CHAPTER 3

Processes Influencing Sediment Movement in Cleveland Bay

In order to assess any possible role which dredging has played in the coastal and nearshore zone changes revealed by the aerial surveys between 1941 and 1988 and the ground surveys of the late 1970's to early 1980's, it is necessary to review the processes influencing sediment movement in Cleveland Bay. Processes operating in the coastal catchments as well as marine processes are important.

A Coastal Catchment Processes

Cleveland Bay is influenced not only by the catchments of the small rivers flowing into it, of which the Ross River (catchment area 750 km^2) and Alligator Creek (69 km^2) are the largest, but also the vast 129,660 km^2 catchment of the Burdekin River, the delta of which lies south of Cleveland Bay(Figure 22). For both geological and climatic reasons ideal conditions exist for a high sediment yield.

1 Geology

Geologically, there are remnants of sedimentary basins containing Palaeozoic flysch sediments, inter-bedded with thick silica-rich volcanic flows and tuffs. Granitoid plutons were densely intruded probably during the Upper Carboniferous and basin outlines were changed later by igneous intrusions, faulting, folding, erosion and concealment by younger sediments. More recently during the Tertiary and Pleistocene large areas were covered by olivine basalts and surficial deposits of unconsolidated sands, gravels, clays and silts.

2 Climate

The seasonally wet and dry tropical climate, with rainfall occurring primarily during the hotter summer months between November and April, when tropical cyclones may occur and generate major river floods, produces rapid weathering and erosion. Rainfall records for Townsville Pilot Station (1871-1940) and Townsville Airport (1941-) have been amalgamated to produce Table 8, which is presented in hydrological years commencing in October. The mean annual rainfall is 1147mm and the monthly means show a clear concentration between December and March, but with moderate rainfall in November and April. Table 8 and Figure 16 reveal a further characteristic of the rainfall, its marked variability from year to year, ranging between a minimum yearly total of 236mm in 1901-2, to a maximum of 2661mm in 1889-90. The highest rainfall totals, as well as the highest intensity rainfall, are usually related to a tropical cyclone nearby.

3 River Regimes

The river regimes strongly reflect the rainfall pattern. Records of monthly volumes for Ross River at the Ross River Dam headwater (1974-1987) (Table 9a), Alligator Creek at Allendale (1974-1987) (Table 9b), and Black River at the Bruce Highway, slightly north of Cleveland Bay (1973-1987) (Table 9c) show maximum discharge between December and May. Low flows occur between June and November in Alligator Creek and Black River during the winter dry season, but on Ross River, dammed since 1973 no water passes over the spillway during most of this season. These are the only rivers flowing into Cleveland Bay or nearby for which Queensland Water Resources Commission (QWRC) records exist for more than 2 years. The high annual rainfall variability is clearly reflected in the variations in the annual volume figures for

these three rivers: Ross River 302,672 - 0 Ml, Alligator Creek 66,932 - 6,327 Ml & Black River 399,051 - 55 Ml, and seasonal variations are shown in the monthly volume figures: for Ross River 191,089 - 0 Ml, for Alligator Creek 33,226 - 0 Ml, and for Black River 186,358 - 0 Ml.

For the much larger Burdekin River south of Cleveland Bay, longer discharge records exist, taken at Home Hill (1920-57) and at Clare (1949-). The Burdekin dominates coastal discharge over a wide area, including Cleveland Bay, with a mean annual discharge of 11,027,855 Ml and a range between 54,066,314 Ml and 305,185 Ml (QWRC data for Clare 1985). Analysis of Burdekin data for the period 1940 to 1980 has identified the major floods, and the close link between them and the passage nearby of a tropical cyclone is clearly shown in Table 10 (after Pringle, 1986). No further cyclones affected this coast between 1981 and 1987.

