BATHYMETRY AND SEDIMENTS OF NGATANGIIA HARBOUR AND MURI LAGOON, RAROTONGA, COOK ISLANDS

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BATHYMETRY AND SEDIMENTS OF NGATANGIIA HARBOUR AND MURI LAGOON, RAROTONGA, COOK ISLANDS

BY

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ABSTRACT

Ngatangiia Harbour and Muri Lagoon are situated on the East side of Rarotonga, Cook Islands. They consist of a reef passage, a harbour up to 3.5 m deep, an inner channel and a lagoon. A shallow reef flat with three islets or motus separates the inner channel from the reef edge. A fourth motu exists on the southern edge of the lagoon. The lagoon is a wide moat 1.25 m below mean sea level at its deepest point.

Analysis of bathymetric surveys dating from 1948 has provided information on the historical development of the area. The data over the recording period showed an infilling of the harbour from 1948 which accelerated in the 1980's. The channel had little net change in sediment deposition where bathymetry is controlled by reef flat topography. The lagoon had a net loss of sediment over the period for which records are available.

Hydrodynamics in the lagoon are controlled by two principal forcing mechanisms: deep water waves and tides. A 90% loss of wave height is predicted as an ocean wave crosses the reef at Muri Lagoon. Waves within the lagoon are primarily influenced by deep ocean waves and water level over the reef. Currents in the lagoon are primarily influenced by the amount of water transgressing the reef which closely correlates with the square of the deep water wave height multiplied by the deep water wave period. Tide becomes the dominant forcing mechanism during times of smaller, low frequency deep water waves. The variability of currents observed in the channel and harbour on a daily scale are related to tides and, on a larger scale, to deep water wave conditions.

Seven sedimentary units have been identified in the study area. These are outer, inner and altered reef flat, lagoon, shoreline, river gravel and Porities boulder fields. Textural analysis of 53 samples shows variable grain size distribution, primarily dependent on transport mechanism. Average grain size for the lagoon and harbour area are coarse sand and, for the channel area, very coarse sand.

Sediment stability in the lagoon is depth dependent. Sediments in water depths greater than 1 m are in motion about 10% of the time, between 0.75 m and 1 m are in motion about 12% and in depths less than 0.5 m are in motion about 25% of the time. Average transport rates of sediments in the channel were approximately twice that of the reef passage at Ngatangiia.

The results indicate that the depositional pattern is the result of hydrodynamic processes active during extreme storm events. Subsequent modification of storm deposits is ongoing and accelerated during less-than-extreme storm conditions.

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c = wave speed

C_g = group wave speed

d = water depth

d_0 = orbital diameter

D = grain diameter

E = energy per unit length along wave crest

f = frequency, referring to wave frequency

f_w = coefficient of friction

F = energy flux

g = acceleration due to gravity = 9.8 m/s^{-1}

H = height of characteristic wave

H_{sig} = significant wave height (average height of highest one-third of waves)

H_0 = deepwater wave height

j = mass discharge of sediment

K = proportionality coefficient

L = wave length

L_0 = deep water wave length

n = fraction of energy advancing with each wave

T = wave period

U_m = maximum horizontal velocity of a fluid

x = distance

ε_f = energy dissipation due to bottom friction

ε_b = energy dissipation due to wave breaking

ρ = density of sea water @ 26° C =1020 Kg m^{-3}

ρ_s = grain density

μ_* = friction velocity

μ_{*c} = critical friction velocity

μ_{100c} = critical friction velocity at 100 cm above the bed

ξ = coefficient of breaking

τ_c = critical threshold stress

CHAPTER 1 INTRODUCTION

1.1 Area and Access

The Cook Islands, named for Captain James Cook, extend between 18° and 27° S Latitude and 157° and 160° W Longitude. Rarotonga is a volcanic island with an associated fringing reef 2750 km northeast of New Zealand (Fig. 1.1), and is the largest island of the Cook Islands. It is mountainous and has an area of 67.2 km^2. The specific area of interest for this study is Ngatangiia Harbour and Muri Lagoon which lie on the southeast corner of Rarotonga (Fig. 1.2).

