PART 4 KOROGORO CREEK PROCESSES STUDY

4.1 Community values and issues survey

The integration of local community values and issues into estuary management planning is critical to the success of the planning process. The local community are a valuable source of local knowledge which has often been accumulated over years of observation and experience. The community's view on estuarine issues and values is however not always unanimous.

In order to gauge the range of views on the estuary and the importance of issues to different sectors of the community a "Community Values and Issues" survey was developed and distributed over the period 14 December 2006 to 19 February 2007 (See Appendix 2). The survey questions were developed in consultation with the Korogoro Creek Estuary Management Plan Working Group, Kempsey Shire Council, and Department of Natural Resources. The surveys were distributed via four local outlets and via download from the Kempsey Shire Council website. Two hundred and twenty (220) surveys were distributed with seventy-one (71) surveys returned. The results of the survey are summarised and interpreted below.

Q. Are you a resident of Hat Head?

	% Yes
Resident (Y/N)	69.0
If no where?	
Macleay Valley	12.7
Mid North Coast	1.4
Other NSW	15.5
Interstate	0.0
Overseas	0.0

Forty-nine (49) respondents were residents. The estimated resident population of Hat Head is 350 people so approximately 14% of residents responded to the survey. Twenty-two respondents were not residents. This figure represents approximately 1/3rd of all responses and is probably attributable to the survey being conducted during the peak summer holiday period.

Q. Please indicate how you use the Korogoro Creek area

	% Yes
Boat access to ocean	39.4
Camping/caravaning	28.2
Walking	80.3
Swimming	**95.8**
Recreational Fishing	66.2
Boating within the creek	19.7
Passive recreation	64.8
Other	11.3

The most common use of the estuary was for swimming 95.4%, followed by walking, recreational fishing, and passive recreation (picnicking, enjoying the scenery, etc).

Q. Please indicate the importance you place on the following estuary related values…

	% Very Low	% Low	% Moderate	% High	% Very High
Permanently open estuary mouth	1.4	0.0	1.4	**16.9**	**80.3**
Vehicle access to creek bank	**43.7**	**22.5**	11.3	7.0	15.5
The ability to fish	8.5	8.5	15.5	22.5	45.1
Healthy estuary ecosystem	0.0	1.4	1.4	9.9	85.9
Safe swimming location	0.0	0.0	4.2	8.5	87.3
Native foreshore vegetation	1.4	1.4	9.9	18.3	69.0

A permanently open estuary mouth was identified as the most important estuary related value from the list provided with 97.2% of respondents rating this value as of high or very high importance (80.3% very high importance). A healthy estuary, a safe swimming location and native foreshore vegetation were also highly rated.

Vehicle access to the creek bank was the least important value of those listed with only 22.5% of respondents rating in as high or very high importance. 66.2% of respondents felt that vehicle access to the creek bank was of low to very low importance with almost half rating it as of very low importance (43.7%).

Q. Are you happy with current access arrangements to the estuary? Comment.

	% Yes	% No
Boat ramps	78.9	14.1
Vehicle access to creek bank	57.7	**38.0**
Pedestrian access	87.3	9.9
Disabled access	35.2	**46.5**

Generally, a high percentage of respondents were happy with boat ramp access and pedestrian access. Where respondents were not happy with these arrangements comments on boat ramp access were generally concerned with conflict between swimmers and boaters using the same area of the estuary mouth, or in terms of pedestrian access were concerned with perceived plans to relocate the footbridge.

The highest dissatisfaction with access arrangements were with disabled access with many respondents commenting that there appeared to be little provision or stating that beach access was particularly poor. More than 1/3rd of respondents were also unhappy with vehicle access to the creek bank with many commenting on perceived impacts to the southern creek bank.

Q. How would you rate the health of Korogoro Creek?

	% Very Poor	% Poor	% Moderate	% Good	% Very Good
Water quality	1.4	1.4	22.5	**42.3**	**32.4**
Fish populations	0.0	7.0	42.3	35.2	14.1
Foreshore vegetation	7.0	14.1	36.6	35.2	7.0
Bank stability	**21.1**	**31.0**	23.9	15.5	4.2

Respondents generally rated the health of Korogoro Creek as moderate to very good for most of the criteria listed with the exception of bank stability which was rated by more than half the respondents as poor to very poor (52.1%). Water quality in particular was rated highly with 74.7% of respondents describing Korogoro Creek water quality as being good to very good quality.

Q. Are any of the following issues of concern to you?

	% Very Unconcerned	% Unconcerned	% Don't know	% Concerned	% Very Concerned
Sea level rise and climate change	1.4	18.3	11.3	33.8	35.2
Habitat protection	0.0	12.7	8.5	31.0	47.9
Bait collection in the creek	**5.6**	**33.8**	12.7	28.2	19.7
Tropical fish collection in the creek	2.8	15.5	8.5	26.8	46.5
Bank erosion	0.0	11.3	9.9	**25.4**	**53.5**
Uncontrolled vehicle access on the southern bank of the creek	4.2	15.5	11.3	**16.9**	**52.1**
Weeds in the foreshore vegetation	2.8	14.1	9.9	38.0	33.8
Litter/rubbish	1.4	9.9	2.8	**31.0**	**54.9**
Stormwater discharge into creek	5.6	19.7	15.5	25.4	33.8
Poor water quality after flooding	**4.2**	**26.8**	25.4	19.7	22.5
Washing of vehicles near the creek	2.8	26.8	18.3	21.1	31.0
scenic amenity	4.2	9.9	15.5	31.0	38.0
Cultural heritage (indigenous)	**18.3**	**21.1**	22.5	16.9	19.7

The three issues causing the highest level of "Very Concerned" responses were litter/ rubbish in the creek, bank erosion, and uncontrolled vehicle access to the southern bank of the creek (all above 50% of respondents rating the issue as of very concerning).

When the % concerned and % very concerned figures are combined, the three highest rating issues are litter/rubbish, habitat protection, and bank erosion.

The three issues of least concern (% very unconcerned and % unconcerned combined) of those listed are bait collection in the creek, indigenous cultural heritage, and poor water quality after flooding (all identified by approximately 1/3rd of respondents). Interestingly, for all three of these issues there is only a small amount of difference between the numbers of those responding as very unconcerned to unconcerned and those responding concerned to very concerned indicating that the community's view on these issues is relatively diverse.

Summary of findings of the Community Survey

Thirty-two percent of the surveys distributed were returned indicating a relatively high level of interest in the survey (71 from 220 distributed). Approximately 14% of residents responded to the survey which is believed to be quite high given that surveys were not delivered directly to residents but were distributed through third party means.

Respondents placed a high level of importance on a permanently open estuary mouth, a healthy estuary, a safe swimming location and native foreshore vegetation. Vehicle access to the creek bank was not viewed as important by about 2/3rd of respondents.

Respondents were generally happy with pedestrian and boating access to the estuary but were unhappy with disabled access (particularly beach access) and less happy with vehicle access to the creek bank (particularly the southern creek bank).

The health of Korogoro Creek was generally perceived to be in good to very good condition with the exception of bank stability which was considered by half of respondents to be in poor to very poor condition.

The three issues attracting the highest level of very concerned responses were litter/rubbish, bank erosion, and uncontrolled vehicle access to the southern creek bank. When the level of very concerned responses was considered in addition to concerned responses the highest rating issues became litter/rubbish, habitat protection, and bank erosion. The three issues of least concern were bait collection in the creek, indigenous cultural heritage, and poor water quality after flooding.

4.2 Catchment Processes and Nutrient Loadings

Nutrient and sediment loads from catchments depend upon soil types, land use types and drainage patterns. Many empirical studies over the years have measured nutrient loadings from different land use types with similar results appearing around the world (Marston et al, 1995). Catchment characteristics such as geology, rainfall and slope also influence delivery of nutrients to waterways. Once in a waterway, nutrients are assimilated by a number of factors including uptake by biota and through storage into bed sediments. Land use type is generally considered the best indicator of nutrient generation rates. Application of fertiliser, percentage of impermeable surfaces and uptake by biota can all be inferred from land use type categories.

Existing Nutrient Loading Estimates

Robyn Tuft and Associates (1999) made an estimate of the nutrient loads contributed to Korogoro Creek under existing conditions. They used average concentrations of Total Nitrogen (TN) and Total Phosphorus (TP) in the creek water, along with estimates of tidal flushing, estimates of nutrient concentrations in seawater and various assumptions to produce a figure of 22kg/day TN and 2.2kg/day TP. Their figures were expected to be conservative.

In the Review of Environmental Factors for the Hat Head Sewerage Scheme, DPWS (1999) predicted that some 60% of effluent discharged into the dune disposal site would interact with Korogoro Creek via the groundwater. This was predicted to add 2.7kg/day total nitrogen, and 0.08kg/day total phosphorus to the diffuse load already in the creek.

Modelled Nutrient Loadings

The Catchment Management Support System (CMSS) is a method of calculating nutrient budgets based upon landuse types and distribution within a catchment. It incorporates nutrient generation rates, assimilation/attenuation rates and water travel times but is considered a first cut approach to calculating a nutrient budget. There are no existing data for nutrient generation rates specific to the Korogoro Creek Catchment or even the wider Macleay Basin. This limits the accuracy of calculating a nutrient budget. Despite this, the nutrient budget calculated is useful in identifying the contributions of the various land use types and subcatchment areas to the nutrient load for Korogoro Creek.

NEXSYS – the Nutrient Expert System was used to predict a range of nutrient generation rates for each landuse category used in the CMSS model. The middle value for each range was chosen as the nutrient generation rate and the uncertainty was calculated as half of the range given by NEXSYS. NEXSYS is a simple rule-based system, which focuses on five broad land use categories – Urban, Grazing, Cropping, Forests and Horticulture. The data it contains is based upon an extensive literature survey and consultation with Australian experts. The nutrient generation rates provided by NEXSYS do not account for climatic differences nor are they specific to geographic regions. The factors accounted for in the formation of each generation rate are summarised in Table 7.

Table 7 *Nutrient Generation Rates for Korogoro Creek Catchment derived from NEXSYS.*

NEXSYS CATEGORY	**CMSS CATEGORY**	**MULTIATTRIBUTE LANDUSE CATEGORIES***	**FACTORS ACCOUNTED FOR**	**TN Generation Rate** *(kg/ha/yr)*	**TP Generation Rate** *(kg/ha/yr)*
Urban	Residential	Intensive Urban, Residential	No Industry, Sandy Soil	1.0 - 5.0	0.4 - 0.9
	Caravan Park	Caravan Park, Semi Natural Recreation	No Industry, Sandy Soil	1.0 - 5.0	0.4 - 0.9
	Road	Road	No Industry, Sandy Soil	1.0 - 5.0	0.4 - 0.9
Grazing	Unimproved Pasture	Native Pasture, Naturalised Pasture, Wet Pasture	Low Fertiliser Use, Low Slope, >700mL/year rain, >100 to creek, No Gullying, >75% Ground Cover, No Irrigation,	0.5 - 6.0	0.05 - 1.0
	Improved Pasture	Improved Pasture	High Fertiliser Use, No Irrigation, No Gullying, >75% Ground Cover, Low Slope, >100m to Creek, >700mL/year rain	2.0 - 6.0	0.05 - 1.0
Forest	Swampland	Floodplain Swamp, Wet Coastal Heath	No Management, Sedimentary Geology, Low Slope	0.5 - 2.0	0.01 - 0.07
	Bushland	Disturbed Forest, Logged Forest, Native Forest, Regrowth Forest	No Management, Sedimentary Geology, Low Slope	0.5 - 2.0	0.01 - 0.07
	Dune Complex	Dune Complex	No Management, Sedimentary Geology, Low Slope	0.5 - 2.0	0.01 - 0.07
	Extraction	Gravel Extraction, Sand Mining	No Management, Sedimentary Geology, Low Slope	0.5 - 2.0	0.01 - 0.07

* Note: see Figure 2-E (p.31) for the spatial distribution of Landuse Categories.

The results of the CMSS run are included in Table 8. Of primary interest are the total loads of 4355±1188kg/yr TN and 235±86kg/yr TP. The nutrient budget calculated here should not be interpreted as absolute. It is most useful as a base case scenario to be used to help determine the qualitative effects of future land use and flood management decisions on the nutrient load of the Korogoro Creek estuary.

The catchment of Korogoro Creek is largely undeveloped and this is reflected in the relative contribution of swampland and bushland to the total nutrient load. The largest contributor of nutrients to the Korogoro Creek system is the swampland area of the Swan Pool. This factor should be treated with caution as the Swanpool is not part of the natural Korogoro Creek catchment and is only open to the creek in times of flood. The next largest contributor in terms of landuse is bushland, which forms a large part of the total catchment. Of interest also, is the contribution from the Dune discharge of effluent, approximately 23% of Total Nitrogen. Before the commissioning of the sewage treatment works and effluent disposal site septic systems would have contributed nutrients to Korogoro Creek via contamination of groundwater and overflow. Unfortunately, no suitable data exists for a comparison between the relative contributions of septic systems and dune disposal of effluent. It is, however, generally accepted within the local community that active sewage treatment and the decommissioning of septic systems is having a positive effect on the water quality of Korogoro Creek (Vince Jordan, *pers comm.,*2007).

Table 8 *Results of CMSS modelling for Korogoro Creek catchment*

Subcatchment Name*	**Landuse Type**												
	Residential	Caravan Park	Road	Unimproved Pasture	Improved Pasture	Swampland	Bushland	Dune Complex	Water	Extraction	Dune Discharge	Total load (kg/yr)	Uncertainty (±kg/yr)
Total Phosphorus (kg/yr)													
Swanpool	0	0	3	75	3	46	1	0	0	0	0	128	76
Drainage Area	0	0	3	0	0	0	29	0	0	0	0	32	22
Town	24	12	10	5	0	0	7	1	0	0	15	75	13
Total	**24**	**12**	**16**	**81**	**3**	**46**	**37**	**1**	**0**	**0**	**15**	**235**	**86**
Total Nitrogen (kg/yr)													
Swanpool	0	0	12	462	24	1428	40	0	0	0	0	1965	942
Drainage Area	0	0	12	0	0	0	909	0	0	5	0	926	545
Town	111	57	48	33	0	0	211	16	0	3	986	1464	186
Total	**111**	**57**	**72**	**494**	**24**	**1428**	**1160**	**16**	**0**	**8**	**986**	**4355**	**1188**

* Note: Drainage area subcatchment includes all areas outside the village area, excluding Swan Pool

Summary of Catchment Processes and Nutrient Loadings

The results of the CMSS model run suggest total loads of 4355±1188kg TN per year and 235±86kg TP per year, however these figures should be considered indicative only and not absolute. The largest contributor of nutrients to the Korogoro Creek system is the swampland area of the Swan Pool. This factor should be treated with caution as the Swanpool is likely to only be a significantly contributor to the creek in times of flood. The next largest contributor in terms of landuse is bushland, which forms a large part of the total catchment. Of interest also, is the contribution from the Dune discharge of effluent, approximately 23% of Total Nitrogen. No suitable data exists to compare the relative contribution of septic systems to nutrient loads prior to the commissioning of the sewerage treatment plant.

The nutrient levels that have been measured in the waters of Korogoro Creek would suggest a greater nutrient load than has been calculated here. This may be partly explained by the following factors:

- The equations used to calculate attenuation rates and time of travel for the CMSS model may not accurately represent the Korogoro Creek catchment.
- No suitable information exists for the contribution of benthic sediments to nutrient levels in Korogoro Creek. It is likely that some elevated levels of nutrients exist in the sediments of Korogoro Creek as a result of septic treatment of sewage in Hat Head village but this requires further investigation.

4.3 Estuary geomorphology

As mentioned in previous sections Korogoro Creek estuary is classified as a strandplain-associated coastal creek (National Land and Water Resources Audit Estuarine Condition Assessment, 2002). However, the creek's natural form and functioning have been significantly modified as a result of flood mitigation works in the 1960s and 1970s.

The current morphology of the estuary can be broken into two broad process zones that reflect differing degrees of fluvial, tidal and marine interaction (Figure 2-M, p.37). These include a *Marine Tidal Delta Process Zone*, which extends from the mouth to the approximate extent of the tidal delta; and, a *Modified Estuarine Basin Process Zone*, which extends from the end of the delta to the floodgates at Korogoro Cut.

Geomorphic Process Zones

Geomorphic attributes of the modified estuarine basin process zone

The geomorphic attributes of this process zone reflect the modifications that have occurred as a result of flood mitigation. Prior to flood mitigation the channel was narrow and sinuous before eventually petering out into a network of back dune wetlands and swamps. Today the channel resembles a drain, uniform in width, leveed on both sides, and relatively homogenous in depth with the exception of scour holes located downstream of constrictions such as at "The Choke" and at Hat Head Road bridge.

Unlike a typical estuarine basin, fluvial processes are not a significant factor in the current day form of this process zone except in times of flood mitigation operation when they become completely dominant. Tidal processes are therefore important in determining the distribution of sediments and energy within the channel. Upstream of "The Choke" bed sediments are dominated by estuarine muds, whereas downstream of "The Choke" sediments are a mix of estuarine silts, muds and fine sands. This distribution pattern possibly reflects an attenuation of the tidal velocities upstream of "The Choke" or may be a result of a backwater effect that occurs when the "The Choke" operates to restrict flow heights downstream during flooding and divert water through Rowes Cut to the ocean.

Geomorphic attributes of the marine tidal delta process zone

The Marine Tidal Delta process zone is dominated by marine-derived sediment sourced from the inner continental shelf and from the coastal barrier systems. Extensive intertidal and supra-tidal flats occur within this process zone. There is little to no natural levee development and bank heights are low (0.5 – 1.5m). Bedrock outcrops on the southern bank from the entrance almost to the location of the footbridge.

Whilst the channel is dominated by marine sands, the intertidal flats are a mix of marine sand and fine-grained (terrestrially sourced) estuarine sands and muds. Similarly, the supra-tidal flats are dominated by organic rich estuarine sediment overlying Holocene sand deposits. Channel bed forms are influenced by tidal processes with subtidal dunes/shoals migrating upstream on the incoming tide and being partly reworked on the outgoing tide. By this process, sands ingress into the estuary with the rate of ingress generally determined by entrance conditions, tidal velocities, and the supply of sand to the entrance through littoral and longshore transport. During periods of heavy flooding in the broader Macleay catchment significant volumes of water can be discharged through Korogoro Creek over a period of days. Discharge of this volume and duration is enough to scour the channel and reset the patterns of shoaling in the creek.

Analysis of Channel Change 1942 –2003

Many references have been made throughout this report to the extent of changes to Korogoro Creek in the past 60 years and particularly as a result of flood mitigation works. In an attempt to quantify these changes the location of the creek bank over the period 1942 to 2003 have been determined through detailed aerial photography analysis (photogrammetry supplied by DNR Coastal Branch, Newcastle, 2007).

The change in channel width between 1942 and 2003 has been analysed with the results of these analyses summarised in Table 9. The location of cross-sections referred to in the table are shown in Figure 4-A (p.88).