4 Sediment Supply to the Coast

The seasonality and high variability of rainfall from year to year is reflected through the river regimes in the rate of sediment supply to the coast. Whilst few measurements of sediment load have been taken along north-east Queensland rivers, some theoretical calculations have been made (Pringle, 1986). Belperio (1979) calculated the sediment and solute loads of the Burdekin River as follows in million tonnes:

	Washload	Bedload	Dissolved Load	Total
Average year	3.00	0.45	0.90	4.35
Flood year 1957-8	19.70	3.70	2.40	25.80
Drought year 1968-9	0.008	0.001	0.080	0.089
24h of peak discharge March 1946 (39,600cumecs)	6.40	1.70	0.30	8.40

For the Ross River (Belperio, 1983) has estimated the total mean annual load as 0.33 million tonnes but proportionate fluctuations will occur. The presence of the Ross River Dam since 1973 will have profoundly affected sediment delivery into Cleveland Bay, with the coarse fraction being trapped in the reservoir under most, if not all, conditions of flow.

5 Pollution

In addition to natural inputs of water and sediment from the rivers to the coast (even if these are distorted by engineering works upstream) man may be responsible for chemical and biological inputs through discharge of sewage and industrial effluent. Up to 1940 septic tanks were used in the Townsville area, but then after the installation of a mains sewage system, raw sewage began to be discharged into Cleveland Bay (G. Jones, Townsville & Thuringowa Water Board, personal communication 1988). Initially this was through a pipe at the Ross River mouth, directly into the inter-tidal zone (Figure 1). In 1986 this pipe was sealed and sewage was diverted to Sandfly Creek to double the existing level of effluent in that Creek. The Sandfly Creek sewage plant was commissioned in 1963, but not completed until 1976 therefore there was a gradual increase in effluent from 1963 to 1976. A secondary treatment plant was installed and became operational in 1989. Improvements are planned for the treatment of sludge from the plant. A further sewage treatment plant is in operation and discharges into lagoons near the Bohle River mouth. For the relatively isolated settlements on part of Magnetic Island and elsewhere in the Cleveland Bay area, package sewage treatment plants are installed and the effluent is used for irrigation water. The remainder of Magnetic Island is on septic systems.

Responsibility for monitoring and analysis of water quality lies with the Queensland Water Quality Council, recently renamed the Queensland Department of Environment and Conservation, Division of Environment. To determine the extent of influence of existing disharges to Cleveland Bay, water and sediment sampling exercises were undertaken between 1980 and 1982 and the results submitted in a report to the 98th Meeting of the Council (31 March 1982) and in a subsequent addendum (undated, c1983). Results of the sediment analyses are of relevance to the present project.

Sediment Pollution Study

Sediment sampling sites were located near the Ross River (eastern suburbs) and Sandfly Creek outfalls and seaward of these in an attempt to completely cover the zone of influence of the discharges (Figure 17a).

a) Sediment grain size

Sediment grain size analysis showed that >85% of most samples was <0.6mm (ie finer than coarse sand on the Wentworth scale). As settlement of particle-associated pollutants takes place mainly on sediment <0.063mm (finer than sand) the proportion of these fines in the samples was examined (Figure 17b). High levels were found in the mangrove fringe near HWM, lower levels in the higher energy mid to lower intertidal zone, then increasing levels seaward of LWM. Superimposed on this general pattern is an area of high levels seaward of the Ross River mouth, which may be part of the settling zone for fine particles discharged by the river and possibly also by Sandfly Creek.

b) Escherichia coli

The detection limit for E. coli was 10^2 colonies/gm of sediment and at most sites levels were lower (Figure 17c). However, positive results were obtained near the outfalls and in a zone northwards; and the shoreline and intertidal zones between the outfalls, together with Ross River were shown to be extensively contaminated.

c) Coprostanol

Coprostanol, found in the faeces of humans and other higher species is another useful indicator of sewage contamination, and persists longer than E. coli. Positive values were grouped round the outfalls, but also extended northwards from Ross River and Sandfly Creek mouths and linked seaward (Figure 17d). Two separate zones north-east of Sandfly Creek may reflect the movement of a plume in that direction under certain wave and tidal conditions.

d) Phosphorus

Total phosphorus shows a similar distribution pattern to that of sediment <0.063mm, as it is readily adsorbed onto fine particles (Figure 17e). As levels were low near the outfalls little enrichment occurred from the discharges.

e) Bicarbonate Extractable Phosphorus (BEP)

Only at sites close to the outfalls were levels raised (Figure 17f). B.E.P. is regarded as an acceptable relative measure of biologically available phosphorus and these results suggest there has been little increase in the eutrophication potential due to this factor.