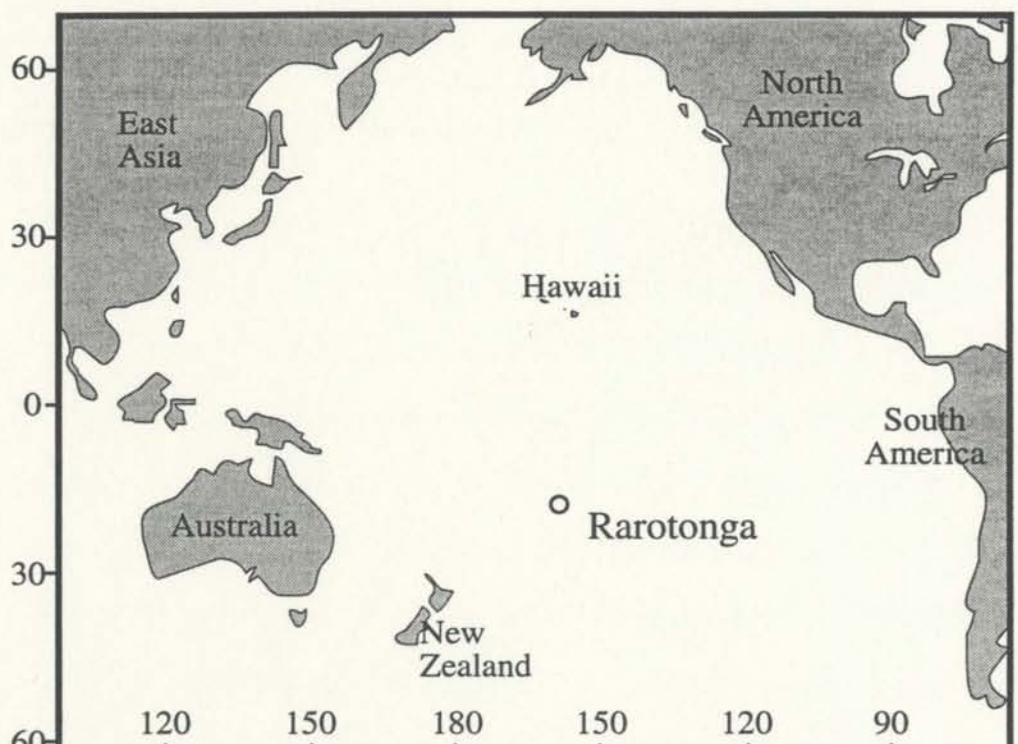

Figure 1.1 Map of the Pacific Ocean showing the location of Rarotonga.