Table 9 *Extent of channel change for representative reaches of Korogoro Creek Estuary (see Figure 4-A) and percentage change in channel width between 1942 and 2003 and post flood mitigation (1979) to 2003 (Source: DNR photogrammetry)*

Year of aerial photograph record	**Width of Channel (m) ***					
	X-section 1	**X-section 2**	**X-section 3**	**X-section 4**	**X-section 5**	**X-section 6**
1942	3.5	10.6	22.7	27.6	44.4	82.6
1956	7.4	9.8	22.0	32.0	44.7	86.0
1979	33.5	34.2	30.0	34.9	66.4	86.6
1997	34.1	37.6	37.1	39.1	72.9	96.0
2003	37.7	41.0	39.8	39.0	74.4	98.8
Change 1942-1956	211% (3.9m)	92% (-0.8m)	97% (-0.7m)	116% (4.4m)	101% (0.3m)	104% (3.4m)
Change 1956-1979	453% (26.1 m)	349% (24.4 m)	136% (8.0 m)	109% (2.9 m)	149% (21.7 m)	101% (0.6 m)
% change post flood mitigation	112% (4.2 m)	120% (5.8 m)	133% (9.8 m)	112% (4.1 m)	112% (8.0 m)	114% (12.2 m)
Total Change 1942-2003	1077% 34.2 m	387% 30.4 m	175% 17.1 m	141% 11.4 m	168% 30 m	120% 16.2 m

* Channel width measurements include intertidal mudflats but not supra-tidal features such as saltmarsh flats. Cross-sections 1-3 are with the Modified Estuarine Basin process zone, sections 4-5 are within the Marine Tidal Delta process zone.

The data show the natural variability in channel width prior to flood mitigation (92% - 211% change 1942 –1956) as opposed to post flood mitigation (101% - 453% change 1956 –1979). In addition, changes above X-section 1 have also been extreme with flood mitigation works extending the creek channel for some 2100m upstream to a width of around 34 m. It is proposed that these changes are the direct result of construction of the flood mitigation works (as opposed to any hydrodynamic changes) as the only significant flood of the period was in 1963 prior to the construction of works.

Post flood mitigation change (1979 to 2003) is in the range of 112% to 133% increase in width. It is likely that these changes are related to the operation of the flood mitigation works during major floods where Korogoro Creek conveys floodwaters far in excess of any that it could have conveyed prior to flood mitigation. Other factors that may have contributed to channel expansion include reduced bank vegetation, impacts associated with concentrated access, and erosion due to wind and boat generated waves.

Bank Erosion

Bank erosion mapping

Bank erosion was determined using a kayak and handheld GPS in April 2007. Bank erosion severity and probable failure mechanism were recorded for each location. In addition, bank erosion control works were also recorded as were natural channel features contributing to stability such as the presence of bedrock or coffee rock. Absolute locations of bank erosion and the aerial extent of erosion are estimated to be accurate within ± 10 m. The entire study area represents 10.5 km of riverbank.

Two main types of bank erosion were identified, with many sites exhibiting evidence of both processes;

- Slab type block failure which results from either inundation and subsequent slumping or from fretting from constant wave action (wind or boat) and subsequent undercutting and failure. Material generally remains insitu.
- Scour and undercutting which results from high velocity flows often acting on the bank toe. Material does not remain insitu. Scour associated with major flooding can remove the evidence of slab type block failures.

The categories of severity of erosion were used;

- *Minor*: where erosion had occurred but processes which led to the erosion were now considered dormant and evidence of natural recovery (such as mangrove colonisation) were apparent
- *Moderate*: where erosion has occurred but processes which led to the erosion were now considered dormant BUT evidence of natural recovery (such as mangrove colonisation) were NOT apparent
- *Severe*: process causing erosion were continuing and no natural recovery mechanisms were apparent

The spatial extent of bank erosion is presented for the entire estuary as well as for individual process zones (Figure 4-B, p.89). This figure shows that the majority of erosion occurs below the Hat Head Road bridge.

Table 10 presents a summary of the results and highlights that 91 % (9.6 km) of the area surveyed is stable with 8 % (0.9 km) experiencing either minor or moderate erosion. No severe erosion was identified. Approximately 8.2% of stable banks were stabilised by erosion control works such as rock revetment while 5.8% were naturally stable as a result of bedrock outcropping on the channel margin. This suggests that 77% of the creek banks are naturally stable.

Table 10 *Severity of bank erosion in the Korogoro Creek estuary process zones (mapped 2007)*

	Total length (m)	*Stable (m)*	*Min. (m)*	*Mod. (m)*	*Severe (m)*	*% Stable*	*% Min.*	*% Mod.*	*% Severe*	*% stable= rocked*	*% stable= bedrock*
ENTIRE ESTUARY	10528	9611	352	565	-	91	3	5	-	8.2	5.8
Modified Estuarine Basin	6865	6185	303	377	-	93	1	5	-	4.8	-
Marine Tidal Delta	3663	3426	49	188	-	90	4	5	-	14.0	16.6

Bank erosion in the modified estuarine basin process zone

Figure 4-B (p.89) shows the spatial distribution of bank erosion in the modified estuarine basin process zone. Ninety-three percent (6185 m) of this process zone is stable with 4.8 % of this being stabilised

with erosion control works (rock revetment). Plate 3 shows typical examples of minor (A) and moderate (B) severity bank erosion in this process zone. Although mapped as stable, several of the upper reaches of this process zone showed signs of previous scour possibly associated with the March 2001 floods during which the flood mitigation scheme operated.

Plate 3 *Typical example of minor bank erosion in the Modified Estuarine Basin Process Zone. A) slab type slumping failure; and moderate bank erosion B) Scour and undercutting of vegetation. Note regeneration of mangrove seedlings in A) which is absent from moderate severity bank erosion B).*

Bank erosion in the marine tidal delta process zone

Figure 4-B (p.89) shows the spatial distribution of bank erosion in the modified estuarine basin process zone. Ninety percent (3426 m) of this process zone is stable with 14 % of this being stabilised with erosion control works (rock revetment) and 16.6% naturally stable due to bedrock outcropping on the southern bank. Plate 4 shows a typical example of moderate severity bank erosion found in this process zone.

The higher proportion of erosion control works indicate that erosion in this process zone has been more prevalent and perceived as more of an issue than in the upstream reaches of the modified estuarine basin process zone. When combined with the percentage figures for existing minor and moderate bank erosion, 23% of the Marine Tidal Delta process zone has been affected by bank erosion in the recent past (last 3 decades). This figure reflects the higher estuary energy in this zone, the erodible nature of the bank sediments (predominantly sands), and potentially the higher impacts on bank and riparian vegetation associated with recreational access particularly on the southern bank.

A)

Plate 4 *Typical example of moderate bank erosion in the Marine Tidal Delta Process Zone A) slab type block failure and slumping. Note sandy soils, poor vegetation cover and evidence of undercut and dead tree roots in bank.*

Estuary Sedimentation

Under natural conditions sediment supply to strandplain estuaries such as Korogoro Creek is low and as a result channel infilling processes are very slow. As freshwater input is minimal, fluvial sediment input is also very limited with most catchment-derived sediment inputs into the creek resulting from sheet runoff or are aeolian inputs (wind-blown). Marine-derived sediments are a more dominant source of sediment supply into the channel when the estuary entrance is open (Boyd et al., 1992).

Figure 4-C presents a longitudinal profile of the Korogoro Creek estuary from the Korogoro Cut floodgates to the mouth based on bathymetrically derived cross-sections collected in November 2005 by the Department of Commerce.

The longitudinal profile highlights the nature of in-channel sediment storage along Korogoro Creek. Areas of the channel bed above the line of best fit (a linear regression with slope of 0.00002) correspond to areas of net sediment storage while areas below this line represent areas of channel scour.

The profile shows that the two identified process zones have distinct sediment storage patterns. The Modified Estuarine Basin Process Zone is predominantly characterised by extensive reaches of sediment accumulation with the major areas of scour correlated with channel constrictions located below "The Choke" and in the vicinity of the Hat Head Road bridge. The channel bed in this zone is relatively planar and homogeneous with sediments dominated by organic muds and sandy muds, often extensively bioturbated by infauna and epifauna. The Marine Tidal Delta Process Zone is characterised by shorter reaches of alternating scour and deposition which represent the extensive shoaling within this zone. Bed features are heterogeneous with multiple dune formations on the bed and sediments mostly composed of coarse-grained marine sands.

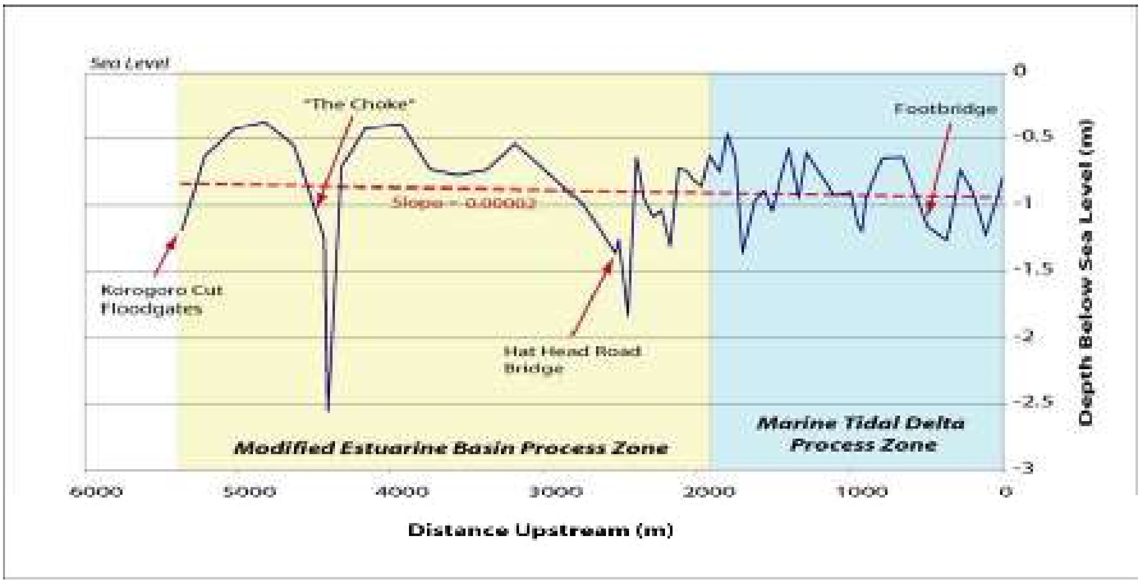

Figure 4-C *2005 Longitudinal profile of the thalweg (deepest point in the channel) of Korogoro Creek - with linear regression (slope = 0.00002). Topography derived from bathymetric data (source: DoC, 2006).*

Although Figure 4-C provides a 'snap shot' of sediment storage patterns along Korogoro Creek in 2005 it does not provide an indication of how these longitudinal patterns have changed through time. It is a commonly expressed community view that the estuary has "silted up" in recent years. Whilst there is no historic quantitative data with which to compare to the 2005 bathymetry, an analysis of aerial photographs from 1942 through 2003 certainly indicates extensive changes to the sedimentation patterns of the estuary. Most notably, the ingress of marine sands associated with the Marine Tidal Delta Zone has extended considerably up the channel for some 830m since 1956 (Figure 4-D, p.90). Unfortunately, due to the lack of quantitative data it is not possible to confirm the processes or determine the scale of sedimentation or the rate of infilling. However possible causes for this ingress include;

- changes to the hydrodynamic processes post flood mitigation including tidal and flood flow currents (volume and velocity); and/or
- an increased supply of sand at the entrance associated with coastal processes such as alongshore transport driven by the wind and wave associated currents.

Summary of Korogoro Creek Geomorphic Condition

The current morphology of the estuary can be broken into two broad process zones reflecting differing degrees of fluvial, tidal and marine interaction. They are the *Marine Tidal Delta Process Zone* which extends from the mouth to the approximate extent of the tidal delta, and the *Modified Estuarine Basin Process Zone* which extends from the end of the delta to the floodgates at Korogoro Cut.

The Korogoro Creek estuary has been significantly modified as a result of flood mitigation works. The extent of channel change has been greatest in the upstream reaches of the Modified Estuarine Basin Process Zone (above the town bridge) with flood mitigation extending the length of channel by ~2100 m and a minimum 4 fold increase in channel width. Downstream of the bridge increases in channel width ranging from 101-349% can be attributed directly to flood mitigation (1956-1979) compared with average width variability of 120% prior to flood mitigation (1942-1956). Post flood mitigation (1979-2003) the channel has continued to expand its width with average increases of 117%. The effect of flood flows being diverted down the creek during broader Macleay valley flooding is thought to be the primary contributor to post works channel expansion although reduced bank vegetation cover, tidal scour, concentrated access impacts, and wind generated wave erosion are also contributing effects.

Bank erosion mapping (2007) reveals that 91% of the estuary banks are considered stable. 8.2% of banks are stable as the result of bank protection works such as rock revetment whereas 5.8% are stable due to bedrock outcropping into the bank (ie. Southern bank below the footbridge). Channel reaches below the town bridge are the most affected by bank erosion. Most erosion is considered to be minor (ie erosion processes assessed to be dormant and natural recovery processes occurring) or moderate (erosion processes considered to be dormant but no natural recovery evident). No severe erosion was recorded. Evidence of scouring post the March 2001 floods is evident in the upper reaches but most areas are now thickly covered with regenerating mangroves, swamp oaks and other riparian vegetation including bitou bush.

Sedimentation patterns in the estuary show a distinct differentiation broadly in line with the identified process zones. The Modified Estuarine Basin process zone is predominantly characterised by extensive reaches of sediment accumulation with the major areas of scour correlated with channel constrictions located below "The Choke" and in the vicinity of the town bridge. The channel bed in this zone is relatively planar and homogeneous with sediments dominated by organic muds and sandy muds. The Marine Tidal Delta Process Zone is characterised by shorter reaches of alternating scour and deposition which represent the extensive shoaling within this zone. Bed features are heterogeneous with multiple dune formations on the bed and sediments mostly composed of coarse-grained marine sands. Aerial photographs comparisons over the period 1942 to 2004 lend weight to anecdotal reports of channel infilling in the estuary. Unfortunately, due to the lack of historical quantitative hydrographic or cross-sectional data it is not possible to confirm the processes or determine the scale of sedimentation or the rate of infilling.

4.4 Entrance Behaviour

The lack of significant freshwater input and the presence of strong tidal currents result in the entrances of small coastal estuaries often being either intermittently or permanently closed to the ocean. However, in Korogoro Creek the entrance is permanently open and untrained, unusual characteristics for a small coastal creek in this locality.

In Korogoro Creek it is believed that the orientation of the headland immediately to the south and east of the entrance and the proximity of the continental shelf have a major influence on along shore currents in the area, which in turn influence the transport of sand to the entrance and wave energy. Thus the potential for berm development at the creek mouth is less than for a typical estuary of this type and size.

In addition, unlike many other small coastal creeks in the vicinity, sands at the entrance tend to build under southerly swell conditions and reduce under north-easterly swells and winds (Vince Jordan, pers.comm..,2007), although tidal currents also play a major role in entrance behaviour and conditions. During small tides (0.4 - 0.6 m lows, 1.2 –1.5 m highs) tidal velocities are low, minimal channel scouring occurs and within channel sediment transport is less. During larger tidal ranges (0 –0.3 m lows, 1.8 –2.0 m highs) tidal velocities are higher and sediment transport increases with the greater sediment load deposited in the slack water where estuary meets the ocean at the creek mouth. Whilst there may be little net loss or gain in sediment quantity, these processes affect shoal size and location at the mouth (Kim Hogno, pers.comm., 2007). Historical records of the wave climate and storm history of the area are provided in the sections below.

Historical characteristics of entrance behaviour

Wave Climate

The wave climate may be inferred from data from the Crowdy Head Waverider buoy operated by MHL which is located in 79 m of water about 10 km east of Crowdy Head (approximately 80 km south of Hat

Head). Long-term statistical analysis of this data is available from 10 October 1985 to date and includes deepwater wave direction from hindcasting from October 1985 to December 1996. A summary of wave height exceedance statistics for the period 10 October 1985 to 30 June 2006 is shown in Figure 4-E and directional statistics are presented in Figure 4-F (p.92).

Storm History

Storms are generally defined as events in which the significant wave height (Hs) exceeds 3 m. Storm events recorded by the Crowdy Head Waverider buoy from 1985 to 2005 where Hs exceeded 5 m are listed in Table 11. As can be seen from the table, the major storm events result in peak swell directions from the south, south east, and south-south east. As mentioned previously, the entrance to Korogoro Creek is protected from swells from this direction by the orientation of the headland, a factor which contributes significantly to the entrance opening characteristics (ie. Permanently open).

Table 11 *Occurrence of Significant Waves $H_s > 5$ m at Crowdy Head for Period 1985 to 2005 (Source: Manly Hydraulics Laboratory, NSW DoC, 2007)*

Storm Start Date	Storm End Date	Peak H_s (m)	Mean T_s (s)	Peak Direction
12-May-86	15-May-86	5.1	8.1	E
4-Aug-86	12-Aug-86	5.9	10.1	SE
12-Nov-87	13-Nov-87	5.9	9.6	S
8-Feb-88	11-Feb-88	6.5	10.6	S
9-Apr-88	12-Apr-88	5.0	9.9	SSE
24-Aug-88	25-Aug-88	5.0	9.6	SSE
23-Apr-89	30-Apr-89	5.3	9.0	E
20-Jun-89	25-Jun-89	5.8	10.2	ESE
26-Sep-89	29-Sep-89	5.8	10.0	SSE
7-Mar-90	10-Mar-90	6.3	10.4	SSE
28-May-90	30-May-90	6.7	9.2	SE
24-Aug-90	28-Aug-90	5.0	10.0	SSE
12-Oct-90	15-Oct-90	6.4	11.1	S
8-Jun-91	11-Jun-91	5.0	9.0	E
30-Nov-92	2-Dec-92	5.2	9.6	SE
12-Mar-94	15-Mar-94	5.3	11.0	S
7-Sep-94	9-Sep-94	5.0	11.2	S
2-Mar-95	5-Mar-95	7.4	9.9	ESE
6-Mar-95	8-Mar-95	6.3	10.4	E
5-Sep-95	8-Sep-95	5.1	10.8	S
25-Sep-95	28-Sep-95	5.4	10.0	SSE
19-Aug-96	20-Aug-96	5.8	9.9	S
9-May-97	12-May-97	6.3	10.1	SSE
4-Feb-99	5-Feb-99	5.3	9.8	E
22-Apr-99	25-Apr-99	6.5	11.2	ESE
13-Jul-99	17-Jul-99	6.8	10.5	ESE
9-Nov-99	12-Nov-99	5.0	11.0	SSE
28-Jul-01	29-Jul-01	6.3	11.9	S
29-Jun-02	02-Jul-02	6.3	11.7	SSE
18-Jul-04	20-Jul-04	5.3	10.4	S
19-Oct-04	21-Oct-04	5.2	8.7	ENE
28-Oct-04	30-Oct-04	5.3	11.4	S

Effects of Sea Level Rise on Entrance Conditions

Over the next 100 years the global mean temperature and sea level are expected to rise due to an increased "greenhouse effect". The greenhouse effect is a predicted global warming associated with the build-up of certain gases in the atmosphere. Greenhouse gases are essentially transparent to incoming short-wave radiation, but they absorb the longer wavelength infrared radiation (heat) emitted by the earth. Thus heat is trapped in the atmosphere and the global temperature is increased.

The most up-to-date estimates of temperature and sea level rise are those provided in the Fourth Assessment Report (FAR) of the Intergovernmental Panel on Climate Change 2007 (http://ipcc-wg1.ucar.edu/wg1/wg1-report.html). The FAR predicts an increase of global averaged surface temperature of 1.1 to 6.4°C over the period 2090 to 2099 relative to the period 1980 to 1999. The range is due largely to uncertainty in the amounts of greenhouse gases which nations will emit under different emission scenarios and variability in different climate models. The projected temperature increases are higher and display a wider range than those of the Third Assessment Report (TAR) of 2001 (Albritton et al., 2001) Sea level rise is expected to increase by 0.18 – 0.59 m over the same period which is a narrower range than that predicted in the TAR (0.09 – 0.88 m). The new estimates reflect improved data analysis and modelling techniques.

