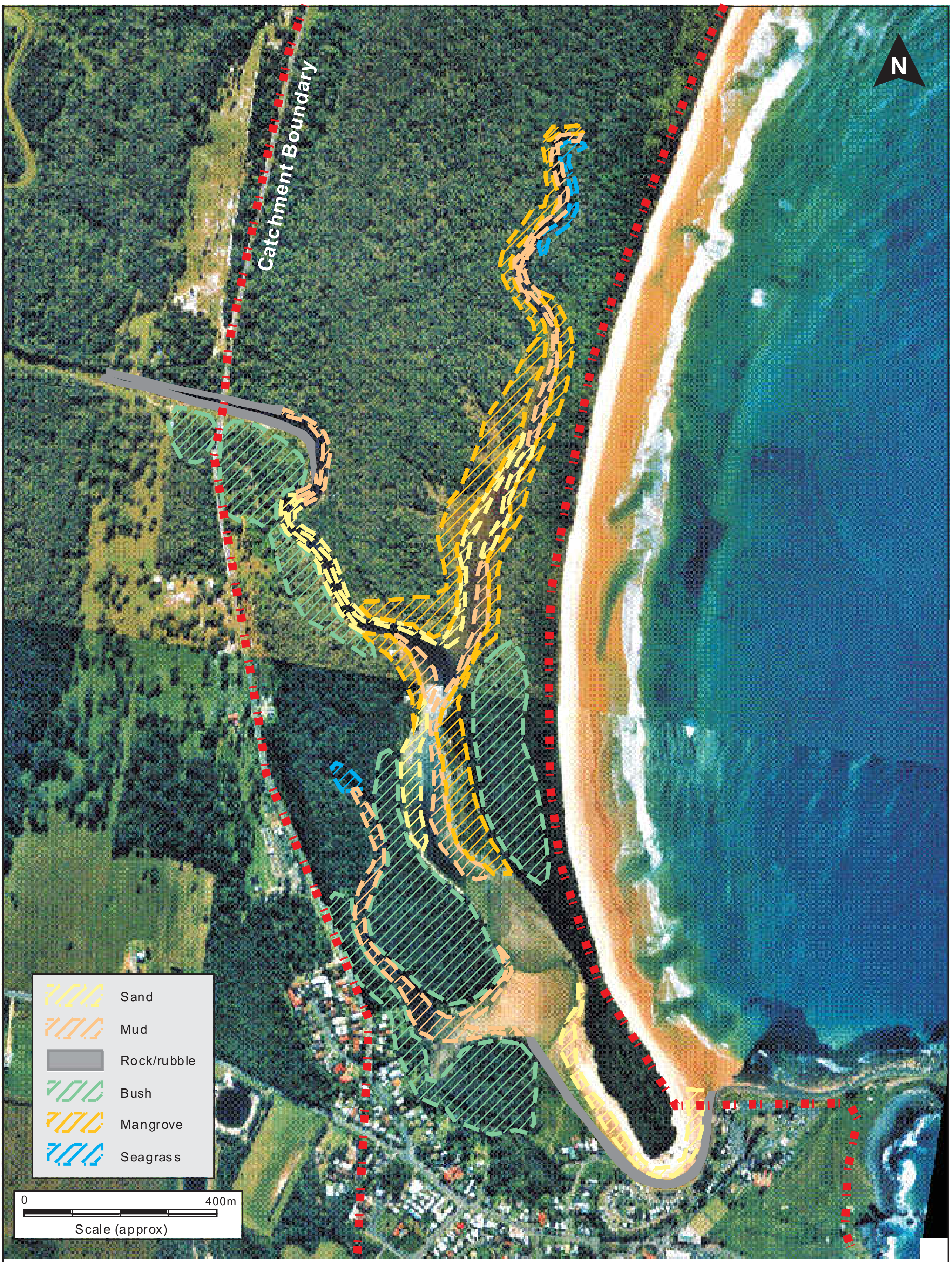
KILLICK CREEK AND SURROUNDS SHOWING SEPP 14 WETLANDS

MHL Report 1125

Figure 5.1

DRAWING 1125-05-01.CDR



Source: Map originally produced by UNE &SCU, 1993

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VEGETATION AND SUBSTRATUM OF KILLICK CREEK

MHL
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Figure
5.2

DRAWING 1125-05-02.CDR

Mangroves along the banks of Killick Creek

Clusters of paperbark (*Melaleuca* sp.), rushes (*Juncus* sp.) and she-oaks (*Casuarina glauca*) along the banks of the flood drain

Source: The Ecology Lab Pty Ltd - Marine and Freshwater Studies

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THE ECOLOGY LAB FIELD INVESTIGATIONS
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Figure
5.3