f) Acid Extractable Phosphorus (AEP)

This has a completely different distribution pattern to those of the other phosphorus fractions (Figure 17g), but showed similarities with the E. coli and coprostanol patterns. Marked contamination occurred around each outfall and extended along the shoreline and intertidal zone between them. It also extended seawards north of Ross River mouth to the edge of the sampling grid (and therefore maybe beyond it) and northwards from Sandfly Creek.

g) Oil and Grease

Values were generally low over the sampling grid area, implying low contamination levels (Figure 17h). The higher values in Ross Creek mouth were believed to have a source other than sewage effluent.

h) E. coli, coprostanol and acid extractable phosphorus

Finally the distribution patterns of these three indicators of sewage contamination were combined (Figure 17i). Areas of greatest contamination lay around the two outfalls and the adjacent shoreline and inter-tidal zone, with a further area seaward of Ross River mouth. It is suggested that the latter is the zone where pollutant particles from both effluent plumes settle out in an area of predominantly fine sediment. A continuous area of lower pollution existed around the more highly polluted cores. Overall however it was concluded that the sewage effluent was making a relatively minor environmental impact because of the high degree of dilution and dispersion in Cleveland Bay. The only serious exception was in Sandfly Creek which was grossly polluted.

Since this report was completed about 1983, the closure of the eastern outfall in 1986 and diversion of its effluent through Sandfly Creek is likely to have changed the pollution pattern and levels considerably. However, the secondary treatment plant which recently became operational in 1989 should improve the situation rapidly.

B Marine Processes

1 Wind Influences

Within the Cleveland Bay area Bureau of Meteorology wind data is available from Townsville Airport and before 1987 was available from Cape Cleveland lighthouse, with observations at 0900h and 1500h local time. Comparison of the two data sets (Oliver, 1978) has revealed some marked differences especially at 1500h. The Cape Cleveland data more closely indicates the regional airflow, with less modification due to topography and urban development and therefore is of greater value in an assessment of wind influences on marine processes. Wind data is available also from the Townsville Port Control Building from 1979 onwards.

The percentage occurrence of wind speed versus direction for Cape Cleveland for the 30 year period from 1957-1986 has been calculated by the Australian Bureau of Meteorology (Table 11). The 0900h observations reveal the dominance of south-east winds throughout the year, with this being especially pronounced during the winter months. The most frequent wind speeds at 0900h between March and August are 21-30km/hr, and between September and February are 11-20km/hr. The 1500h observations reveal that east winds are dominant between January and October, but north-east winds dominate in November and December. The most frequent wind speeds at this time are 11-20km/h between August and

February and also in June, but they rise to 21-30km/h between March and May and in July. The regional air flow is most closely represented by the 0900h records, as the 1500h records are influenced also by the diurnal sea and land breeze cycle (Oliver, 1978). The sea breeze, which is more strongly developed than the land breeze, generally blows normal to the coast. It is the south-east winds therefore which exert a major control on wave development over the sea, and on wind-induced currents in shallow water.

Whilst the 30 year data gives a valuable summary of wind conditions generally in the Cleveland Bay area it does mask considerable variations within this period. In order to examine wind conditions preceding most of the aerial surveys, and at other times which might be significant in relation to particular dredging projects for which monthly data has been compiled, monthly summary wind data were obtained for the period January 1965 to November 1987 in a form similar to the 30 year data in Table 11.

2 Waves

Since July 1975 the Townsville Port Authority has owned, and the Queensland Beach Protection Authority (BPA) operated, a Datawell 'Waverider' buoy sited 6km north-east of Cape Cleveland. For most of this period four 20 minute records have been taken daily at 0300h, 0900h, 1500h and 2100h. The BPA has analysed those records by computer using routine and spectral techniques to obtain the following parameters:

i	Zero crossing period (Tz) in seconds	The average period of all waves in the record based on upward zero crossings.
ii	Crest period (Tc) in seconds	The average period of all the waves in the record based on successive crests.
iii	Root mean square wave height (Hrms) in metres	The root mean square of the heights from the record.

iv	Significant wave height (Hsig) in metres	The average of the highest one third of waves in the record.
v	Maximum recorded wave height (Hmax) in metres	The highest individual wave in the record.
vi	Significant period (Ts) in seconds	The average period of the highest one third of waves in the record.
vii	Peak energy period (Tp) in seconds	The wave period corresponding to the peak of the energy density spectrum.