Increased sea level is expected to lead to general beach recession. Concerning ICOLLs, beach recession is expected to be accompanied by landward and upward translation of the entrance berm (Hanslow et al., 2000). This results in higher lagoon levels and a higher flood risk to shoreline development.

Besides sea level and temperature rise, another possible effect of climate change is a change in weather patterns through changes in wind and precipitation patterns. The range of predicted changes may severely effect coastal areas, including foreshore alignment and stability, increased coastal flooding, salinity intrusion into estuaries and aquifers, altered tidal regimes, changed sedimentation patterns inundation and displacement of wetlands and lowlands, and changes to ecological processes and functioning (Engineers Australia, 2004). These potential changes need to be accommodated in planning foreshore development, facilities and services.

Summary of entrance conditions and behaviour

The entrance of Korogoro Creek estuary is permanently open and untrained. The orientation of the headland and long shore currents off Korogoro Point interrupt the littoral and along shore sediment transport processes by creating a relatively protective environment with low wave energy. As such, shoaling patterns are more influenced by swell and wind directions (entrance shoals building under north-east conditions and reducing under southerly conditions) and tidal cycles. Intermittent large floods also affect the entrance with scouring occurring during the prolonged flows associated with the operation of the flood mitigation scheme. Build-up of sand deposits in the vicinity of the boat ramp has at times necessitated the removal of sand by Council. The regularity of such works is not known. Sea level rise and climate change have the potential to significantly affect entrance conditions and the estuary as a whole with the major effects being alterations to foreshore alignment and stability, increased coastal flooding, salinity intrusion into the estuary and aquifers, altered tidal regimes, changed sedimentation patterns inundation and displacement of wetlands and lowlands, and changes to ecological processes and functioning. The range and extent of impacts specific to Korogoro Creek cannot be quantified at this time.

4.5 Hydrodynamics

Manly Hydraulics Laboratory was commissioned by GECO Environmental to undertake the hydrodynamic assessment of Korogoro Creek. MHL was specifically requested to;

- Provide information on tidal planes and tidal phasing

- Developing and explaining a Conceptual Water Balance Model including a preliminary volumetric assessment and describing the effect of freshwater inflows including inflows from floodplain wetlands and the periodic operation of the Macleay Valley Flood Mitigation Scheme, and the effects of groundwater and evaporation
- Developing and explaining a Conceptual Model of Circulation and Flushing including describing the stratification and mixing processes of the estuary.

The results of the MHL investigations are presented below but can also be viewed in MHL Report 1729 - Korogoro Creek Estuary Processes Study Hydrodynamics (2007).

Tidal Planes and Phasing

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 (Site 2), upstream (Site 4) and in the ocean at Crowdy Head (Figure 4-G, p.93). The figure highlights the attenuation of the tides between the ocean and the entrance gauge and further attenuation upstream at the Hat Head Road bridge. This increase in the tidal level in the upstream reaches of the estuary may be attributed to resonance effects. This occurs because the frequency of the ocean tide is close to the frequency of free oscillation of the main estuary channel (which is dictated by its length and depth). A narrowing of the waterway cross-section in an upstream direction also encourages tidal amplification (DNR 2007).

A detailed tidal data collection study was undertaken by MHL in 2004-05. As part of this study, time-series water levels were recorded at three locations within Korogoro Creek (see Figure 4-H, p.94). Data from these three sites and an ocean tide gauge (Crowdy Head) were analysed using the Foreman method of tidal height analysis to determine the tidal planes and tidal ranges along the estuary. Data for the 39-day period from 2 July to 10 August 2004 was used to calculate the tidal planes presented in Table 12 and Figure 4-I (p.95).

Table 12 *Comparison of Tidal Planes (July-August 2004) (MHL 2005)*

Tidal Planes	**Ocean Site 0 (m AHD)**	**Korogoro Creek Site 2 (m AHD)**	**Site 4 (m AHD)**	**Site 5 (m AHD)**
Distance from Entrance (m)	0	570	2440	5200
HHW(SS)	0.991	0.816	0.869	0.832
MHWS	0.546	0.473	0.507	0.486
MHW	0.427	0.412	0.440	0.421
MHWN	0.308	0.350	0.374	0.355
MTL	-0.109	0.065	0.121	0.115
MLWN	-0.526	-0.221	-0.131	-0.125
MLW	-0.645	-0.282	-0.198	-0.190
MLWS	-0.764	-0.344	-0.264	-0.256
ISLW	-1.082	-0.589	-0.523	-0.503

HHW(SS) - Higher High Water (Spring Solstices)
MHWS - Mean High Water Springs
MHW - Mean High Water
MHWN - Mean High Water Neaps
MTL - Mean Tide Level
MLWN - Mean Low Water Neaps
MLW - Mean Low Water
MLWS - Mean Low Water Springs
ISLW - Indian Spring Low Water

Tidal Phasing

The tidal phasing relates to the rate of propagation of the tides into the estuary. By using the data collected from the three sites within Korogoro Creek and the ocean tide gauge at Crowdy Head, a measure is provided of the time lag between high tide in the ocean and high tide at the upstream sites. The methodology for calculating the tidal phases is described in MHL (2005) and results are presented in Table 13.

Table 13 *Tide Phase Differences for Springs and Neaps (July-August 2004) (MHL 2005)*

Site	Spring/Neap	Mean (minutes)	Standard Deviation (minutes)	Minimum (minutes)	Maximum (minutes)
2	MHWS	30	11.9	13	45
	MLWS	83	19.1	53	106
	Mean Springs	56	31.1	13	106
	MHWN	17	5.3	9	24
	MLWN	46	13.7	33	68
	Mean Neaps	31	17.8	9	68
	Mean of All	44	28.3	9	106
4	MHWS	32	9.8	20	46
	MLWS	126	13.3	114	147
	Mean Springs	79	48.2	20	147
	MHWN	36	3.2	32	40
	MLWN	106	35.8	58	159
	Mean Neaps	71	43.4	32	159
	Mean of All	75	46.0	20	159
5	MHWS	44	15.4	26	68
	MLWS	165	18.0	147	192
	Mean Springs	104	62.4	26	192
	MHWN	49	15.6	33	72
	MLWN	145	47.2	79	211
	Mean Neaps	97	59.5	33	211
	Mean of All	100	61.1	26	211

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 4-G highlight these oscillations during March 2005 when a significant increase in the average water level occurred between 22 and 24 March and then a gradual decrease ensued between 25 and 31 March. The effect of this sea level change can be seen by a significant increase in tidal levels through the entire tidal cycle for Site 2, located on the footbridge near the estuary entrance. A lesser effect can also be observed in the upper estuary (Site 4) where the greatest change occurs during high water, with minimal difference at low water.

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.

Conceptual Water Balance

Preliminary Volumetric Assessment

A simple volumetric analysis of the tidal hydraulics provides a useful preliminary understanding of the tidal effects.

The volumetric analysis is based on hydrographic survey data collected in November 2005 by DIPNR which constitutes a total of 75 cross-sections between the entrance and closed flood gates. The volumetric analysis was carried out using a box model of the creek. The creek was divided into 11 boxes centred on available salinity profiles (MHL 2005) for the 5300 m of estuary and distribution of cross-sections. A plan view of the extent of these boxes is shown in Figure 4-H (p.94). Tidal characteristics, as presented in the tidal data collection report (MHL 2005), were interpolated for each box to determine appropriate water levels for volume calculations.

The hydrographic survey data around the entrance of the estuary is well defined, allowing for a grid method to be applied when calculating the volumes for boxes 1 and 2 (see Figure 4-H, p.94). The grid method involves fitting the survey data to an appropriate resolution grid and linearly interpolating to form interim grid points such that the bathymetry between cross-sections is defined as a grid. The volume is then calculated by integrating the surface area from the bed to the height of interest.

The hydrographic survey data for the remaining boxes were less defined than for boxes 1 and 2, with cross-section data ranging between 2 and 10 cross-sections per box. For these boxes an alternative method of volumetric assessment was employed. The submerged area for each water level at each cross-section is calculated and applied to a specified length considering relevant structures and bathymetry.

Based on the volumetric analysis of the estuary an estimate of the total volume of the creek at mean tidal level of 87 ML was derived. Tidal prism volumes for the mean neap tide, 91 ML, and mean spring tide, 137 ML, were also derived.

The tidal prism at the mean neap tide is of similar magnitude to the estuary volume, while the tidal prism at mean spring tide is about 1.5 times the estuary volume. This difference in tidal prisms between the neap and spring tides suggested that in an overall sense the system should be well flushed.

The physical characteristics of volume, cross-sectional area and bed elevation in relation to the distance from the ocean are presented in Figure 4-J (p.96; thalweg data is presented in Appendix 3). The volume of the creek increases approximately linearly with distance from the ocean, while the cross-sectional area is somewhat variable but essentially decreases from the mouth of the creek to the open floodgates (chainage 4400). The average depth of the estuary is -1 m AHD with shallower shoals of -0.8 m AHD near the entrance and -0.9 m AHD in the upper channel. Around the floodgates, in the upper reaches of the estuary, the depth increases to -2.6 m AHD. In these deep sections, the reduction in tidal-induced turbulence, and hence lower mixing, may promote the development of prolonged periods of stratification.

Influence of Freshwater Inflows

Local Catchment

Freshwater flows in Korogoro Creek are primarily generated from catchment rainfall. The land use within the catchment includes National Park bushland, natural and drained wetlands (Swan Pool) as well as the coastal dunes and township of Hat Head.

The flow in Korogoro Creek is un-gauged and it has not been considered within the scope of this study to derive estimates of the flows. Estimates of the freshwater inputs from the local catchment were derived from a simple rainfall-runoff relationship.

The average monthly freshwater inflow entering the estuary has been calculated by approximating the runoff from the local catchment area. The catchment area was defined by DPWS (1999) to be approximately 16 km^2 however this area may vary depending on the operation of complicated drainage and flood mitigation structures in the area. A number a factors determine the percentage of rainfall that may enter the estuary systems as runoff. As rain falls, it may be intercepted by the leaves and branches of vegetation. When the rain lands on the ground it may be absorbed into the ground (infiltration); this process depends on the moisture content of the soil, and infiltration will continue until the soil has reached saturation. The infiltrated rainfall may pass down through the soil to the watertable and into groundwater flow or it may be taken up through root systems of trees. The rainfall that remains at the surface may run off to a depression where it is stored until the depression fills. The water may then evaporate from the surface or flow overland into the estuary.

By assuming a runoff coefficient of 0.15, which is typical for these catchments when unsaturated, and applying the average monthly rainfall statistics available for South West Rocks (the nearest station to Korogoro Creek) (BoM 2007) the average monthly inflow entering the estuary may be calculated. The average monthly inflow for the Korogoro Creek catchment is 297.4 ML and the average daily inflow is 9.6 ML which is around 10% of the tidal prism. A breakdown of average monthly freshwater inflows is given in Table 14.

Table 14 *Monthly Rainfall and Associated Inflow Volume Due to Surface Runoff (1939-2007)*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Rainfall (mm)	147.4	165.6	194.0	167.9	139.1	130.8	79.4	82.7	55.2	91.1	111.3	122.6	1487.1
Local Catchment Runoff (ML)	353.8	397.4	465.6	403.0	333.8	313.9	190.6	198.5	132.5	218.6	267.1	294.2	3569.0

Flood Flows

Another significant feature of inflows to Korogoro Creek is the increase in flows when the Macleay River is in flood. Korogoro Creek lies in the catchment of the Macleay River and is part of the Macleay River Flood Mitigation Scheme. During floods the overland flooding associated with high water levels on the Macleay is designed to flow through Korogoro providing an efficient mechanism for relief of the inundation of surrounding low-lying areas.

Peak flows through the flood gates at Hat Head were modelled to be 108 m^3/s for the 1% AEP and water levels around 2.6 m AHD (Webb McKeown 1994). It is also noted that some failure of levies may occur and thus further overland flooding is possible (Webb McKeown 1994).

There is no available information about the recorded magnitude of flood flows through Korogoro Creek or the extent of flooding expected, and thus it is difficult to quantify these effects. In the case of an extreme flood it would be expected that large flows and large velocities would be experienced and hence scouring of wetland, drainage channels and ocean entrance can be expected. The nature of flooding is such that these extreme conditions are only likely to last for a few hours to a day as the flood peak moves through the area and can be characterised as a high volume, short duration input into Korogoro Creek.

Groundwater

There have been several investigations into the groundwater associated with the Hat Head Dune Effluent Disposal Site conducted by the UNSW Water Research Laboratory (Turner & Pells 2003, 2004). These investigations primarily focus on the disposal site at the north-east of the Hat Head Road bridge, however they do provide limited information on the characteristics of the regional hydrogeology.

The groundwater in the Korogoro Creek area is characterised by a predominantly clean sand aquifer at least 15 m thick which in some areas is split by organic silt layers to create an upper and lower aquifer (Turner & Pells 2003).

The hydraulic conductivity of the aquifer at the disposal site is reported as being an average of 25 m/day and the hydraulic gradient is described as flowing from higher water levels in the coastal dunes towards the lower water levels adjacent to the creek (Turner & Pells 2003).

The water table elevations recorded in test bores were between 0.3 m and 1.0 m AHD with water table fluctuations of up to 0.5 m observed in response to rainfall recharge and/or super-elevation at the ocean boundary due to storm water events (Turner & Pells 2003).

Given this information about the groundwater in the region it is expected that the surface water to groundwater interaction is characterised by a high water table which shows a strong response to rainfall events through infiltration of rainfall. With high rainfall events it is expected that at many low-lying areas the water table will rise to the surface and large amounts of runoff will follow. However if rainfall occurs on an unsaturated catchment, higher infiltration is expected.

The centralised sewage collection and treatment system which services the township of Hat Head incorporates the disposal of sewage effluent within sand dunes located north of the Hat Head settlement. The effluent is disposed into the sand dunes through the use of two exfiltration basins which collectively dispose of 450 kL/day of treated effluent (DPWS 1999). Post-commissioning groundwater quality studies conducted by Turner and Pells (2004) conclude that there is ‘no groundwater response attributable to the commissioning of the exfiltration basins detected’. It was observed, however, that a ‘net horizontal flow towards the creek prevails beneath the dune disposal site’, thus it can be expected that the effluent disposed in the dunes contributes to the creek freshwater flows.

The amount of groundwater contributing to the Korogoro Creek freshwater flows is difficult to quantify, however a simplified estimate of the maximum average groundwater inflow may be derived using the following assumptions:

- Transmissivity (*T*) of the sand aquifer is estimated by multiplying the hydraulic conductivity by the average vertical thickness of the aquifer. The average thickness of the aquifer is taken to be 15 m and thus $T = 25 \text{ x } 15 = 375 \text{ m}^2/\text{day}$
- The hydraulic gradient towards the creek is assumed to be 0.001. This assumption was checked based on the standing water level in bores close to the creek and in the dunes and found to be representative to the conditions.
- The length of the creek to the closed flood gates is approximately 5200 m.
- It is also assumed that the groundwater is primarily flowing from the inland catchment into the creek and the perimeter may be approximated as the length multiplied by 1.5.

The average groundwater inflow can be calculated from the following relationship:

$$Q = T.I.L$$

where:

Q = flow (m^3/day)
T = transmissivity (m^2/day)
I = hydraulic gradient (dimensionless)
L = length (m)

From this equation the maximum estimated groundwater flow into Korogoro Creek is expected to be approximately 2.93 ML/day or 87.75 ML/month and 1053 ML/year. This value may vary significantly depending on the amount of rainfall and the saturation of the catchment soils at the time of rainfall. It should also be noted that these assumptions represent a highly generalised situation, and thus can only be relied upon as a guide.

Discussion of Inflows

The results of the investigation into freshwater flows contributing to Korogoro Creek reveal that it is possible that the main source of fresh water is catchment rainfall/runoff which averages 297 ML/month. The other major input is groundwater at 87.75 ML/month or 6 ML per tidal cycle or approximately 5% of the tidal prism. Therefore total freshwater inflow is approximately 384.75 ML/month. It should be noted that these values represent highly idealised scenarios, however they do provide an insight into what can be expected under average conditions.

These estimations can be expected to vary significantly depending on the state of the catchment before a rainfall event. If the catchment is dry (i.e. unsaturated soils) there is likely to be less runoff from the catchment when rainfall occurs, due to the rainfall infiltrating the soil before runoff can be generated. Another limitation to the estimation of the catchment runoff is the catchment area which may change during large rainfall events where drainage or flood mitigation schemes will alter this estimation. The groundwater response to rainfall may also be significant as during a large rainfall event the water table may rise to the surface and saturate soils creating additional runoff.

During dry periods the main source of freshwater inflow will be groundwater from the aquifer in the region, and in particular the effluent disposal site may provide the most constant source of groundwater flow into the creek.

If a flood event occurs there will be significantly more freshwater inflow as the low-lying areas in the greater catchment are drained through Korogoro Creek and associated levies. It is expected that the high flows, water level and velocities associated with this will lead to the creek being completely flushed with fresh water during this period.

Effects of Evaporation

The surface area of the Korogoro Creek estuary (not including wetlands) at mean tide level is approximately 200,000 m^2. This is relatively small and does not provide a significant evaporation surface area. The magnitude of the evaporation rate may be estimated by assuming the available monthly average evaporation data for Coffs Harbour as representative of the conditions in Korogoro Creek. The rate of evaporation is then multiplied by the surface area. Estimates of the evaporation volume for each month and annually are displayed below in Table 15.

Table 15 *Monthly Evaporation Potential (1968-2007) and Volume Lost to Evaporation (also presented as a fraction of runoff volume)*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Evaporation (mm)	202	170	164	126	93	81	87	115	150	177	195	208	1766
Volume Evaporated (ML)	40	34	33	25	19	16	17	23	30	35	39	42	353
Fraction of runoff	11%	9%	7%	6%	6%	5%	9%	12%	23%	16%	15%	14%	10%

The percentage of monthly runoff is also listed in Table 16 and indicates that on an annual basis around 10% of the catchment runoff is lost to evaporation, with the losses during the drier spring months up to 23%.

The evaporation process essentially removes the fresh water from the system and leaves behind any salts and other constituents leading to increased concentrations in the estuary waters. The evaporation losses in the Korogoro Creek estuary are not of significance when compared to the other amounts accounted for in the water budget and are not expected to have a significant effect on the water balance.

The potential for evapotranspiration (uptake of water by plants) in the wetlands surrounding the channel and in the low-lying areas within the catchment may be an additional source of losses of fresh water. The area of the wetlands associated with Korogoro Creek and its catchment are unknown and thus it is difficult to quantify these losses to any degree of accuracy.

Summary of Water Balance

A summary of the findings of the water balance with respect to the volumetric analysis is presented below in Table 16 and summarised in Figure 4-K (p.97). This table shows that the flushing from the tidal influence dominates the flows in the creek whilst groundwater and catchment runoff provide freshwater flows. It is also clear that evaporation does not play a large role in Korogoro Creek as there is not a large amount of surface area. Evapotranspiration through wetland areas may be significant to the water balance in these areas.

Table 16 *Summary of Water Balance compared to Volumetric Analysis*

Contribution	Volumes (ML)
Volume of Creek at MTL	87
Tidal Prism Range	91 (neap)-137 (spring)
Rainfall	~ 10/day
Groundwater	~ 3/day
Evaporation	~ -1/day
Total Fresh Inflow	**~12/day**

Conceptual Model of Circulation

Flushing Analysis

The degree of flushing in an estuary is determined by the complex interaction of hydrodynamic processes including freshwater inflows, tidal circulation, groundwater inputs, turbulent mixing and density effects. A common measure of the degree of flushing is to calculate the flushing time, that is the average time it takes for a tracer in the estuary to be flushed out of the creek. This is often determined by the change in tracer concentration over a period of time rather than the time for complete flushing.