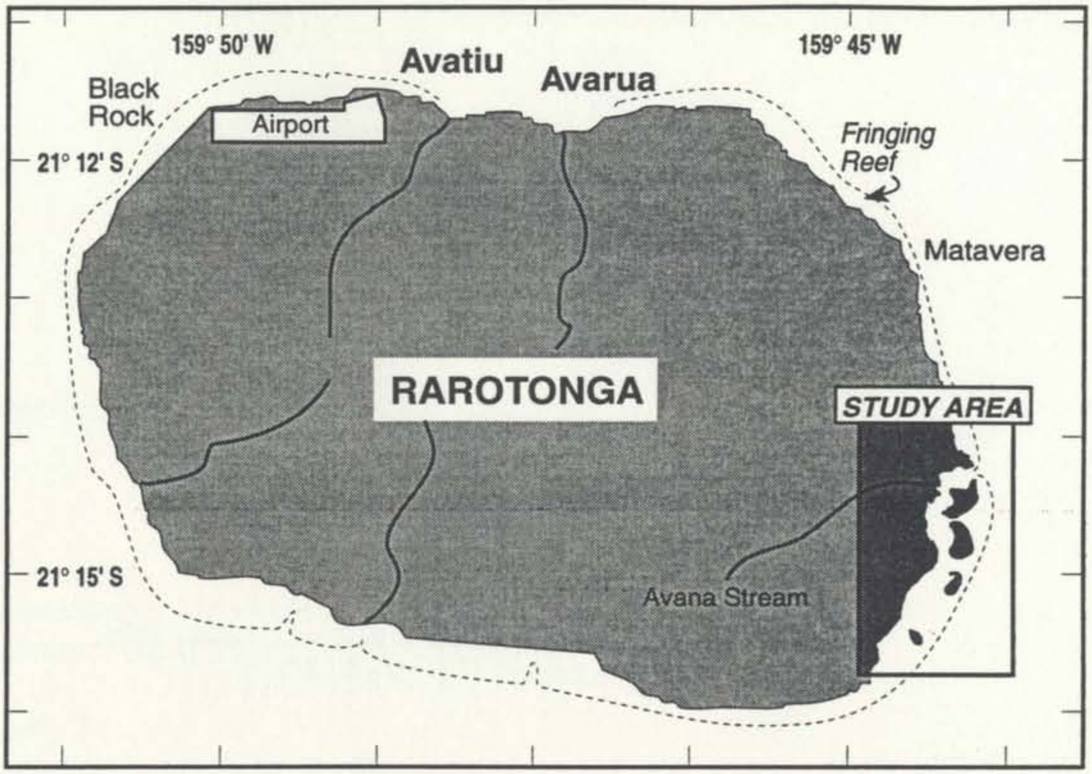

Figure 1.2 Location of the study area at Ngatangiia Harbour and Muri Lagoon.

Marshall (1930) suggested that Rarotonga was populated by expeditions from Tangiia in Tahiti and Karika in Western Samoa in the year 1250. The first confirmed European contact was by the Reverend John Williams of the London Missionary Society in 1823 (Wood and Hay, 1970). There is evidence that Rarotonga was sighted by the Bounty in 1789 (Wood and Hay, 1970), by the ship Seringapalam in 1814 and visited by Captain Goodenough on an unidentified merchant ship in 1820 (Wood and Hay, 1970).

1.2 Climate and Weather

The climate of Rarotonga is tropical, characterized by warm temperatures and high humidity (Thompson, 1986). The position of the South Pacific Convergence Zone (SPCZ) greatly influences the weather patterns of the Cook

Islands and in particular Rarotonga. This is an area of cyclonic wind shear and semi-permanent cloud resulting from the convergence of the equatorial easterly trade winds and the higher latitude southeasterly trades.

1.2.1 Winds

The Southern Cook Islands lie in the South Pacific trade-wind zone with the dominant wind direction being from the east and southeast (Fig. 1.3).

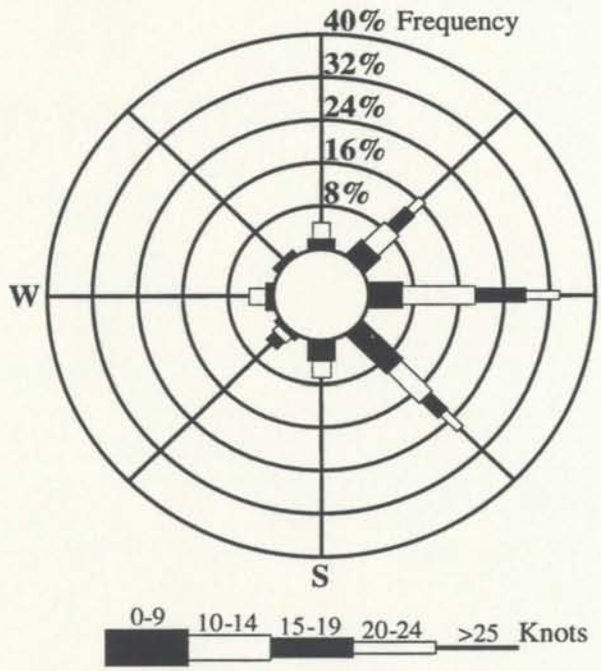

Figure 1.3 Open ocean surface wind estimates for the Southern Cook Islands (after Thompson, 1986).