DRAWING 1125-05-03.CDR

Banks of 'coffee rock' along the banks of the flood drain

Erosion along the creek downstream of the flood drain

Source: The Ecology Lab Pty Ltd - Marine and Freshwater Studies

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Figure
5.4

DRAWING 1125-05-04.CDR

Iron precipitate evident on the surface of the mud at the confluence of the flood drain

Dead mangrove seedlings along the shore near the flood drain

Source: The Ecology Lab Pty Ltd - Marine and Freshwater Studies

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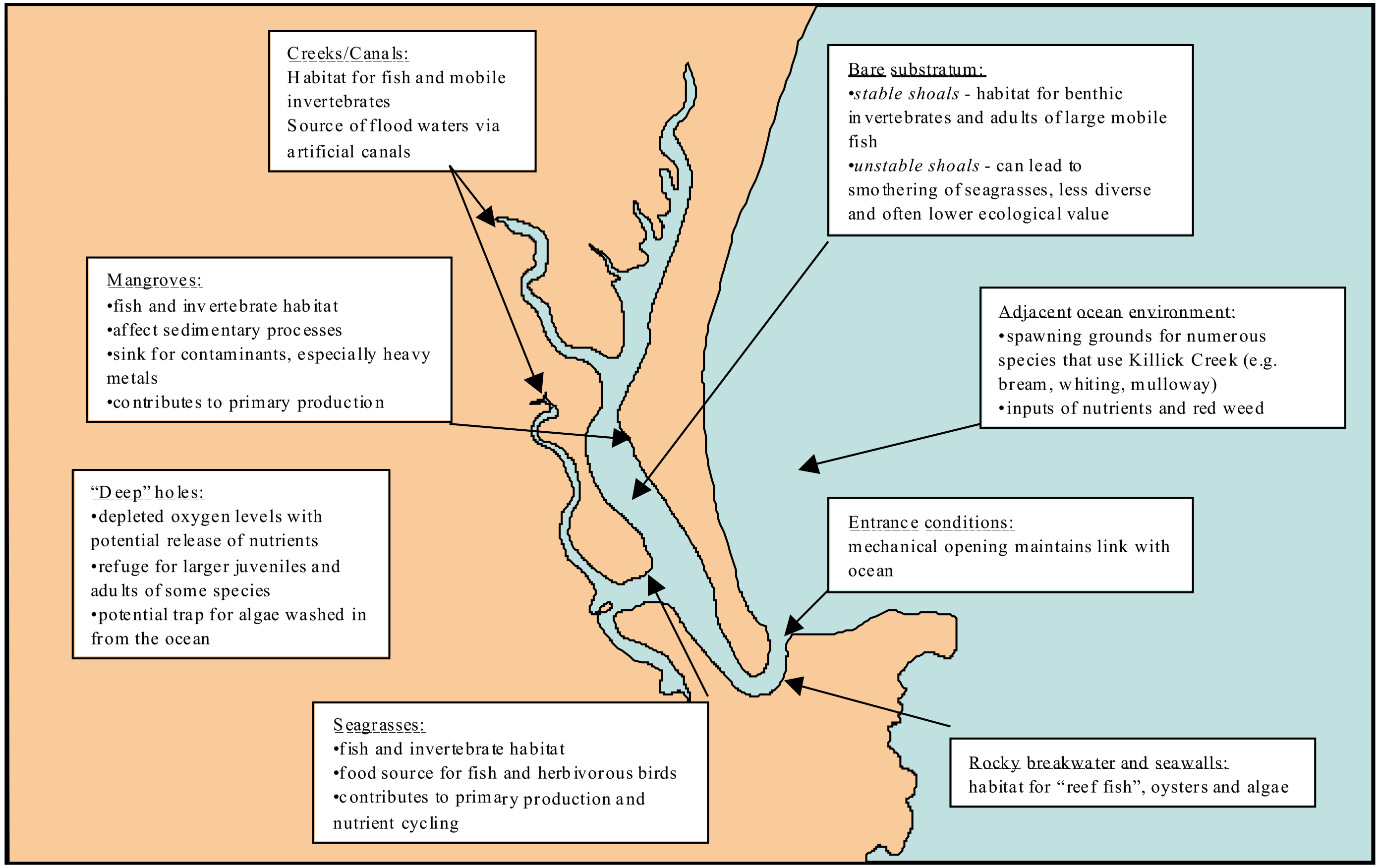
Figure
5.5

DRAWING 1125-05-05.CDR



Creeks/Canals:
Habitat for fish and mobile invertebrates
Source of flood waters via artificial canals

Mangroves:
- fish and invertebrate habitat
- affect sedimentary processes
- sink for contaminants, especially heavy metals
- contributes to primary production

"Deep" holes:
- depleted oxygen levels with potential release of nutrients
- refuge for larger juveniles and adults of some species
- potential trap for algae washed in from the ocean