Traditionally, salinity is used as a tracer and flushing time has been defined in two ways:

1. the time interval in which the total volume of the existing estuary water will be replaced by new water entering the estuary, or
2. the 'freshwater flushing time', being the time required to replace existing fresh water in the estuary at a rate equal to the freshwater inflow.

In Korogoro Creek the primary inputs of water, as identified by the water balance presented above, are tidal circulation and freshwater flows; thus these represent the primary flushing mechanisms. Two simple methods which are commonly used to calculate flushing times are investigated below in regards to Korogoro Creek, namely the 'Tidal Prism Estimate' and the 'Freshwater Fraction Method' (MHL 2003). A comparison between these two methods of flushing (tidal and freshwater flow) is then made in order to determine which flushing time is the shorter and thus represents the primary mechanism.

Tidal Prism Estimate

The classic tidal prism estimate is the simplest method of calculating flushing time as it only takes into consideration the volume exchange of water during tidal cycles. In an estuary where tidal flushing is largely dominant, this method provides a reasonable estimate. The volume of water introduced (i.e. the tidal prism) is the change in estuary volume between the high and low slack water levels. The tidal prism is assumed to completely mix with the existing estuarine water within a tidal cycle and some fraction (tidal mixing efficiency) of this volume is exchanged with ocean water.

The flushing time is determined by multiplying the semi-diurnal tidal period of 12.5 hours by the ratio of the volume at high tide to the tidal prism. The tidal prisms for spring and neap tides were calculated from the available tidal planes analysis as explained above.

This method assumes complete mixing (i.e. mixing efficiency of 100%) of the tidal prism with the existing estuarine waters and is very sensitive to the tidal mixing efficiency. These assumptions essentially mean that this calculation may represent an underestimate of the actual flushing time. In order to test the sensitivity of this assumption the flushing time was recalculated assuming a mixing efficiency of 70%. This change in mixing efficiency showed the estuary would still be almost completely flushed within approximately 1-2 days, supporting the suggestion of a well-flushed estuary. Results of flushing time calculations and sensitivity analysis are presented in Table 17.

Table 17 *Flushing Times Using the Tidal Prism Estimate*

Tide	Volume of Estuary at Low Slack Water (ML)	Tidal Prism (ML)	Flushing Time (hrs)	
			100% Mixing Efficiency	70% Mixing Efficiency
Spring	32.5	137.5	~15.5	~22.1
Neap	48.0	91.6	~19.1	~27.2
Mean	40.1	114.6	~16.9	~24.1

The spring tidal prism is over four times the volume at spring low slack water and the neap tidal prism is almost double the volume at neap low slack water. This, in itself, suggests a well-mixed estuary due to volume exchange, but even in a well-mixed estuary complete mixing will be rare. Thus, the flushing times in Table 18 are minimum times and the sensitivity analysis suggests a reasonable estimate of average flushing time for the whole estuary is 1-2 days.

Freshwater Fraction Method

It is possible to obtain an estimate of estuary flushing time by tracking the transport of a continuous tracer (in this case salinity) from the tidal inlet location to various locations within the estuary. The freshwater fraction method requires a salinity gradient between the ocean (the salt source) and various locations within the estuary. Freshwater fraction flushing time is calculated as the time required to replace existing fresh water in the estuary at a rate equal to the total freshwater input.

Salinity profiles obtained on 4 May 2004 by MHL (2005) at 11 sites along the length of the creek and an assumed ocean salinity of 35.49 ppt were used for the analysis.

The model boxes outlined in Figure 4-H are defined around each of the salinity profile sites, and the box volume, depth-averaged salinity and freshwater inflow are used to assess the flushing time for each box. Using the Crowdy Head ocean water level and data from each water level site in the estuary (Figure 4-G, p.93), water levels were interpolated for all boxes. Freshwater inflow is assumed to be evenly distributed over the length of the estuary and inflow to each box is calculated as the average fresh inflow (Table 17) per cycle apportioned by box length to total creek length for each box.

Sensitivity analysis was conducted to simulate periods of increased (wet) and decreased (dry) freshwater inflow and its effect on flushing times. Flushing times determined using this method are highly sensitive to freshwater inflow (Table 18).

Table 18 *Flushing Times Using the Freshwater Fraction Method*

	Flushing Time (days)		
	Average Fresh Inflow (AFI)	**Wet (2AFI)**	**Dry (0.5AFI)**
Boxes 1-6 Up to Ch 2500	0-10	0-5	1-19
Boxes 7-11 Up to Ch 5200	7-16	4-8	15-32

This method assumes steady state which implies the salinity data represent an average over the derived flushing time. As the salinity data used here is only representative of the conditions present on 4 May 2004 during an above average spring tide range, the derived flushing times may not represent the estuary flushing at all times.

The estimates indicate rapid flushing near the mouth increasing with distance upstream to >1 day to ~2-3 days, which is typical of these estuaries.

Discussion of Flushing

The results presented in Table 18 when compared with Table 19 suggest that flushing mechanisms within Korogoro Creek are dominated by tidal circulation. The tidal prism method suggests that at both springs and neaps, tidal flushing times at all locations are very short to within 1-2 days. This calculation is somewhat dependent on the mixing efficiency - the estuary was assumed to have a reasonably high value, 0.7, as the tidal prism is significantly greater than the low tide estuary volume.

The freshwater fraction method suggests flushing times increase with distance from the ocean and could be greater than seven days in the upper reaches. This estimate is based on one sampling event and a crude estimate of the freshwater inflow and hence could be improved by collecting more salinity and inflow data.

Stratification and Mixing

Data was collected in Korogoro Creek in May 2004 by MHL (MHL 2005) using a Seabird SBE25 water quality profiler. This data is presented as long channel contours at high and low water of key water quality variables such as density, temperature, salinity, % saturation of dissolved oxygen, pH and chlorophyll-a.

A trend was observed in each of these variables from the mouth of the creek to the head of the creek at the closed floodgates. At high water the tidal oceanic influence extends through most of the creek to Station 8 (Figure 4-G, p.93). The plot of high water and low water contours shows the influx and recession of the sea water through the creek with very little evidence of vertical stratification. There is some influx of fresh water at Station 12 (closed floodgates) at low water, however it would appear that this quickly mixes during the next flood tide and is barely discernable at the subsequent high water.

There is evidence of vertical stratification at Station 9 (open floodgates). At this location the bathymetry is 2 m deeper than the surrounding channel. This deep hole in the bathymetry allows denser saline sea water to flow into the hole during the flood tide and remain trapped during the subsequent ebb tide as the lighter/less saline water flows over the top of this heavier saline water. Eventually vertical mixing and continued tidal propagation of salt water flushes this deeper water. It may however reside in the bottom for a number of days resulting in low DO and other water quality issues. The short period of water quality data available does not indicate the persistence of the stratification, however it is considered to be a potential area for strong stratification and subsequent water quality changes.

Overall the creek is dominated by tidal flushing as the tides influence nearly the entire length of the creek to the closed floodgates. This tidal flushing maintains the creek in a well mixed state. There are, however, scenarios in which the tidal influence may be reduced, that is, the semi-monthly neap cycle in which the tidal range is at its lowest. The decreased tidal range means that there is a decrease in the forces driving both the exchange of water with the ocean and the mixing between ocean and estuarine water, the combined result being less flushing of the creek during this cycle. During the neap cycle there is more potential for stratification at deep sections in the creek particularly if this coincides with a low rainfall period.

A conceptual model of circulation and flushing is provided in Figure 4-L (p.98).

4.6 Water quality

The following subsections summarise the findings of the various water quality programs that have focussed on the Korogoro Creek Estuary over the past 13 years (see Section 2.5). Where possible the results are interpreted against applicable Australian and New Zealand Environment Conservation Council (ANZECC) guidelines with a summary of the key findings presented at the end of each subsection. Summary tables of water quality data are provided in Appendix 4.

Physical Parameters

Korogoro Creek is well flushed by tidal inundation with seawater and the observed measurements of physical parameters reflect this. The influence of seawater extends the entire length of the estuary during high tides. At low tide the influence of brackish 'brown' water extends to the very mouth of the estuary.

MHL (2005) Collected data covering density, temperature, salinity, dissolved oxygen, pH, backscatterance and photosynthetically activated radiation (PAR) at high and low tides over a single cycle. The variations in physical parameters observed by MHL (2005) over the tidal cycle were predictable given the nature of the Korogoro Creek system, i.e. limited freshwater flows, continuously open entrance. With the influx of seawater on the flood tide, salinity, dissolved oxygen (DO) and pH all increased to levels associated with seawater throughout the estuary. Backscatterance, chlorophyll-a and PAR all increased significantly in the middle and lower reaches of the creek during the ebb tide as the ocean water receded and was replaced with tannin and iron stained 'brown water' from the upper reaches. Water temperature appears to fluctuate with tidal cycles as well as seasonally.

Though the dune disposal of effluent increases the freshwater input to the creek (via groundwater) the effect upon salinity is marginal. The freshwater input from the effluent disposal scheme of 270 kL/day (DPWS 1999) is relatively small compared with the tidal prism of 180 ML/day (MHL 2005).

The following ANZECC (2000) guidelines for the protection of estuarine aquatic ecosystems apply to physical parameters.

Parameter	Lower Limit	Upper Limit
pH	7.0	8.5
DO (% saturation)	80	110
Turbidity (NTU)	0.5	10

When assessed against the above criteria, the data collected by MHL (2005) shows that, at high tide, the water in Korogoro Creek falls within the above guidelines at all sites except for the most upstream, taken at the choke. At the choke, values for pH (6.55) and DO (61.84% saturated) did not meet the guidelines. No samples were taken upstream of the choke at high tide. At low tide pH was below the guidelines at all sites except the most downstream site at the mouth of the estuary. The minimum pH measure was 6.11, taken at the floodgates. DO values measured at low water were outside the guidelines at all sites upstream of the point half way between the footbridge and the traffic bridge. The lowest DO value measured was 38.14% saturated, taken upstream of the traffic bridge.

The data collected by the KSC Water Laboratory for the period between 01/1994 and 04/1995 is summarised in Appendix 4 (Table A). The data does not permit analysis against the tidal cycle as it was taken weekly at 7.30 AM (Lynne Colgan *pers comm.*). Whilst DO was measured on each occasion it was taken as a concentration and without associated measurements of temperature cannot be converted to % saturation and thus will not be compared to the ANZECC (2000) guidelines. When pH and turbidity data are compared against the ANZECC (2000) guidelines the following conclusions can be made:

- The mean, median and 90th percentile values for pH were all within the range at all sampling sites.
- The 10th percentile value for pH was marginally outside the range at the most upstream site only (200m upstream of traffic bridge).
- The mean, median and 90th percentile values for turbidity were all within the range at all sampling sites.
- The 10th percentile value for turbidity was below the lower level of the range at the three most downstream sites (All sites downstream of the site located 50m downstream of Phillippa's Drain).

The data collected by KSC Water Laboratory between 01/1997 and 06/1998 include values for DO, pH and Conductivity. The data is summarised in Appendix 4 (Table B). Sampling was not designed to coincide with specific tidal ranges. DO measurements do not facilitate comparison with ANZECC (2000) guidelines. Comparison of pH values with ANZECC guidelines yields the following conclusions.

- The mean, median, 90th percentile and 10th percentile values at the most upstream site (the choke) all fell below the lower limit.
- The mean, median and 10th percentile values at the traffic bridge all fell below the lower limit.
- The 10th percentile value at the most downstream site (50m downstream of Phillipa's Drain) fell below the lower limit.

Data collected by KSC Water Laboratory between 07/2000 and 11/2000 include measurements of conductivity, DO, pH, total suspended solids and turbidity. The data is summarised in Appendix 4 (Table C). Comparisons of pH and turbidity values with the ANZECC (2000) guidelines yield the following conclusions.

- Mean, median, 90th and 10th percentile values for pH at the choke were below the lower limit.
- median, 90th percentile and 10th percentile values were marginally below the lower limit.
- pH at the footbridge conformed with ANZECC guidelines
- Turbidity values conformed with ANZECC guidelines at all sites

UNSW (2003, 2004 & 2006) collected data including conductivity, total dissolved solids, temperature and pH at 2 sites (1 site in 2006). Sampling was done quarterly for 2 years and 6 monthly afterwards, at or near low tide to ensure consistency. The data is summarised in Appendix 4 (Table D). Comparison of their data with ANZECC (2000) guidelines yield the following conclusions:

- The mean and 10th percentile values for pH at the footbridge (8 data points only) fall below the lower limit.
- The mean median and 10th percentile values at the traffic bridge fall below the lower limit.

While no measurements have been taken in times of severe flood, anecdotal evidence suggests that the large volumes of acidic and deoxygenated water flush the creek and cause large, short to medium term, changes to the ecosystem (Vince Jordan, Lynne Colgan, *pers comm.*). In particular, sensitive immobile and less mobile creatures like juvenile fish, crustaceans, annelid worms and molluscs are most susceptible to flushes of poor quality water.

In conclusion, on the basis of the available data, it can be said that low pH probably causes few negative effects in the Korogoro Creek estuary. At high tide, pH values are generally within ANZECC guidelines throughout the estuary. At low tide, pH levels in the lower part of the estuary are generally within ANZECC guidelines. Upstream of the traffic bridge pH at low tide is generally outside ANZECC values. A very few instances of pH below 6 have been recorded and these generally correspond to the very upper reaches of the estuary. It is likely that floodgate seepage is a consistent but slow source of acidic water to the Korogoro Creek estuary but tidal flushing mitigates the effects of this seepage. At present, no available data has been collected during severe flood events.

At low tide deoxygenated water makes its way down to the lower reaches of the estuary. The levels in some cases are low enough to cause some distress to aquatic organisms. This problem would be exacerbated in times of flood.

The occasional low levels of turbidity measured are most likely a result of the influence of clear ocean water influx during high tides. As the results are not associated with low pH values, acidity is not a likely explanation for low turbidity values.

Nutrients

The relevant ANZECC (2000) guidelines for the protection of estuarine aquatic ecosystems are as follows.

Parameter	Units	Trigger Value
Total Phosphorus (TP)	µg/L	30
Filterable Reactive Phosphate (FRP)	µg/L	5
Total Nitrogen (TN)	µg/L	300
Oxides of Nitrogen (NO_x)	µg/L	15
Ammonia (NH_4^+)	µg/L	15

The region of the creek upstream of the township is characterised by elevated concentrations of ammonia and oxidised nitrogen. In addition to this the reddish colour of the creek on the ebb tide is suggestive of the presence of tannins and iron. All of these factors are suggested to be the influence of swamp drainage and the overall appearance of the creek suggests relatively low nutrient concentrations (Robyn Tuft and Associates 1999)

UNSW (2003&2004) sampled nutrients from two sites within Korogoro Creek, quarterly for one year before the commissioning of the dune disposal site and one year after. Ongoing studies are being conducted at one site every 6 months (UNSW 2006). Their data is summarised in Appendix 4 (Table D). Comparison of their data with ANZECC guidelines yields the following conclusions.

- The mean and median values for TKN at the traffic bridge were above the trigger value.
- The 90th percentile value for TKN at the footbridge was above the trigger value.
- The mean, median and 10th percentile values for Ammonia at the traffic bridge all exceeded the trigger value.
- The mean and median values for Ammonia at the footbridge exceeded the trigger value.
- The mean and 90th percentile values for TP at the traffic bridge and the footbridge exceeded the trigger value.

Using criteria developed by DLWC (1999) UNSW (2003, 2004 & 2006) have identified a minor, but inconsistent, trend towards increasing levels of Ammonia, Total Kjeldahl Nitrogen and Phosphorus in Korogoro Creek. Further monitoring, currently being undertaken, will probably reveal the significance of these trends.

As elevated Nitrogen levels from the treated sewage makes its way through the reducing conditions of the groundwater to the creek some of it is likely to be transformed to ammonia, exacerbating the high ambient levels, particularly in the mixing zone (RT&A 1999). In addition to this, elevated levels of various Nitrogen species have been found in Korogoro Creek since before the commissioning of a sewage treatment system.

Kempsey shire council analysed water samples from Korogoro Creek for Chloride, Ammonia, Nitrate and TP between January 1994 and April 1995. The data is summarised in Appendix 4 (Table A). A weak trend of increasing nutrient concentration in the upstream regions of the creek is apparent. Comparison of their data with the ANZECC (2000) guidelines yields the following conclusions:

- Mean, median and 10^{th} percentile values for Ammonia exceeded the trigger value at all sites.
- Mean median and 10^{th} percentile values for Nitrate far exceeded the trigger value for Oxides of Nitrogen at all sites.
- Median values for TP at all sites conformed with guidelines but 90^{th} percentile values at all sites exceeded trigger values.

KSC Water Laboratory analysed water samples from Korogoro Ck for TN, NOX, and TKN between January 1997 and December 1997 and for TP between January 1997 and June 1998. The data is summarised in Appendix 4 (Table B). Comparison of their data with ANZECC (2000) guidelines reveals the following conclusions.

- Mean and median values for TP greatly exceeded trigger values at all sites and 10^{th} percentile value for TP exceed trigger values at the choke.
- Mean and 90^{th} percentile values for TKN greatly exceeded the trigger value at all three sites.
- Mean, median and 90^{th} percentile values for TN exceeded the trigger value at the most upstream and the most downstream sites. The median value for TN did not exceed the trigger value at the traffic bridge.
- Mean, median and 90^{th} percentile values for NOX exceeded the trigger value at all sites.

KSC Water Laboratory analysed water samples for Ammonia, Nitrate, Nitrite, TKN, TN, TP between July 2000 and November 2000. Three sites were sampled on 6 occasions. The data is summarised in Appendix 4 (Table C). Comparison of their data with ANZECC (2000) guidelines reveals the following conclusions.

- Mean and 90^{th} percentile values for Ammonia exceeded the trigger value at all sites. Median values for Ammonia exceeded the trigger value at the most upstream and downstream sites.
- Mean, median and 90^{th} percentile values for nitrate exceed the trigger value. The 10^{th} percentile value for nitrate at the floodgates and the traffic bridge exceed the trigger value.
- The mean, median and 10^{th} percentile values for TKN exceeded the trigger value at the choke. The 90^{th} percentile values for TKN at the two downstream sites exceeded the trigger value.
- The mean and median values for TN exceeded the trigger value at the traffic bridge.
- The mean, median and 10^{th} percentile values for TP exceeded the trigger values at the choke. The 90^{th} percentile values for TP at the two downstream sites exceeded the trigger value.

Robyn Tuft and Associates (1999) report that until 1998 the methods of analysis used by Kempsey Shire Council were coarse and only provided a low confidence limit for the detection of nutrients.

The body of data indicates that Korogoro Creek has historically had elevated levels of Nitrogen, particularly in the form of Ammonia. In general the amount of data detailing nutrient levels in the waters of Korogoro Creek after the commissioning of the effluent discharge site is scarce. It is insufficient to ascertain trends or isolate the contribution of dune discharge and the decommissioning of septic systems to changes in water quality. While some increases in TKN and Ammonia appear apparent, further sampling is required to gain a clearer picture. Comparisons between the Kempsey Shire Council dataset and the UNSW dataset are unfeasible due to differences in analysis and sampling regimes.