This data has been obtained for the period 19 November 1975 to 29 December 1988. For each calendar month the average, standard deviation, maximum and minimum have been determined for each of the 7 parameters (Table 12). (NB There are a few gaps owing to wave recording failures). As with the monthly wind data, this enables conditions to be considered in relation to the monthly dredging records and in the periods preceding the later aerial surveys. To provide a more generalised view similar wave statistics have been determined for each calendar year and dredging year ending on 30 June (Table 13). In addition, each parameter was plotted on a computer-drawn annual graph to aid visual inspection of the data.

The Beach Protection Authority (1988) have summarised their analysis of this wave data for the period 16 July 1975 to 29 December 1987. Annual graphs for significant wave height (Hsig) and peak energy period (Tp) form Figure 18. Wave period has been tabulated against wave height occurrences for all the data (Table 14a) and this shows that waves of 0.21-0.40m height and 3.00-4.99s period occur most frequently. For the summer data only (Table 14b) and for the winter data only (Table 14c) the same is the case. This data (but from 19 November 1975 onwards) is plotted in a different form as histograms showing percentage of time occurrence of wave heights (Hsig) for all wave periods (Figure 19a) and of wave periods (Tp) for all wave heights (Figure 19b).

The predominance of south-east winds which has been demonstrated in the preceding section, suggests that these are responsible for producing a high proportion of the waves recorded near Cape Cleveland. Regretably this 'Waverider' buoy system measures only vertical water movements and not wave direction as well, so this cannot be examined in the records. The relatively small frequently occurring recorded waves will have been generated mainly in the limited 240km fetch to the south-east landward of the Great Barrier Reef, although some will probably have been generated from the east and north-east in shorter fetches of 112km and 72km respectively. When the waves enter shallow water (depth less than half the wave length) they will start to interact with the seabed and become refracted. Wave refraction diagrams have been constructed for 5 second period waves from south-east, east and north-east (McIntyre and Associates, 1974). The south-east waves (Figure 20a) are partially refracted before entering Cleveland Bay and wave energy levels east of about Sandfly Creek are very low. The orthogonals show that wave energy is mainly concentrated on the coast west of Townsville Harbour. With this wind direction waves can be generated also in the 18km fetch of Cleveland Bay itself and may reach heights of 0.5m before breaking on the south-east Magnetic Island coast. Easterly waves (Figure 20b) are also considerably refracted in the bay resulting in energy levels being very low east of about Alligator Creek, but considerably greater on the western coasts. North-east waves (Figure 20c) approach Cleveland Bay from its most open direction, therefore refraction and dissipation of energy are at their least, but the relatively short fetch limits potential wave size. Cape Cleveland provides some shelter from north-east waves and the orthogonals indicate relatively low energy levels eastwards from between Alligator and Crocodile Creeks. Most of this wave energy is concentrated on the coasts west of Alligator Creek.

Only on rare occasions, such as when a tropical cyclone passes near Cleveland Bay are moderate to large waves likely to be generated from any other direction. Then, normally sheltered, low energy coasts may experience high energy waves and suffer considerable erosion.

3 Tides and Tidal Currents

Tides in the Cleveland Bay area are mainly semi-diurnal in type with a range of up to 4.0m during spring tides and down to 0.0m at neap tides, during 1988 (British Admiralty Tide Tables for Townsville, 1988). Easton (1970) notes that the solar influence on tides along the Queensland coast increases north of Mackay and this results in an increase in neap to spring variations. At extreme neap tides they become almost diurnal in type at Townsville, whereas at spring tides successive semi-diurnal tides may differ by about 1m in height.