Seagrasses:
- fish and invertebrate habitat
- food source for fish and herbivorous birds
- contributes to primary production and nutrient cycling

Bare substratum:
- *stable shoals* - habitat for benthic invertebrates and adults of large mobile fish
- *unstable shoals* - can lead to smothering of seagrasses, less diverse and often lower ecological value

Adjacent ocean environment:
- spawning grounds for numerous species that use Killick Creek (e.g. bream, whiting, mulloway)
- inputs of nutrients and red weed

Entrance conditions:
mechanical opening maintains link with ocean

Rocky breakwater and seawalls:
habitat for "reef fish", oysters and algae

Data gaps:
- current extent and distribution of seagrasses and mangroves
- spatial distribution and community structure of fish, macroinvertebrates and plankton. Limited data available
- temporal relationships between entrance conditions, water quality and biota
- impacts of release of floodwaters
- detailed information of locations and timing of fish kills and their effects on Killick Creek ecology
- inputs of contaminants and nutrients from local sources and the catchments of the Macleay and Maria Rivers

Source: The Ecology Lab Pty Ltd - Marine and Freshwater Studies

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

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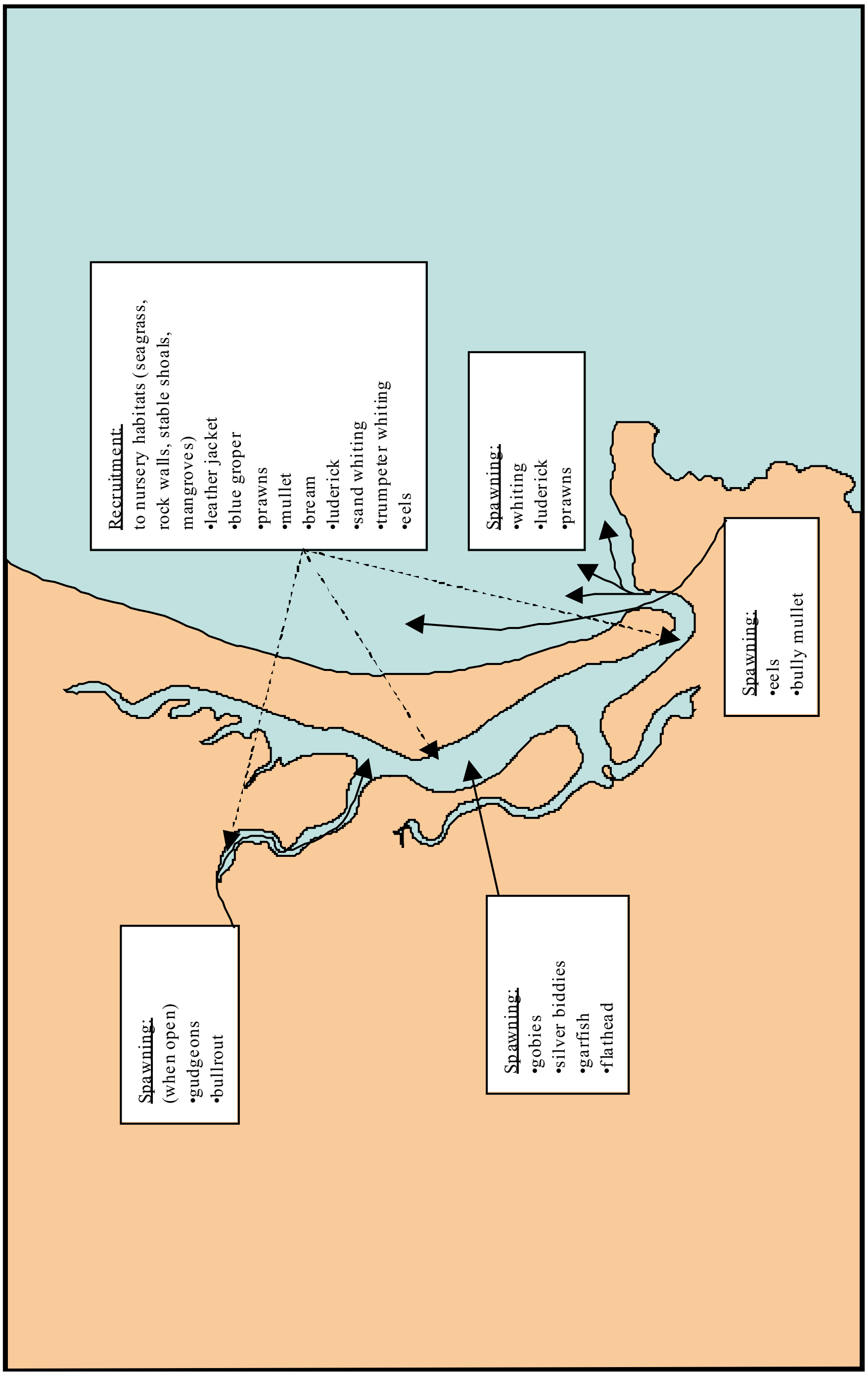
Figure
5.6
DRAWING 1125-05-06.CDR