Trace Metals and Organochlorine Pesticides

UNSW (2003, 2004) measured concentrations of Iron, Aluminium, Boron, Manganese and Organochlorine Pesticides at two locations in the creek. Further monitoring (2006) analysed samples for Aluminium, Copper, Manganese and Zinc. Their results can be summarised as follows;

- Iron and Aluminium levels satisfied ANZECC (2000) criteria in all creek samples.
- Elevated Boron concentrations were found in the baseline study but not in the post commissioning study
- Slightly increased concentrations of Manganese were found in the post commissioning studies but these were still well below ANZECC (2000) criteria for the protection of 99% of biota.
- Low levels of Copper and Zinc were detected in the first year of ongoing monitoring.
- No Organochlorine Pesticides have been detected in the waters of Korogoro Creek

The compiled data does not indicate any concern for trace metal levels in Korogoro Creek.

Biological Parameters

Elevated nutrient levels can lead to outbreaks of nuisance aquatic plants which in turn can lead to reduced recreational amenity, reduced levels of dissolved oxygen, toxic effects on biota and changes in biodiversity.

Data collected since 1994 by Kempsey Shire Council (KSC) Water Laboratory suggests that average levels of pathogens outside of the peak summer season are generally safe for primary contact recreation. Occasional high levels have been measured during the peak summer periods and, after a stormwater monitoring program, were found to be most likely a result of septic tank overflows (Robyn Tuft and Associates 1999). It must be noted that this refers to the period before the installation of the Sewage Treatment Plant.

The ANZECC (2000) trigger value for chlorophyll a is 4µg/L for the protection of estuarine environments. Chlorophyll-a values were measured by MHL (2005) at high and low water. They found that the ANZECC (2000) guidelines were exceeded in most parts of the creek during low tide and that at high tide, the chlorophyll-a levels were below the trigger values at all sites downstream of the traffic bridge. The source of these high levels is unknown.

Discussions with long-term residents have revealed that algal blooms have never been a problem in Korogoro Creek (Vince Jordan, Lynne Colgan *pers comm.*, Robyn Tuft and Associates 1999). However, algal blooms are a likely occurrence if the mouth of the creek becomes closed for an extended period, due to the nutrient input from the dune disposal of treated effluent (DPWS 1999) and due to elevated ambient level of nutrients.

Robyn Tuft and Associates (1999) reported no obvious epiphytic growth on sea grasses. They report that the major source of faecal coliforms to the estuary, prior to 1999, was stormwater carrying septic tank overflow.

The oysters and other shellfish growing around the rocks in the lower part of the estuary are collected for human consumption (Vince Jordan, *pers comm.*).

For faecal coliforms guidelines the ANZECC (2000) guidelines are as follows;

Faecal Coliforms (µg/L)	**Recommendation**
0 – 14	No Restrictions
>14 – 150	No Aquaculture
>150 – 1000	No Primary Contact Recreation
>1000	No Secondary Contact Recreation

These trigger values are to be compared to the median value of a minimum of 5 samples collected no more than a month apart.

KSC Water Laboratory analysed faecal coliforms in Korogoro Creek between January 1994 and April 1995, January 1997 and June 1998, July 2000 and November 2000 and have a current monitoring program since May 2004 (EPA Beachwatch Partnership Program). In 1994-95 and 1997-98 the highest values for faecal coliforms were generally found between the footbridge and the traffic bridge, closest to the village (see Appendix 4 Tables A and B). This trend was reversed in 2000 when the highest values were found in the region of the choke (see Appendix 4 Table C). Comparison of their data with the ANZECC (2000) guidelines yields the following conclusions.

- The median values for faecal coliforms in 1994/95 were in the no restrictions range for all sites.
- The mean and 90th percentile values in 1994/95 were well within the range suitable for primary contact recreation for all sites.
- The mean, median and 90th percentile values for 1997/98 were well within the range suitable for primary contact recreation at all sites.
- The median values in 2000 were all within the range where no restrictions apply apart from at the choke, where the value was 14.5cfu/100mL. The 90th percentile values for this period were below 40cfu/100mL.
- The median value for the period since 2004 is 15 cfu/100mL, the 90th percentile value is 94.8 cfu/100mL. Only one, unspecified, sampling site has been monitored in this time.

UNSW (2003, 2004 and 2006) measured faecal coliforms quarterly at 2 sites for 2 years and 6 monthly at one site for a further year. Their monitoring is ongoing. Their data is summarised in Appendix 4 (Table D). No definite trends are apparent in their results. The period between sampling events makes their data unsuitable for comparison with ANZECC guidelines. The median values at the footbridge and traffic bridge were both 9cfu/100mL.

Analysis of the collected data indicates that Korogoro Creek does not suffer from elevated levels of Faecal Coliforms under normal circumstances. During times of heavy rainfall and at peak holiday periods there are occasional concerns. There are no records of algal blooms but elevated levels of chlorophyll-a are apparent, particularly on the outgoing tide.

Groundwater

The groundwater table lies close to the surface at Hat Head (Robyn Tuft and Associates 1999). Studies of groundwater quality in the Hat Head region have focussed on portion 246, now the site for the dune disposal of treated effluent. UNSW (2003 and 2004) found that there is a general hydraulic gradient from underneath portion 246 and underneath Hat Head village towards Korogoro Creek meaning the groundwater in the vicinity of the Korogoro Creek estuary provides flow to the creek in times of low rainfall. It is also accessed by a significant number of households in Hat Head via spear and pump systems for use in gardens and laundries (Vince Jordan *pers comm.,* 2007). Comparisons could be made between groundwater and the ANZECC (2000) guidelines for aquatic ecosystem protection, agricultural use and the NHMRC (1996) guidelines for drinking water. It is considered here that the most meaningful comparison for groundwater quality in Hat Head Village is with the ANZECC guidelines for agricultural use. The reasons for this are as follows;

- Hat Head obtains its drinking water from elsewhere.
- Groundwater accessed privately in the town is generally used for gardens and laundries.
- Groundwater seepage to Korogoro Creek would be diluted quickly by rigorous tidal flushing.

Comprehensive sampling of the groundwater in the vicinity of the discharge area and around Hat Head village has been undertaken both before and after the installation of the Hat Head Sewerage Scheme. In general, physical characteristics of the groundwater did not change significantly over the study period. Levels of Nitrate, Nitrite, Ammonia and TKN increased slightly after the installation of the dune disposal site indicating possible detrimental trends. Levels of some trace metals (Aluminium, Manganese, Boron, Cadmium, Lead and Mercury) increased marginally post-commissioning, also indicating possible detrimental trends that warrant further monitoring. No significant increase in coliforms was detected in the first two years of dune disposal of effluent (UNSW 2004, 2006).

Groundwater at the dune disposal site and in the village was found to meet ANZECC (2000) criteria for agricultural use with the following exceptions:

- Deep groundwater adjacent to the creek in the region of the effluent disposal site generally fell into the very saline category.
- Groundwater in the village frequently fell outside the range for pH.
- Shallow groundwater adjacent to the creek generally exceeded guidelines for Ammonia.
- Shallow groundwater adjacent to the creek, in the region of the effluent disposal site, frequently exceeded guidelines for long term irrigation for TP, chloride, iron and manganese.
- Groundwater in the village area frequently exceeded guidelines for long-term irrigation for Boron after commissioning.

The high groundwater table in parts of Hat Head has been deleteriously affected in the past due to overflow of septic tank systems and spread of septic tank effluent away from absorption trenches into the environment. It is likely that this has led to increased nutrient and pathogen loading in the groundwater underneath the town and that this would have spread into Korogoro Creek (Robyn Tuft and Associates 1999). Local residents frequently complained of the smell of groundwater before the introduction of the Sewage Treatment Plant (Vince Jordan *pers comm*., 2007).

Despite this, the groundwater under Hat Head Village and the nearby effluent disposal site are generally in good order. Some possible deleterious trends may have been detected for levels of nitrogen-based ions and levels of trace metals. Ongoing monitoring, currently being undertaken, should resolve the significance of these findings.

Summary of Water Quality Analyses

Water Quality in Korogoro Creek is generally acceptable. Regular tidal flushing mitigates many of the impacts of poor water quality from point and diffuse sources within the Korogoro Creek catchment. The input of acidic water from over drainage of the sulfidic sediments in the Swanpool is the likely cause of pH levels below the lower limits set by the ANZECC (2000) guidelines but these are rarely low enough to be considered highly toxic to marine life. Levels of dissolved oxygen measured at low tides present a possible barrier to sensitive biota.

Elevated concentrations of nutrients, particularly nitrogen and ammonia, have existed within Korogoro Creek since the beginning of monitoring in 1994. These cannot be linked to a specific source, as there are no obvious trends indicating the effect of sewage treatment and the dune disposal of effluent on the Korogoro Creek system. Despite this, the most recent data do suggest that close monitoring of nutrient levels would be prudent. At present, typical symptoms of eutrophication such as algal blooms and excessive epiphytic growth are not visible. Chlorophyll-a levels are elevated and warrant further investigation. Faecal coliforms rarely reach levels of concern for recreational users but at times could be considered a constraint to the collection of shellfish for human consumption. There is no indication of problems associated with trace metals. Drainage of the Swanpool into Korogoro Creek not only provides a source of acidic and deoxygenated water but also greatly increases the nutrient load.

The acceptable water quality levels depend heavily on the fact that Korogoro Creek remains open. A significant closure would certainly result in increased acidity and decreased dissolved oxygen along with elevated levels of nutrients and faecal coliforms. The result would be greatly reduced recreational amenity and deleterious effects on fish, invertebrates and seagrasses.

4.7 Ecological Processes

An initial field inspection was made on 26th August 2006 with members of the Korogoro Creek Estuary Working Group. This provided a valuable opportunity to gather information about local ecology and the ways in which the local community uses and values the estuary. Using information gathered it was decided that for the purposes of this study the estuarine environment could be divided up into three conceptual regions. In this report they will be referred to as the upper estuary, the middle estuary and the lower estuary. The upper estuary is from the floodgates past the choke to the place where the traffic bridge crosses Korogoro Creek, close to Hat Head village. The middle estuary is between the road bridge and the where the footbridge crosses the creek from the caravan park. The lower estuary is from the footbridge to the creek mouth.

Fieldwork was undertaken on the 19th and 20th December 2006 and on the 19th January 2007. Activities were specifically aimed at filling known gaps in the information available for Korogoro Creek. An inventory of estuarine habitats was developed, a list of saltmarsh species was collected and a list of fish species was collected using seine net, bait trap and snorkel based observation (NSW DPI Fisheries Permit #P06/0131-1.0). Incidental sightings of bird species and macro invertebrates were noted, as were species-habitat associations.

Habitat Mapping

Representative locations were chosen within each of the three conceptual zones in Korogoro Creek. At each location a 25m stretch of creek was described in detail. Information collected included channel width, benthic material, instream vegetation, riparian vegetation and observed fauna. The results are summarised in Table 19 with mapped habitat types shown in Figure 4-M (p.99). A discussion of the mapped habitat types is provided in the following sections. Lists of fauna and flora observed during the field survey are compiled in Appendix 5.

Table 19 *Descriptions of Korogoro Creek Habitat Types*

Location	Channel Width	Benthos	Bank	Riparian Habitat
U1	15m	Silt, mud, some *Zostera sp.*.	1m high, slight undercut.	Medium density *Avicennia marina*, 2-15m deep, 2-4m tall. Bitou bush, *Acacia sp.*, *Callistemon sp.*, *Casuarina glauca*, *Melaleuca quinquinervia*, *Banksia integrifolia* and lantana present.
U2	18m	Silt, mud.	0.7m high.	Dense *A. marina*, 4-10m deep, 2-5m tall. Regular *M. quinquinervia, Callistemon sp.* and lantana present.
U3	25m	Silt, mud.	1m high.	Dense A. marina, 4-12m deep, 1-4m tall. Regular M. quinquinervia and *Acacia sp.*. Some *C. Glauca*, *B. integrifolia* and bitou bush present.

Location	Channel Width	Benthos	Bank	Riparian Habitat
U4	25m	Silt, mud.	0.5m high, slight undercut. Confluence with drainage path on western side	Dense A. marina, 6m deep, 3-5m tall. Dense *Acacia sp*., some *M. quinquinervia* and *B. integrifolia* present.
U5	25m	Silt, mud, some *Zostera sp.*.	0.5m high, gentle slope.	Dense *A. marina* on western side, 1-2m deep, 0.5-1m tall. Some tall *A. marina* and large bare gap with small regenerating *A. marina* on eastern side. Some *B. integrifolia* and *Juncus krausii* present.
M1	25m	Intertidal sand, silt.	0.5-1m high, eroding.	Western bank largely saltmarsh/bare. Some bitou bush, *J. kraussi* and *Phragmites australis.* Eastern bank has small bare patch and dense *A. marina*, 0.5-5m tall, 4-15m deep. Some *C. glauca*, *M. quinquinervia* behind.
M2	25m	Intertidal sand, silt.	Western bank gradual slope, eastern bank 1m high, eroding.	Sparse *A. marina* on western bank, 2m deep, 1-2m tall, saltmarsh species behind. Eastern bank grassed w/ *B. integrifolia* and *C. glauca* present.
M3	40m	Intertidal sand, silt.	Banks sloping.	Medium density, mature *A. marina*, 15m deep, 10 m tall on eastern bank. *C. glauca* behind. Western bank vegetated with *C. glauca* and saltmarsh behind.
M4	40m	Intertidal sand, silt.	Banks sloping.	Dense-medium dense *A. marina*, 8-15m deep, 1-3m tall on west bank, 6m tall on east bank. Saltmarsh behind.
M5	40m	Intertidal sand, sand, patchy *Zostera sp.*.	Banks sloping.	SW bank medium density *A. marina*, 4m tall, 2m deep. Dense *C. glauca* and sparse *M. quinquenervia* behind. NE bank mostly bare with some disturbed saltmarsh species.
L1	60m	Wide intertidal sand flat, silt, patchy *Sargassum sp.*, some boulders and shell grit	Banks mostly rocky.	SE bank mostly boulder fields, 1 mangrove tree. *M. quinquinervia* and bitou bush behind. NW bank shallow intertidal boulders (revetment), *B. integrifolia* and bitou bush behind.
L2	50m	Wide intertidal sand flat, some boulders.	Mostly bedrock/boulders	E bank, intertidal boulders and rock. Few scattered young mangroves. W bank intertidal boulders (revetment) covered with bitou bush. Sparse *B. integrifolia* and *Leptospermum laevigatum* behind.
L3	40m	Wide intertidal sand flat, some boulders. Very sparse *Sargassum sp.* and *Delisea pulchra*.	E bank rocks and sand, W bank sand	Spinifex on W bank, boulders and boat ramp. E bank w/ intertidal boulders and sparse *A. marina*, 2m tall. *C. glauca*, *B. integrifolia* and bitou bush behind.
L4	15m	Sand, shell grit.	Western bank beach, E bank bedrock and boulders.	Bitou bush and *B. integrifolia*. Intertidal boulders associated with *Galeolaria caespitosa*, cunjevoi, *Cellana tramoserica*, *Bembicium nanum*, *Austrocochlea porcata*.

Mangroves

Mangroves perform numerous ecological functions. They are primary producers, providing a source of food for food chains. They have a positive effect on water quality by trapping and binding sediments, recycling nutrients and acting as a sink for pollutants. They buffer shorelines from the erosive forces of floodwaters, reducing infill of waterways. They also provide substrate and habitat for birds, fish, molluscs, insects and crustaceans (DNR 2007)

Mangroves form the dominant ecological community in the Korogoro Creek estuary. They are present in all parts of the estuary. Only the grey mangrove (*Avicennia marina*) is present. In the upper part of the estuary, there are very few breaks in the dense band of mangroves lining each bank. In the middle part of the estuary, there are large patches of deep, dense mature mangrove stands and many areas where young trees are becoming established. In the lower part of the estuary, mangroves are only found on the southeastern bank, and tend to occur as single, scattered trees. Fish, invertebrates and birds observed in association with mangrove habitats are listed in Appendix 5 (Tables A and B).

Saltmarsh

Saltmarshes are communities of salt tolerant terrestrial vegetation that occur in areas that experience regular but infrequent tidal inundation. Saltmarshes assist in maintaining water quality by trapping sediment. They provide organic matter to estuarine food chains, and provide habitat for aquatic organisms, birds and insects (DNR 2007).

Saltmarsh communities are well represented in the Korogoro Creek estuary. Their distribution is mostly confined to the middle section of the estuary. An inventory of Saltmarsh species can be found in Table 12. Saltmarsh communities are listed as an Endangered Ecological Community under the *Threatened Species Conservation Act 1995*. Saltmarsh communities of the Korogoro Creek estuary are heavily disturbed by vehicle and walking trails (see Plate 5). The natural distribution of Saltmarsh has been influenced by the construction of levees and unnatural drainage patterns have resulted in deep channels through Saltmarsh habitat. These factors, combined with the landward migration of mangroves can lead to significant reductions in Saltmarsh extent (NSW DPI Fisheries 2003). These concerns should be addressed in any future management plans.

Plate 5 *Typical example of disturbance to Saltmarsh communities from vehicles on the southern bank of the creek.*

The Rainbow Bee-eater, protected as a migratory species under the *Environmental Protection and Biodiversity Conservation Act 1999*, was observed in Saltmarsh habitat during field investigations. Juvenile mullet and flathead were observed swimming in Saltmarsh during high tide.

Seagrass

Seagrasses are vascular plants that have completely adapted to aquatic life. They are significant contributors of organic matter to estuarine food chains. They oxygenate the water and act as sediment traps, improving water quality. They also provide foraging and nursery habitat for many aquatic organisms and birds and are a direct source of food for large marine herbivores such as turtles (DNR 2007).

Eelgrass (*Zostera sp.*) occurs in all areas of the Korogoro Creek estuary. The total area of seagrass, however, is small and its distribution is limited to numerous small patches. The seagrass of Korogoro Creek does not appear to be adversely effected by excessive epiphytic growth, despite elevated nutrient levels and regular inundation by highly turbid waters moving from the upper estuary. Seagrass distribution in Korogoro Creek is most likely to be limited by the following factors:

- Mobile shoals in the lower section of the estuary.
- Limited light availability in the upper section.
- Intensive recreational use of the lower and middle parts of the estuary.

All seagrasses are protected under the *Fisheries Management Act* 1994. In the upper part of the estuary a number of fish, usually juveniles, were associated with seagrass (listed in Appendix 5 Table A).

Seaweeds

Seaweed growth in Korogoro creek is limited to a few sparse patches in the lower part of the estuary. The dominant species is *Sargassum sp.*. Additional species represented include *Dictyota dichotoma* and *Delisea pulchra*. The loggerhead turtle, listed as an endangered species under the *Threatened Species Conservation Act* 1995 was observed foraging among *Sargassum* during field investigations.

Boulder Fields and Rocky Shores

Boulder fields and rocky shores provide primary and secondary habitat for a wide diversity of aquatic organisms. By baffling flows, and providing physical shelter they form an essential part of many estuarine systems (DNR 2007).

In the lower and middle parts of the estuary there are relatively large areas of intertidal and sub tidal boulder fields. More than half of these are unnatural, a result of rock revetment of unstable banks and around the traffic bridge. The intertidal boulders provide a base for secondary habitat including Oysters, Sydney Coral, cunjevoi and macroalgae. Fish and bird species associated with these habitats are listed in Appendix 5 (Tables A and B). In particular, the boulder fields and rocky shores of Korogoro Creek support a wide diversity of fish of tropical origin.