Tidal ebb and flood generates important tidal currents especially during the higher range spring tides. Drogue measurements made by the Townsville Port Authority on a number of different dates and tidal conditions (although avoiding neap tides) are amalgamated into Figure 21a and b (McIntyre and Associates, 1974). The flood tide (Figure 21a) is shown entering Cleveland Bay in three streams. The first originates from the east, swings round Cape Cleveland and moves across the bay south-westwards with speeds of up to $0.5ms^{-1}$. The second stream enters the bay from the north and swings closer to Magnetic Island, reaching speeds of 0.2 and $0.3ms^{-1}$. The third stream enters the bay through West Channel between Magnetic Island and Cape Pallarenda, and reaches speeds of $0.7ms^{-1}$. The opposing flood currents meet off Cape Pallarenda. On the ebb tide the current continues to flow south-eastward through West Channel reaching speeds of $0.3ms^{-1}$ on spring tides. Water therefore leaves the bay either close to Magnetic Island in a northerly direction at

speeds of up to 0.4ms^{-1}, or towards the north-east at the same speed on maximum spring tides.

Belperio (1978) from a series of spot measurements of tidal current confirmed this pattern, but took no ebb current measurements in West Channel. Furthermore he gives no indications of dates or tidal ranges when the measurements were made. Carter and Johnson (1987) used recording current meters at 3 sites in Cleveland Bay (Figure 1) to measure water depth, and current speed and direction during a full neap to spring tidal cycle. Their findings are not presented alone, but are amalgamated with earlier published observations. They indicate that the tide floods into Cleveland Bay in a "south to south-south-east (170^{o}-230^{o}) direction" (there is an obvious discrepency here) and rotates anticlockwise to ebb north-north-east to north-east (030^{o}-050^{o}). At the eastern end of West Channel the flood is more westerly and the ebb more easterly, and furthermore during neap tides a weak current floods and ebbs in a consistently north-east direction. The source of this information relating to West Channel is unclear as none of their current meters was placed here and a current flowing at right angles to West Channel is very difficult to explain. Overall this pattern described by Carter and Johnson is similar to that revealed by the Townsville Port Authority drogue measurements except that the latter indicate a south-eastward flow through West Channel. A close linear relationship is reported by Carter and Johnson between tidal magnitude and measured bottom currents. During neap tides (0.5-0.8m range) currents are irregular in direction and less than 0.05ms^{-1} velocity; during spring tides (2.3-3.6m range) currents vary between 0.2 and 0.3ms^{-1} with minor asymmetry between the slightly stronger flood and slightly weaker ebb, but with regular orientation.

C Sediment Movement in the Cleveland Bay Area

Except close to the Magnetic Island fringing coral reefs, coastal sediment and sediment on the neighbouring seabed is dominantly siliceous and has a terrigenous source. The main source of sediment in Cleveland Bay is the small rivers and creeks which flow into it, although the damming of Ross River is likely to have reduced the overall quantity significantly. It has been noted above also that the very large Burdekin River further south is capable of delivering huge quantities of sediment to the coast during times of major floods associated with tropical cyclones. Belperio (1978) has suggested that at such times a turbulent jet from the Burdekin is turned north to north-westwards from the mouth due to the prevailing south-east winds and waves and its influence may be felt as far as Townsville. (Geostrophic effects and coastal trapping, together with the effects of the wind, provide an alternative explanation of this north to north-westward movement.) As an example Belperio considers a long period of heavy rainfall between 15 January and 8 February 1974, which followed Cyclone Una in December 1973, during which the average flow of the Burdekin was 16,000 cumecs and the total discharge $33 \times 10^9 m^3$. Such rare but massive inputs of fresh water must have a considerable effect on the circulation pattern, sediment transport, salinity and biota. It is possible that fine sediment from the Burdekin was deposited in Cleveland Bay as a result of this event.

As the Cape Cleveland 0900h records show, 60% of winds blow from the east and south-east, and they are almost solely from these directions when the wind velocity is over $7.5 ms^{-1}$. As a result wind-induced surface water currents move predominantly towards the west and north-west carrying suspended sediment alongshore. Belperio (1978) reports observing such surface currents moving over tidal flood and