Source: The Ecology Lab Pty Ltd - Marine and Freshwater Studies

BASED ON INFORMATION FROM OTHER NSW ESTUARIES

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

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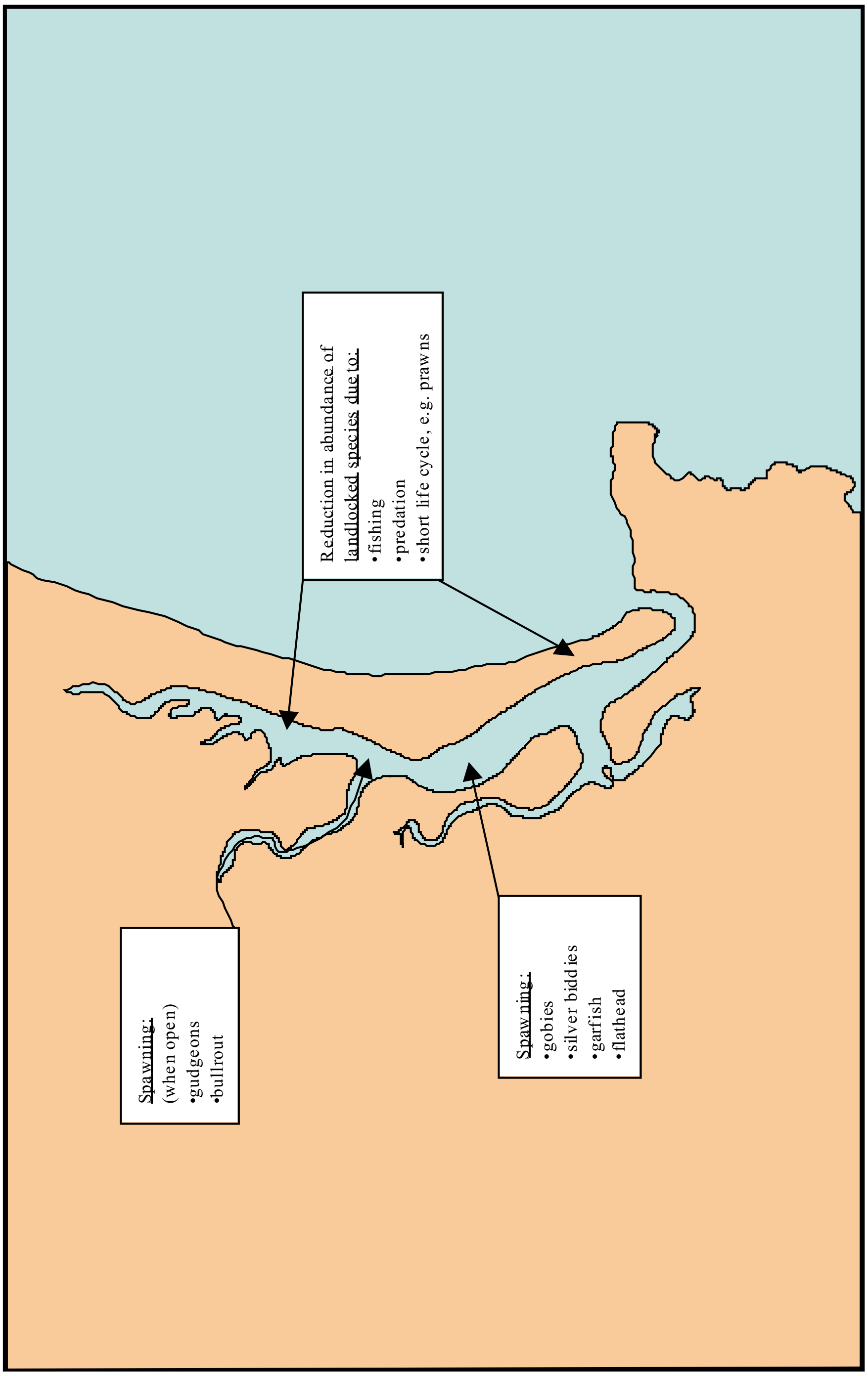
Figure
5.7

DRAWING 1125-05-07.CDR



Source: The Ecology Lab Pty Ltd - Marine and Freshwater Studies

BASED ON INFORMATION FROM OTHER NSW ESTUARIES

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EXPECTED PATTERNS OF SPAWNING OF FISH IN KILLICK CREEK IF THE ENTRANCE REVERTS TO BEING INTERMITTENTLY CLOSED

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Figure
5.8

DRAWING 1125-05-08.CDR