Intertidal Sand and Mud Flats

Intertidal sand and mud flats are the most extensive habitat represented in estuaries. They are important feeding areas for birds and at high tide a variety of fish species forage for the crustaceans, molluscs and polychaetes that live there as well as the microalgae and diatoms that bind the sediments (DNR 2007).

Large areas of intertidal sand flats are present in the lower and middle sections of Korogoro Creek. In the upper part of the estuary there are small areas of intertidal mudflats. Species associated with intertidal sand and mudflats in Korogoro Creek are listed in Appendix 5 (Tables A and B).

Riparian Vegetation

Plants growing alongside waterways are known as riparian vegetation. They provide organic material to the food chain, stabilise banks against erosion and provide important shade that can reduce water temperatures and camouflage fish from predators. Riparian vegetation also provides habitat for birds.

In the upper section of the Korogoro Creek estuary the riparian vegetation growing along the levees is almost unbroken, consisting largely of Paperbark, Swamp Mahogany, Swamp Oak, Banksia and Acacia and Bitou Bush. In the Middle section of the estuary, the riparian vegetation is largely disturbed and patchy. Paperbark and Saltmarsh communities are dominant in the middle reaches with She Oak and Banksia dominated communities also occurring. Both the Saltmarsh and paperbark communities show signs of degradation with bank erosion and access impacts affecting Saltmarsh areas and poor recruitment and regeneration affecting paperbark communities. The lower section of the estuary has an unbroken riparian strip with the exception of the area around the boat ramp. Pandanus, Melaleuca and Banksia spp dominate the steep southern shore interspersed with some litoral rainforest patches in protected locations. The northern shore, bordering the caravan park is dominated by Tea tree, Banksia and Bitou Bush. Bird species observed in Riparian Vegetation are listed in Appendix 5 (Table A).

Riparian Weed Mapping

Introduced weed species occur along the length of Korogoro Creek. The major weed species identified include bitou bush (*Chrysanthemoides monilifera*), coastal morning glory (*Ipomoea cairica*), and pink lantana (*Lantana camara*). Other exotic plants including introduced grasses and assorted garden escapees occur in the vicinity of the village but have not been mapped for this study.

The distribution of the three major identified environmental weeds found in the riparian (creek bank) zone is provided in Figure 4-B (p.89).

Aquatic Weeds and Algal Blooms

No aquatic weeds or algal blooms were observed during the field visits to Korogoro Creek.

Fish Sampling

Fish sampling was undertaken on 19-20 December 2006. A bait net 18m long, 1m deep with a stretched mesh size of 10mm was used for seining shallow sedimentary habitats. Bait traps were set in groups of 5 at four sites within the creek, around rocky and vegetated habitats. The lower section of the creek was snorkelled. Observed fish species were identified with the help of guides (Kuiter 2000, Hutchins & Swainston 1999)

An inventory of all aquatic fauna observed in Korogoro Creek is given in Appendix 5 (Table B). In total, 9 crustacean species, 48 fish species and 1 marine reptile were observed during field investigations for this report. The most diverse region of Korogoro Creek, with respect to free-swimming aquatic species, is the lower part of the estuary.

The only aquatic species of special conservation interest that was observed was the Loggerhead Turtle, *Caretta caretta*. No other species listed under the *Threatened Species Act 1995*, *Fisheries Management Act1994* or under the *Environment Protection and Biodiversity Conservation Act 1999*, nor species at or near their northern or southern limit of distribution were found. It should be noted that locals have reported the occurrence of Black Cod (*Epinephelus daemelii*), a species listed as Vulnerable within NSW, in Korogoro Creek.

Several species of commercial interest were observed. These included Bream, Whiting, Mullet, Flathead, Silver Biddy, Tarwhine, Luderick and Mangrove Jack. Juveniles of most of these species were observed, indicating that Korogoro Creek is a valuable nursery area for many fish species.

Fish Recruitment and Life Cycles

Fish recruitment to estuarine environments is a function of available habitat (Smith & Suthers 2000) and estuarine opening regimes and their interaction with fish life cycles (Hannan & Williams 1998). Dredging activities, whilst opening estuaries to fish recruitment of ocean spawning fishes can negatively impact upon vital habitats for juvenile fish.

Fish recruitment to the Korogoro Creek estuary is currently unimpeded by estuary closure or by dredging activities. Juvenile fish of many species recruit to Korogoro Creek, most likely attracted to the varied physical and ecological habitats available, eg., Mangroves, saltmarsh and intertidal boulder fields.

Effects of Flood Management

Negative effects on fish recruitment and spawning activities in Korogoro Creek are most likely to be a result of flood management. Freshwater wetlands and floodplains provide habitat for some estuarine fish in times of flood. The construction of levees and installation of unidirectional drains limits the movement of fish into freshwater wetlands in times of flood (Kroon *et al.* 2004). The effects of levees constructed around Korogoro Creek and the unidirectional drains and floodgates are as follows:

- They restrict the available habitat of juvenile fish and thus fish diversity and abundance.
- The acidic and deoxygenated waters that are released from the Swanpool are a deterrent to fish that undertake upstream migrations to spawn in times of flood, such as species of Goby
- They reduce the contribution of organic materials from primary producers in wetland swamps.

Effects of Estuary Closure

In general, a negative impact on the diversity and abundance of fish species in Korogoro Creek would be expected with any long-term closure of the estuary. The following scenarios are considered likely:

- The abundance of fish that spawn in estuaries but live their adult lives in marine environments, such as Mangrove Jack, could be negatively influenced by long term closure of the estuary.
- The abundance of fish that migrate to and spawn in the ocean and recruit to estuarine environments, including, Bream, Sand Whiting, Mullet species, Luderick would be negatively effected by closure of the estuary. The majority of these species recruit in the late winter to early summer. Closures during this period would potentially have the greatest effect upon the local abundance of fish species.
- The abundance and diversity of fish of tropical origin including the various Butterflyfish, Angelfish, Damselfish and Wrasses would be negatively affected by extended closures. Most of these fish recruit to the estuary during the summer months. Closures during this period would potentially have the greatest effect upon local fish diversity.
- The abundance of fish that live and spawn within the estuary, including Dusky Flathead, Silver Biddy and Glassfish, is less likely to be affected by possible estuary closure.

Effects of Dredging

Negative impacts of dredging on fish diversity and abundance are usually associated with the effects of dredging upon vegetative habitats such as seagrasses and macroalgae. Any assessment of negative impacts of dredging on fish recruitment to Korogoro Creek would require a specific proposal citing the locations of dredging activities.

Estuarine Health

No definitive system exists for the quantitative assessment of estuarine health. Instead, there are a number of physical and biological indicators of estuarine health that are commonly used in a qualitative fashion. These are:

- Water Quality, using measures such as Chlorophyll, physical attributes, nutrients and pathogens.
- Sediment Quality, using measures such as benthic invertebrates, CO2 flux, contaminants, and sediment denitrification efficiency
- Habitat Extent and Quality, using indicators such as changes in area, maturity index and habitat variability index.
- Biotic indicators such as Benthic Invertebrates, Fish Assemblages, Macroalgae, Seagrass, Shorebirds and Hermit Crabs.
- Ecosystem Integrity using algal blooms, pest invasions and fish kills.

In assessing the health of Korogoro Creek, the following comments can be made:

- Water quality in Korogoro is generally acceptable for recreational use despite occasional elevated levels of Chlorophyll-a, persistently elevated levels of Nitrogen and Ammonia and the influences of poor quality water spreading through the estuary at low tide.
- Korogoro creek contains a wide diversity of aquatic habitats. Mangroves are well represented and appear to be expanding. Seagrass habitats are healthy but sparse. Saltmarsh habitats are relatively extensive but somewhat degraded. Rocky shores provide habitat for many species. Macroalgal distribution is limited.
- Fish in Korogoro Creek are diverse and abundant, as are shorebirds.
- There are no reports of algal blooms or pest invasions. Fish kills have occurred but their extent and frequency have not been great enough to attract much attention.

With regard to available biotic indicators, the health of the Korogoro Creek estuary is good. With regard to the habitat extent and distribution, it is acceptable. With regard to water quality indicators, it is acceptable. With regard to ecosystem integrity the health of the system is good.

Additional data that would assist with assessing the health of Korogoro Creek includes:

- Some measures of sediment quality, focussing on denitrification efficiency and contaminant levels.
- A study of the temporal and spatial variability of benthic invertebrates.
- A detailed study of temporal variation in seagrass, Saltmarsh and mangrove habitats.

Improvements to the health of the Korogoro Creek system could be made by:

- Managing inputs of acidic, deoxygenated and nutrient rich waters from point and diffuse sources within the catchment.
- Managing the degradation of Saltmarsh habitats and paperbark communities.

Summary of Estuarine Ecology

A large body of information exists for the flora and fauna of the Korogoro Creek catchment. This is primarily due to the fact that most of the catchment lies inside the boundaries of the Hat Head National Park. There is a good dataset available describing the distribution of vegetative habitats but very little information about the fauna of Korogoro Creek and general ecological processes.

Field visits for this study revealed diverse habitat forms, and diverse and abundant fish. Mangroves are the dominant and most important habitat type represented in the Korogoro Creek estuary.

Many of the fish species observed spend a part of their lifecycle outside of the estuarine environment. Recruitment of fish to Korogoro Creek primarily occurs between late winter and early summer. Some species of tropical origin are likely to recruit later in the summer. Anecdotal evidence suggests that these species die or migrate during the winter. At present, there are no impediments to recruitment of fish from the ocean but there is limited access to some traditional habitat areas due to the effects of flood management. The potential effects of entrance management are difficult to predict without a specific proposal.

The health of the Korogoro Creek estuary is largely dependent upon the entrance remaining open. An extended closure would most likely result in a temporary reduction of fish abundance and diversity. In combination with reduced tidal flushing, increasing water levels and associated effects this would be considered a reduction in estuarine health. It is, however, likely that Korogoro Creek would return to equilibrium relatively quickly after the entrance was re-opened. Improvements to the health of Korogoro Creek could be achieved through the management of water quality and of Saltmarsh areas.

4.8 Estuary Access

The issue of access to the estuary was raised in all three phases of community consultation. During the initial estuary planning community meeting in March 2006, the primary issue raised was related to vehicular access to the southern creek bank below the town bridge. The issue was again raised during the creek walk held in August 2006 as damage to the Saltmarsh vegetation was abundantly evident. Questions relating to the issue were included in the Community survey of 2006/07 with the following responses recorded (see Section 4.1);

- 66% of respondents placed a low to very low importance on vehicle access to the creek bank
- 38% of respondents were not satisfied with current vehicle access arrangements
- 68% of respondents were concerned or very concerned about uncontrolled vehicle access to the southern creek bank.

Issues relating to estuary access (including boating, vehicle, pedestrian, and disabled access) will be addressed in future stages of the Estuary Management Planning Process. However, for the purposes of this Study an attempt has been made to describe the observed impacts and to map the existing extent of vehicle tracks and access points on the southern creek bank below the bridge.

Figure 4-N (p.100) shows the location of vehicular tracks derived from 2004 1:10,000 aerial photography and access points recorded using a handheld GPS unit. Ten (10) access points off Gap Road were identified, only one of which appeared to be semi-formalised (upstream of the footbridge). An eleventh access point has been blocked off using large rocks and is now a pedestrian access leading to a bench seat on the creek bank.

The highest concentration of vehicle tracks can be seen in areas of easy access to the creek bank. Impacts observed included;

- Extensive damage to Coastal Saltmarsh, an *Endangered Ecological Community* listed under the Threatened Species Conservation Act 1995 (see Plates 5 and 6)
- Impacts on vegetation and low banks particularly where tracks cross small tidally inundated flats (Plate 6). Damage is worse where flow is concentrated during heavy rain and in boggy areas.
- Damage to the levee where vehicles attempt to negotiate the steep climb back onto Gap Road.

Plate 6 *Typical example of disturbance to Saltmarsh communities from vehicles on the southern bank of the creek.*

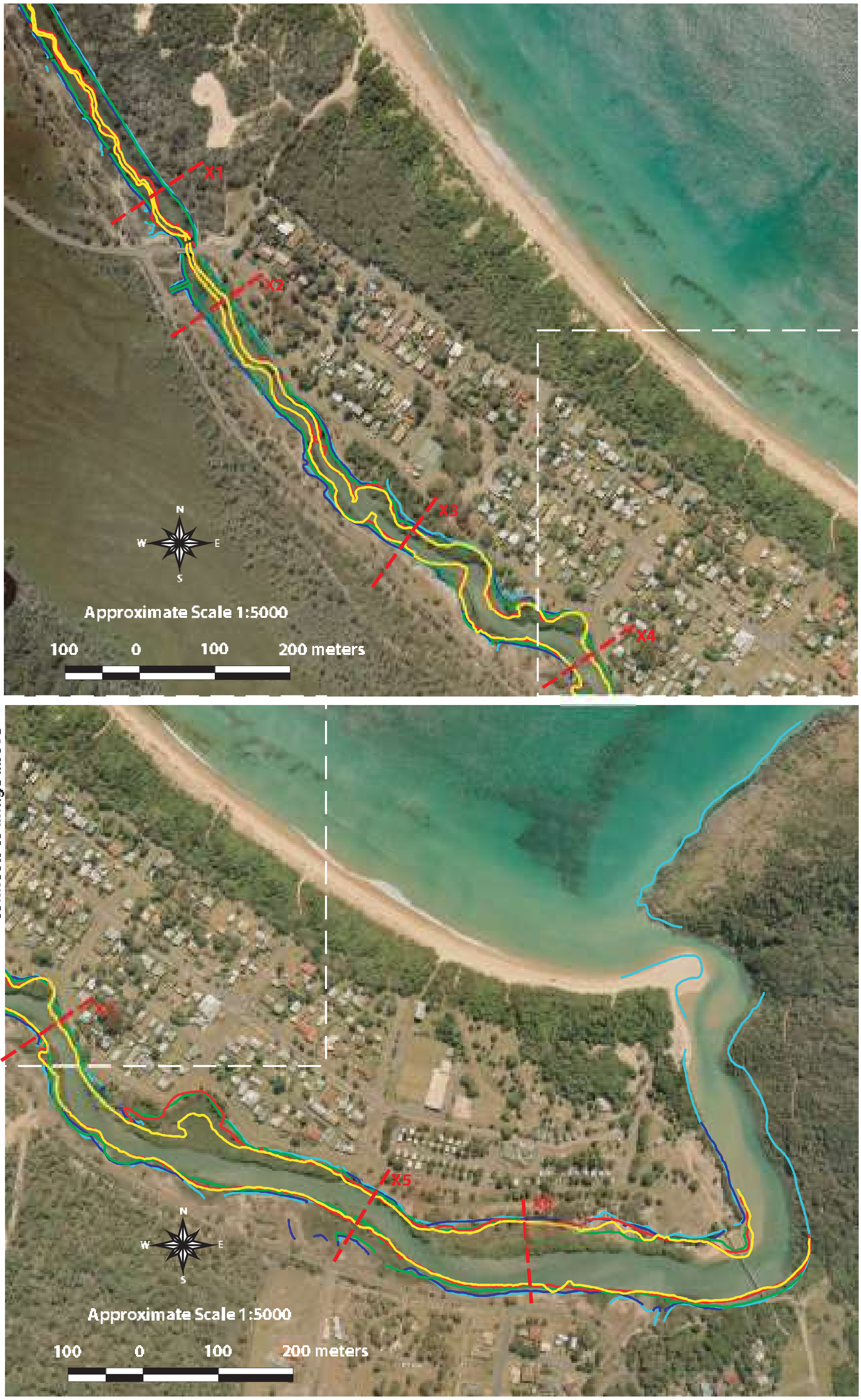

Figure 4-A	**Korogoro Creek Estuary - Channel Location 1942 to 2003**	LEGEND
Created by: Damon Telfer *GECO Environmental,* Grassy Head, NSW 2441	Data Sources: Bank position - photogrammetrically derived from aerial photography by DNR, Newcastle Base Orthophoto - derived from LIP NSW 1:10,000 Coastal Surveilenec (2004)	1942 bank position 1956 bank position 1979 bank position 1997 bank position 2003 bank position X2 channel width x-sections

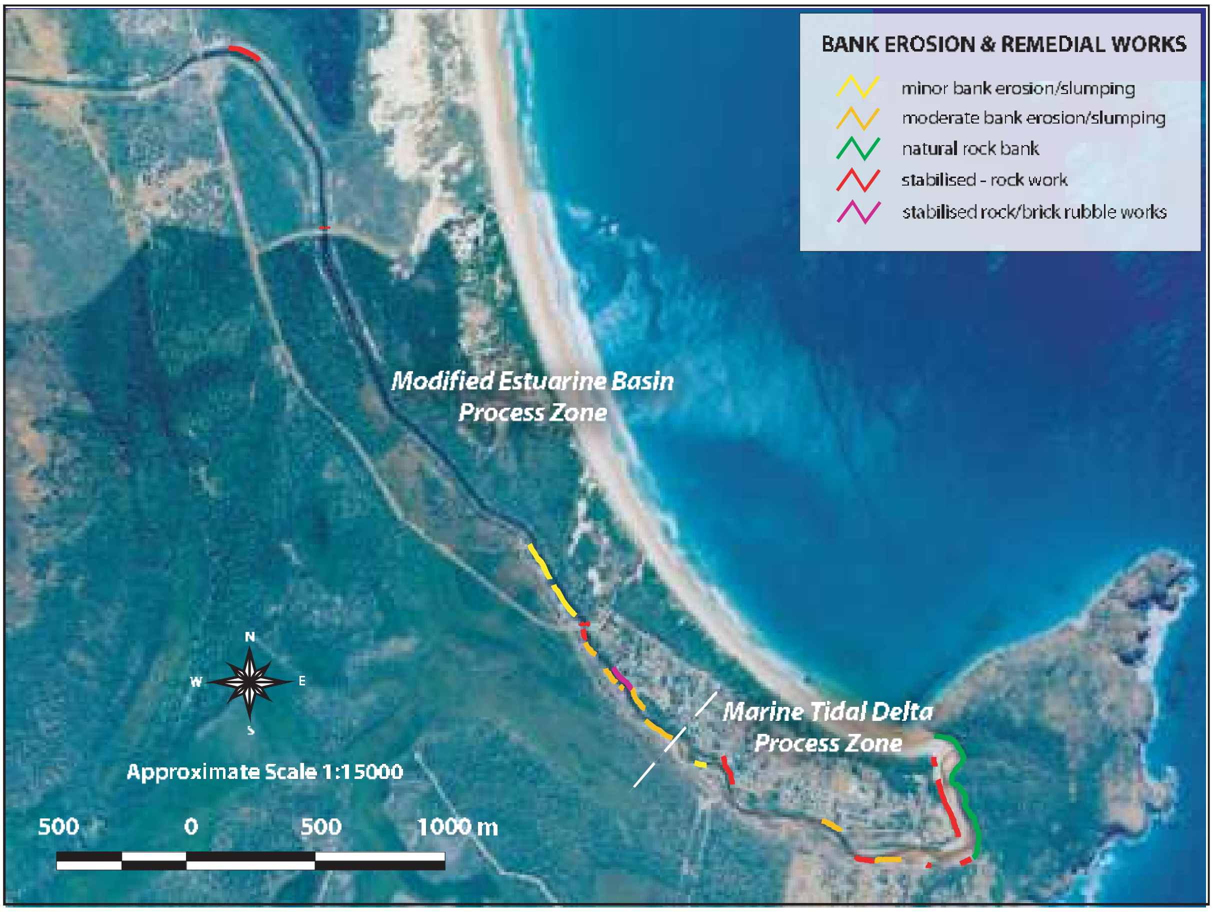

Figure 4-B

Korogoro Creek Estuary -
Bank Erosion, Remedial Works and Introduced Weed Infestation Levels