ebb currents during spring tides, although the tidal currents were deflected to some degree towards the north-west. Measurements taken off Cape Cleveland and in West Channel indicate that a 7-10ms^{-1} east or south-east wind is sufficient to obliterate the southward moving flood tidal current and set up a unidirectional current around each headland so that inner shelf water is moving through Cleveland Bay and the adjacent bays in a north-westward direction. This current, combined with wind-induced currents in south Cleveland Bay induces a major current flowing southwards along the west leeward coast of Cape Cleveland, which is reinforced by the tidal flood current. Belperio found the best sorted sub-tidal sediments in this area, which is also one where, unusually, sub-tidal bed load movement occurs. Moderately sorted sand, from sub-aqueous erosion of deep weathered rock along Cape Cleveland, moves south by ripple migration and supplies sediment to the intertidal flats along the south coast of Cleveland Bay. Wave induced longshore drift is then claimed by Belperio to result in substantial suspended sediment movement westwards past Townsville and through West Channel into Halifax Bay. Wind induced surface currents were observed to have a velocity of 0.2-0.3ms^{-1} in open water areas, but reached 0.5ms^{-1} in the constricted West Channel.

To study the movement of wind-induced currents below the water surface Woodhead sea-bed drifters (Phillips, 1970) were released by Belperio at times of low tidal range but strong wind and wave activity. From the recovery pattern it was shown (Figure 22) that the drifters had moved alongshore north-westwards, and a particularly strong sea-bed water movement had been demonstrated around Cape Cleveland and southwards along its west, leeward side and also through West Channel into Halifax Bay. From these results Belperio concluded that the entire water column in Cleveland Bay and the adjacent bays is essentially wind driven when wind

velocity exceeds 7-10ms^{-1}, and this will influence both suspended sediment and bed load movement. This conclusion that the entire water column moves in a downwind direction is contrary to findings from seabed drifter investigations in Morecambe Bay, north-west England (a temperate storm wave environment) where strong winds blowing from the prevailing westerly quarter set up counter currents near the seabed moving from east to west (Phillips, 1968 and 1969). Although Cleveland Bay and Morecambe Bay are of similar dimensions, it may be that West Channel acts as an escape route for such wind driven water in Cleveland Bay and prevents development of counter currents. Further current measurements are required to clarify this.

Wind waves and wind-induced currents, as well as tidal currents in restricted localities such as West Channel on spring tides, are strong enough to entrain fine sediment from the bed of Cleveland Bay and even fine to medium sand on occasions. Belperio (1978) has mapped suspended sediment concentrations under different sea states (Figure 23). For smooth to slight seas, less than 10ppm were measured except over the intertidal flats, where wave action would be dominant. During slight to moderate seas (wind velocity 5.0-7.0 ms^{-1} and wave height up to 0.8m) a narrow continuous 1-2km turbid coastal zone developed with over 10ppm. With moderate to rough seas (winds 7.5-9.5ms^{-1}, wave heights 1.0-1.8m) the coastal turbid zone widened to 2-7km. Under rough sea conditions (winds 10-12.5ms^{-1}, wave heights 1.9-2.5m) the entire bay became turbid, but effective transport off Cape Cleveland did not extend beyond 5km from the tip of the headland. In addition a marked plume of turbid water extended round Cape Cleveland and south-westwards into Cleveland Bay indicating, according to Belperio, advective transport of suspended sediment from Bowling Green Bay.

Transport of sand along the inter-tidal zone and in the surf zone is primarily the result of waves breaking obliquely to the coast. Belperio (1978) calculated a transport rate of 50 tonnes per day in the surf zone at Rowes Bay under moderate sea conditions. If these prevailed for 71 days in a year, north-westward transport of sand would be about 3,500 tones yr^{-1}, but would be supplemented by higher rates under rough sea conditions. The loss of sand from the Townsville beaches along The Strand and the southern end of Rowes Bay result from Townsville Harbour interrupting the natural north-westward sediment movement from south Cleveland Bay and especially Ross River and Ross Creek.

Recently the existence of a further water movement in Cleveland Bay has been suggested (E. Wolanski, personal communication 1988). This involves a narrow inshore strip of water moving very slowly eastwards along the south Cleveland Bay coast, then northwards along the west Cape Cleveland coast to finally escape as a jet past the tip of the headland. This is produced by the development of baroclinic and barotropic coastal boundary layers in wet and dry seasons respectively. In the dry season this inhibits mixing of estuarine and shelf waters and limits estuary flushing. Pollutants would then either be retained in an estuary, such as Sandfly Creek, or would escape only into this narrow coastal water body to be evacuated from there extremely slowly. The sediment in this zone would not be moved by this slow moving water but, especially the fine fraction, would be likely to become very polluted.