Created by:
Damon Telfer
GECO Environmental,
Grassy Head, NSW 2441

Data Sources:
Bank eroson, remedial works & weed infestation data - collected using handheld GPS and kayak, May 2007.
Base Orthophoto - derived from LIP NSW 1:25,000 Coastal Surveilenec (2003)

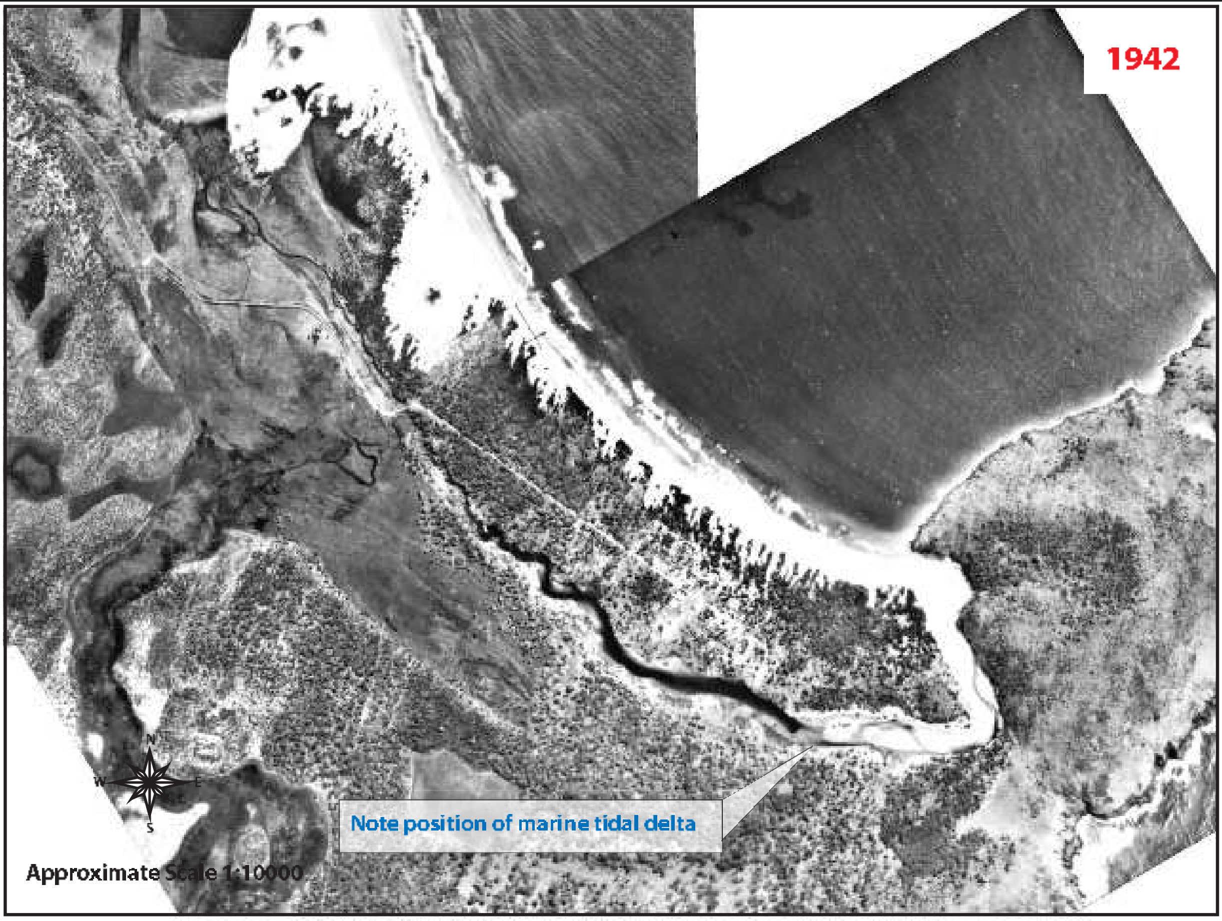

Figure 4-D

Comparative aerial photographs 1942 (top) to 2003 (bottom)

Created by:
Damon Telfer
GECO Environmental,
Grassy Head, NSW 2441

Base orthophoto images created from:
2003 1:25,000 aerial photography LPI, Dept Lands, Bathurst &
1942 aerial supplied by United Photo & Graphic, Melbourne

LEGEND
1942 bank position

EXCEEDANCE STATISTICS

NSW Department of Commerce
Manly Hydraulics Laboratory
110B King Street
MANLY VALE NSW 2093

Site Name : CROWDY HEAD
Site Code : CRHDOW

Nominated Start/Finish : 10-OCT-1985 to 30-JUN-2006, Record Length : 20.74 years
Data Start/Finish : 10-OCT-1985 to 30-JUN-2006, Record Length : 20.73 years

Filename : CRHDOW.HS
Creation date : 19-SEP-2006

PERCENTAGE EXCEEDANCE FOR Hsig(m)

Hsig	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	Hsig
0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.000	0.00
0.50	100.00	100.00	99.99	99.96	99.91	99.76	99.96	99.93	100.00	99.82	99.97	99.99	99.940	0.50
1.00	85.27	88.22	92.63	89.45	87.26	83.85	85.35	82.92	82.02	82.21	86.79	83.72	85.730	1.00
1.50	44.08	45.36	55.39	51.69	54.07	49.33	52.18	48.51	42.99	41.50	44.07	38.98	47.321	1.50
2.00	17.50	20.85	26.00	24.32	27.81	23.46	26.80	25.40	17.87	18.13	18.46	16.01	21.895	2.00
2.50	4.96	9.38	13.07	10.18	11.94	10.66	13.29	13.08	7.53	8.24	7.82	6.53	9.732	2.50
3.00	1.12	4.52	5.85	4.96	5.21	5.50	5.95	6.14	3.43	4.13	3.47	2.49	4.397	3.00
3.50	0.14	1.87	3.16	2.50	2.50	3.00	2.66	2.96	1.89	2.01	1.52	0.89	2.092	3.50
4.00	0.02	0.72	1.52	1.21	1.05	1.55	1.36	1.17	0.84	0.95	0.63	0.28	0.940	4.00
4.50	0.00	0.38	0.85	0.59	0.53	0.75	0.70	0.50	0.43	0.36	0.21	0.11	0.448	4.50
5.00	0.00	0.15	0.50	0.19	0.27	0.35	0.37	0.19	0.15	0.11	0.04	0.02	0.194	5.00
5.50	0.00	0.09	0.29	0.10	0.14	0.11	0.18	0.06	0.05	0.03	0.01	0.00	0.087	5.50
6.00	0.00	0.05	0.18	0.06	0.04	0.02	0.09	0.00	0.00	0.02	0.00	0.00	0.038	6.00
6.50	0.00	0.00	0.07	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.006	6.50
7.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.002	7.00
7.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	7.50
Average :	1.52	1.61	1.75	1.66	1.70	1.62	1.70	1.67	1.53	1.54	1.56	1.51	1.62	
Maximum :	4.14	6.48	7.35	6.46	6.66	6.28	6.78	5.89	5.82	6.42	5.86	5.23	7.35	
Minimum :	0.53	0.59	0.48	0.43	0.44	0.39	0.42	0.46	0.50	0.44	0.42	0.48	0.39	

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Number of data points used for statistical analysis:	12506	11103	12138	12409	13922	13007	13621	13299	12736	13163	14060	13701	155665
Percent capture based on Data start/finish:	80.04	78.06	77.69	82.07	89.11	86.03	91.54	89.37	88.44	85.61	92.99	87.69	85.67
Percent capture based on Nominated start/finish:	80.04	78.06	77.69	82.07	89.11	86.03	91.54	89.37	88.44	85.61	92.99	87.69	85.67

NSW Department of Commerce | Manly Hydraulics Laboratory

CROWDY HEAD
WAVE HEIGHT EXCEEDANCE STATISTICS
OCTOBER 1985 TO JUNE 2006

Figure 4-E

OCCURRENCE STATISTICS

NSW Department of Commerce
Manly Hydraulics Laboratory
110B King Street
MANLY VALE NSW 2093

Site Name : CROWDY HEAD
Site Code : CRHDOW

Nominated Start/Finish : 10-OCT-1985 to 31-DEC-1996, Record Length : 11.24 years
Data Start/Finish : 10-OCT-1985 to 31-DEC-1996, Record Length : 11.23 years

Filename : CRHDOW85_96.WDR
Creation date : 18-FEB-2004

PERCENTAGE OCCURRENCE FOR WDIR(Deg TN)

DIRN	DEGREES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
N	348.75 - 11.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
NNE	11.25 - 33.74	1.17	0.00	0.00	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.58	0.52	0.255
NE	33.75 - 56.24	8.67	1.73	2.48	2.79	2.55	1.78	1.61	2.61	6.66	13.61	9.83	13.71	5.852
ENE	56.25 - 78.74	16.36	11.99	10.03	9.83	7.63	4.20	7.82	6.96	11.36	12.50	17.28	15.60	11.085
E	78.75 - 101.24	20.35	23.13	21.59	22.81	17.60	18.41	11.33	14.25	14.90	11.00	13.93	17.91	17.131
ESE	101.25 - 123.74	20.81	23.62	23.34	16.53	21.10	20.41	22.38	15.81	15.82	13.01	13.88	13.96	18.229
SE	123.75 - 146.24	17.81	23.62	21.56	21.99	27.75	26.57	27.65	31.89	20.99	22.33	23.00	17.40	23.541
SSE	146.25 - 168.74	8.03	10.74	12.86	15.38	14.04	15.38	14.65	15.80	17.45	14.71	11.26	9.98	13.289
S	168.75 - 191.24	6.78	5.18	8.15	10.66	8.69	13.25	14.56	12.68	12.83	12.84	10.24	10.92	10.619
SSW	191.25 - 213.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
SW	213.75 - 236.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
WSW	236.25 - 258.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
W	258.75 - 281.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
WNW	281.25 - 303.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
NW	303.75 - 326.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
NNW	326.25 - 348.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Average :		107.80	114.62	123.63	119.69	122.35	127.65	127.75	126.99	120.11	114.25	111.54	108.25	117.77
Maximum :		180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00	180.00
Minimum :		22.00	45.00	45.00	45.00	22.00	45.00	45.00	45.00	45.00	45.00	22.00	22.00	22.00
Number of data points used for statistical analysis:		6899	6490	6453	6734	7132	7237	7158	7128	6471	7048	8484	7956	85190
Percent capture based on Data start/finish:		84.30	86.94	78.85	85.03	87.15	91.38	87.46	87.10	81.70	81.32	98.19	89.11	86.61
Percent capture based on Nominated start/finish:		84.30	86.94	78.85	85.03	87.15	91.38	87.46	87.10	81.70	81.32	98.19	89.11	86.61

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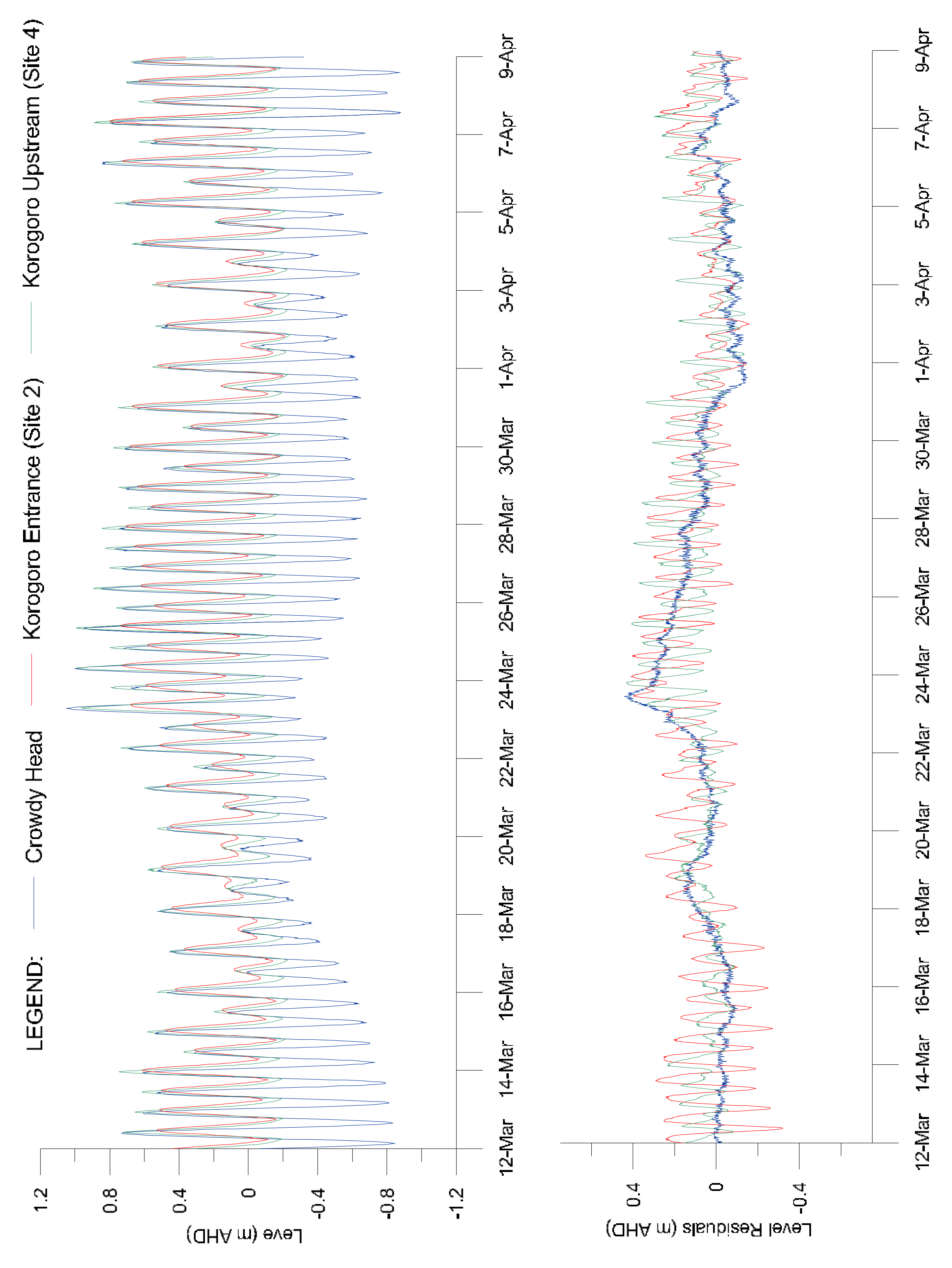
CROWDY HEAD
DIRECTIONAL STATISTICS
OCTOBER 1985 TO DECEMBER 1996

Figure 4-F



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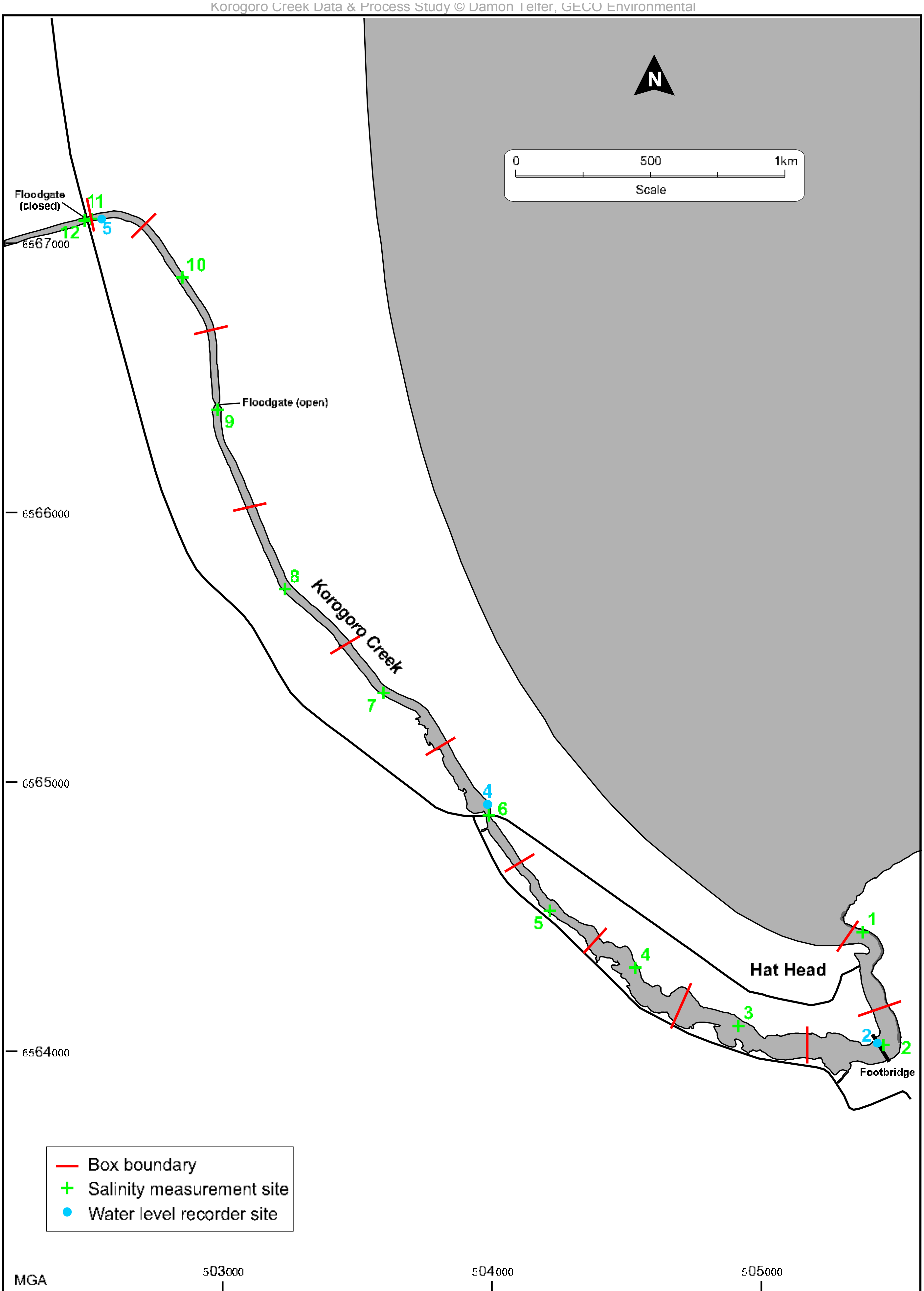
RECORDED WATER LEVELS AND TIDAL RESIDUALS

Figure 4-G



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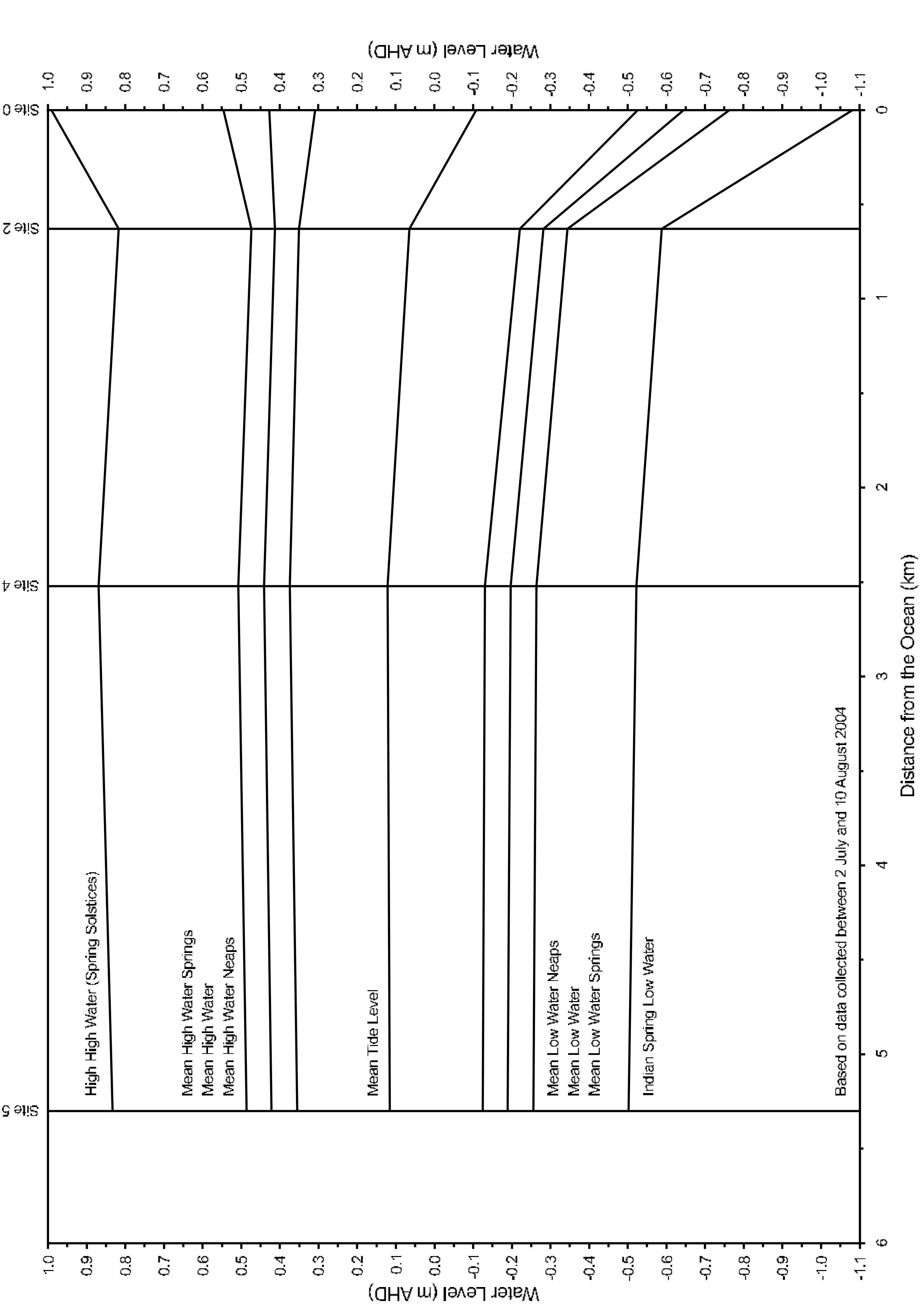
LOCATION MAP
KOROGORO CREEK HYDRODYNAMIC STUDY

Figure 4-H



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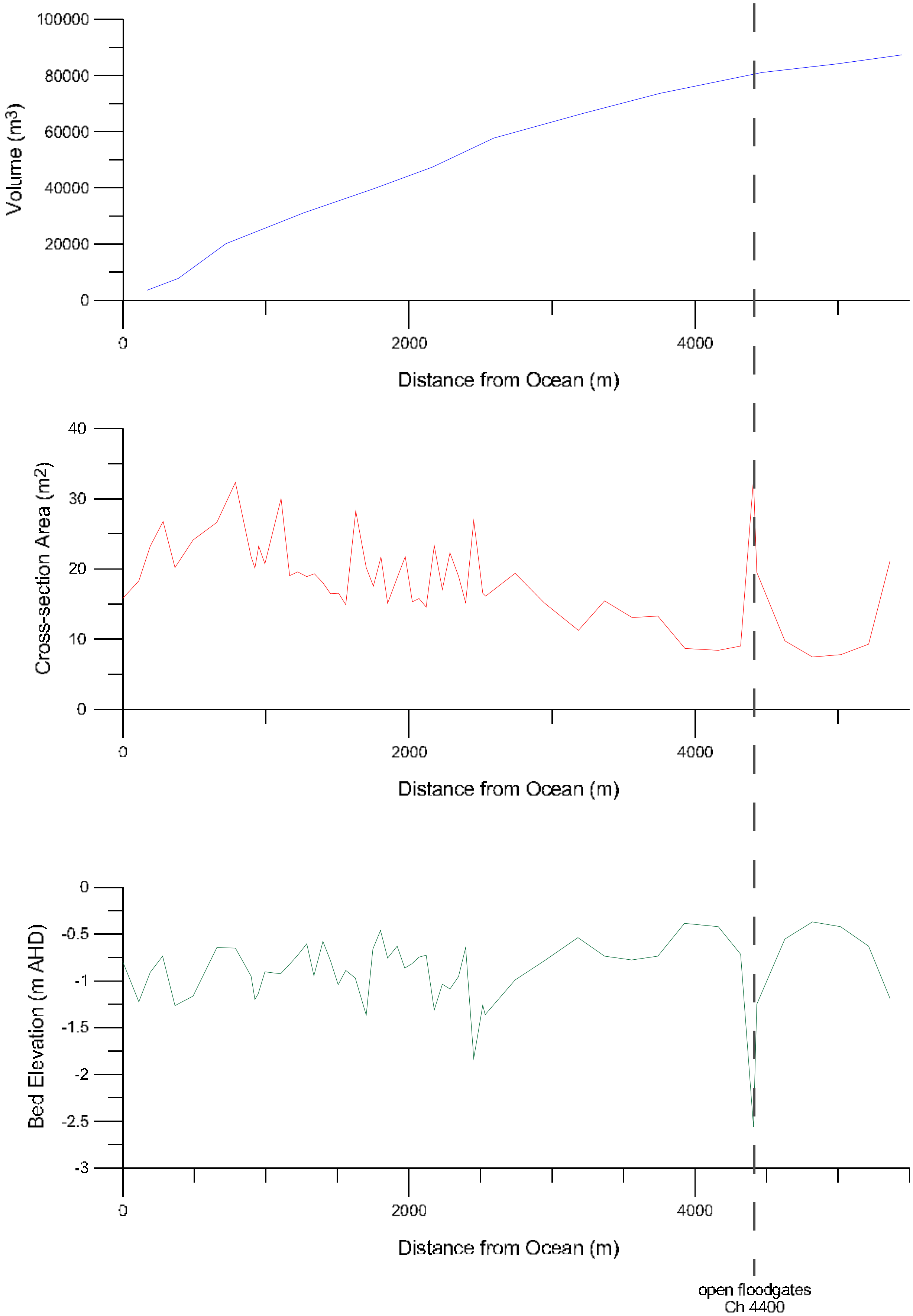
TIDAL PLANES
KOROGORO CREEK SITES 0, 2, 4 AND 5
2 JULY-10 AUGUST 2004

Figure 4-I



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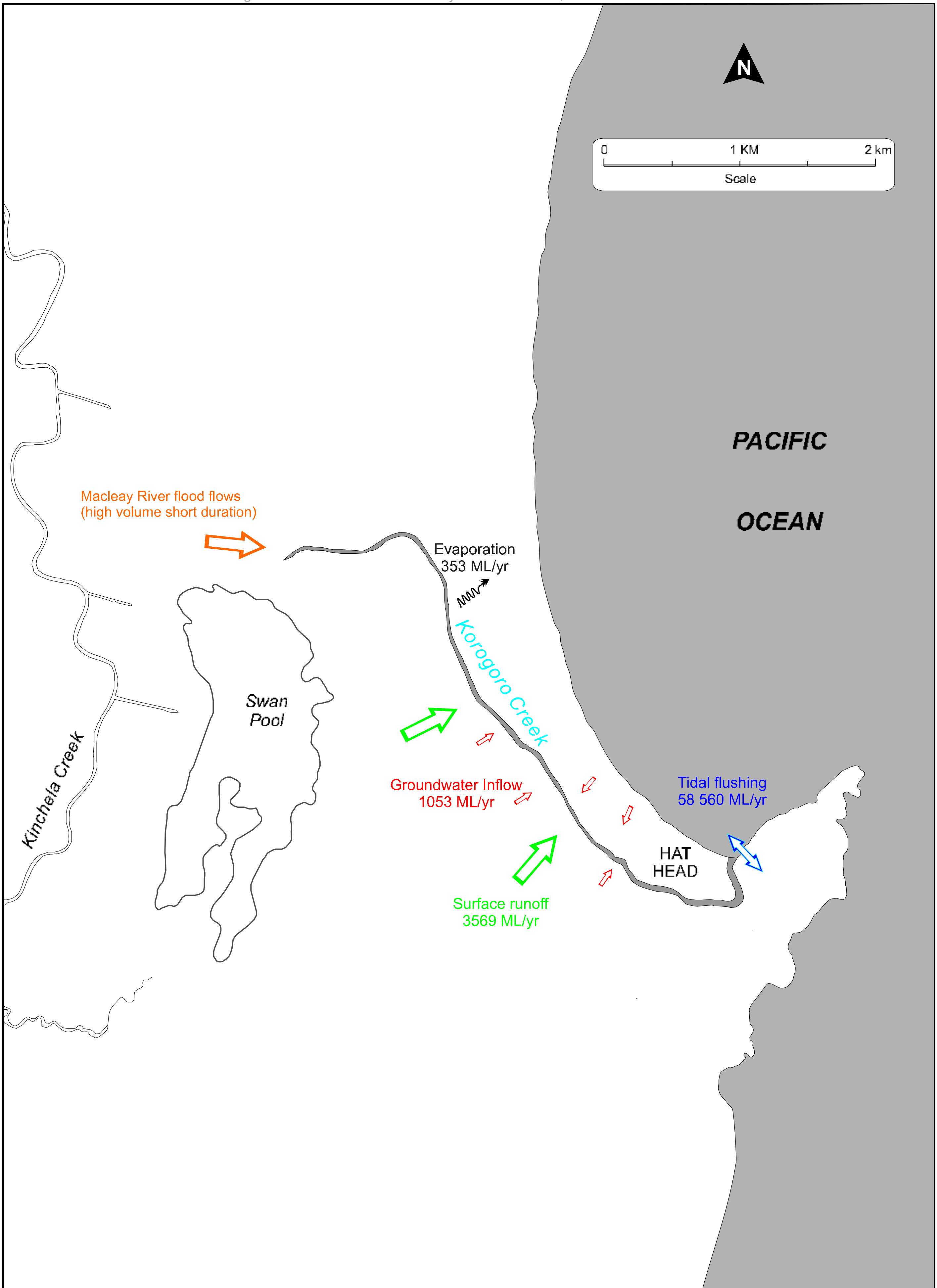
PHYSICAL CHARACTERISTICS OF KOROGORO CREEK AT MEAN TIDE LEVEL

Figure 4-J



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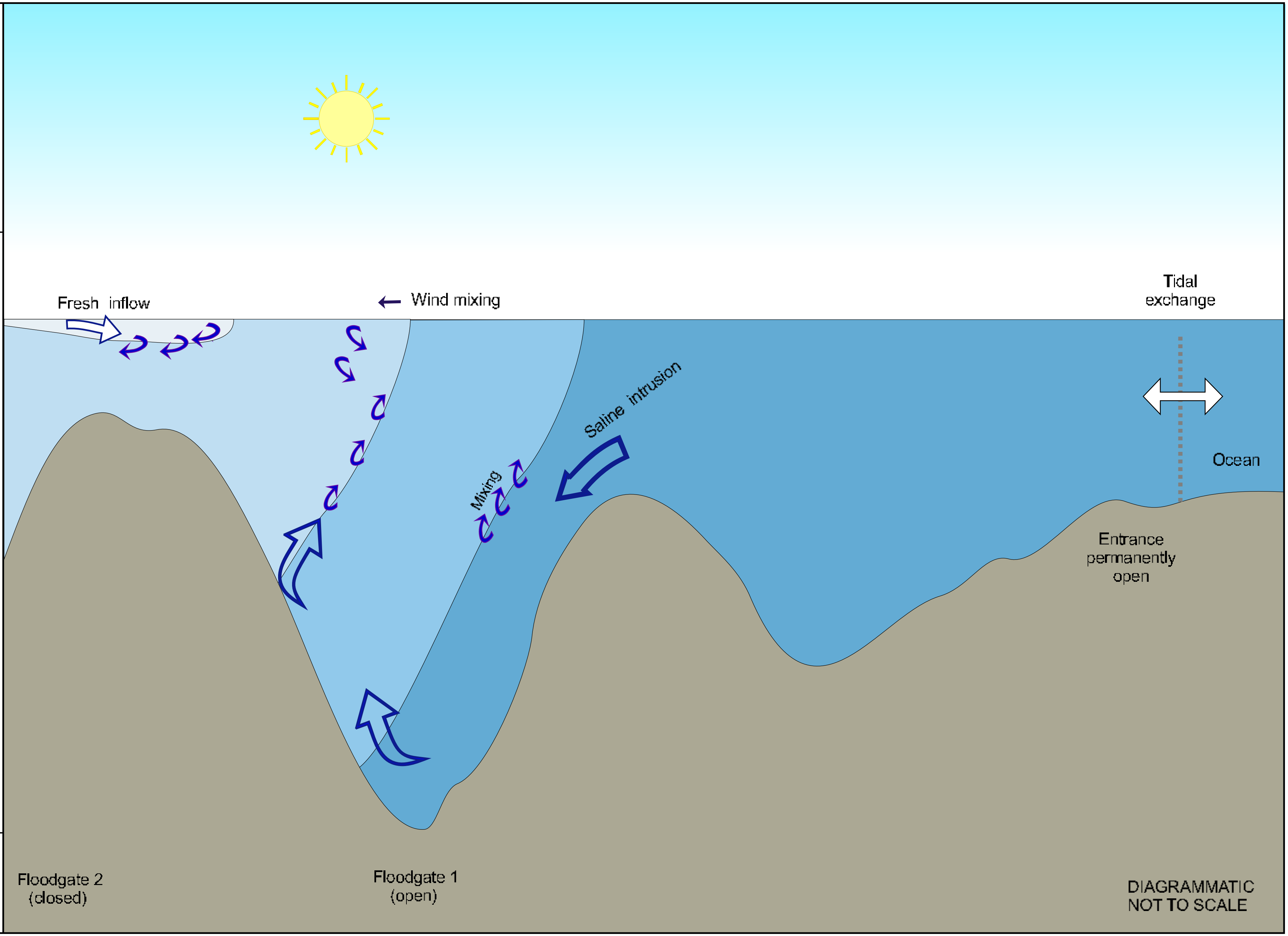
CONCEPTUAL WATER BALANCE MODEL

Figure 4-K



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CONCEPTUAL CIRCULATION AND FLUSHING

Figure 4-L

Figure 4-M

Created by:
Damon Telfer
GECO Environmental,
Grassy Head, NSW 2441

Korogoro Creek Catchment - Survey Estuary Habitat Types

Data Source:
Aquatic Macrophytes - Dept Primary Industries Fisheries
Orthophotos - derived from LIP NSW images (2003,2004)
Roads - Dept Environment and Climate Change

LEGEND

Approximate Catchment Boundary
Roads

ESTUARINE HABITATS

Mangrove
Seagrass
Saltmarsh
Intertidal sand/mud flats
Rocky shore/boulder fields
Seaweed

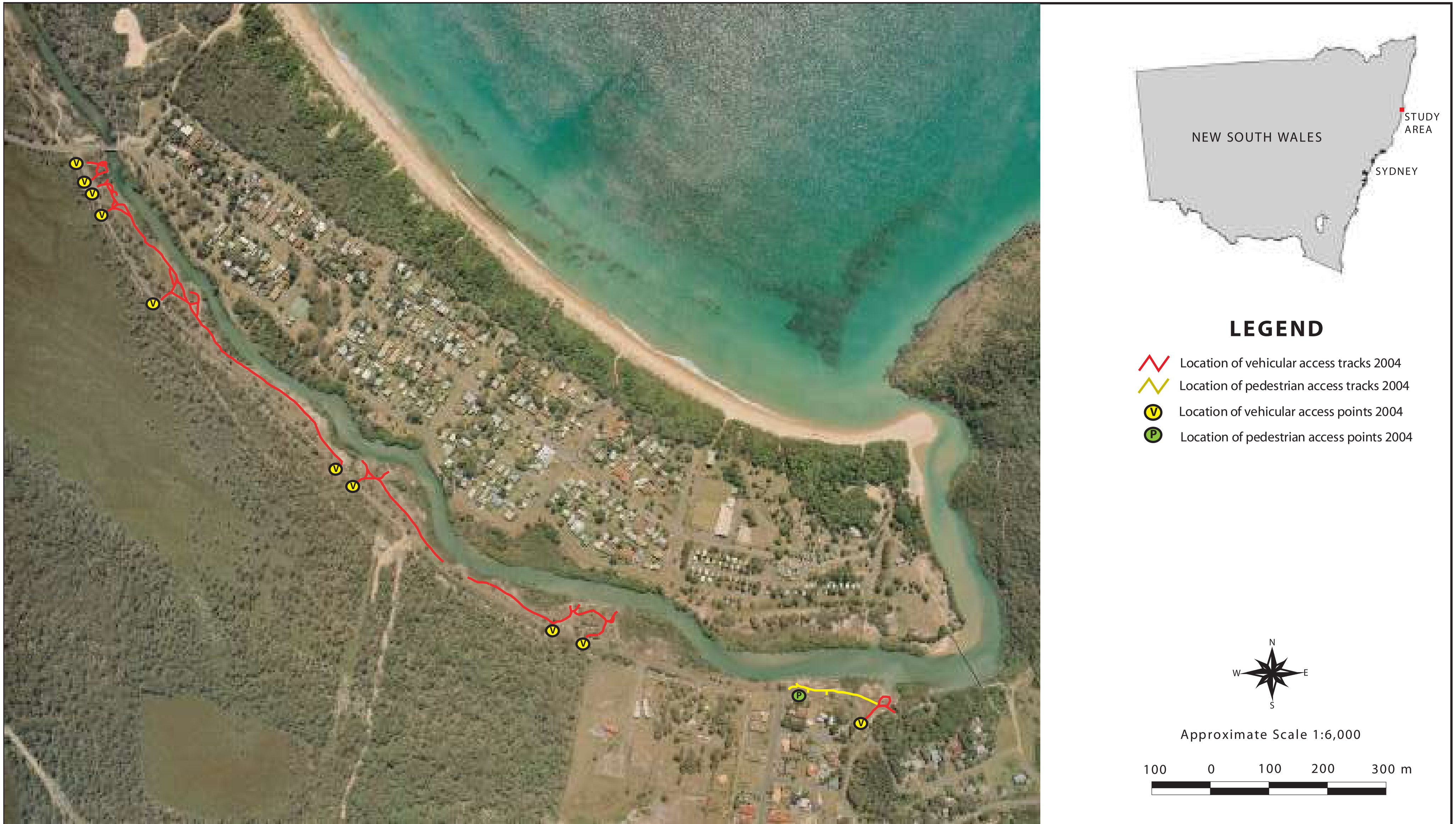

Figure 4-N

Vehicle and Pedestrian Access Points and Tracks - South Bank of Korogoro Creek, below Hat Head Road Bridge

Created by:
Damon Telfer
GECO Environmental,
Grassy Head, NSW 2441

Sources: Base orthophoto images: created from 2004 1:10,000 coastal surveillance aerial photography LPI, Dept Lands, Bathurst
Access mapping: derived through aerial photograph interpretation and field recording using handheld GPS