Both wind speed and direction on Rarotonga are influenced by orographic effects. Rarotonga International Airport records show that in excess of 83% of wind speeds are less than 16 knots (kts). Monthly wind speeds average between 7 and 13 kts with higher averages being recorded at the Matavera Station situated approximately 3 km north of Ngatangiia. Hindcast analysis indicates that a gust of

51 kts has a return period of one year and a gust of 83 kts has a return period of 50 years.

1.2.2 Rainfall

The distribution of mean average rainfall on Rarotonga from 1951-1987 is shown in Figure 1.4. The amount of rainfall on Rarotonga is influenced by the southeasterly trade winds and elevation.

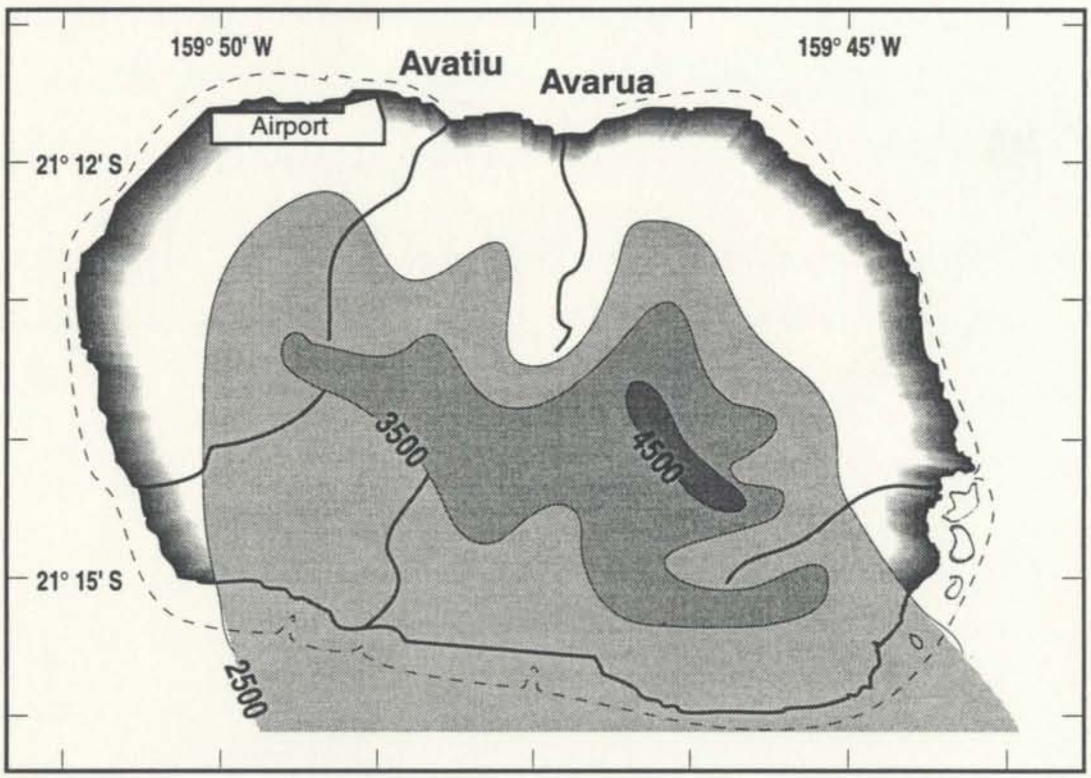

Figure 1.4 Distribution of mean annual rainfall (mm) on Rarotonga between the years 1951 and 1987 (after Thompson, 1986).

There are pronounced wet and dry seasons with variations resulting from the movement of the SPCZ. In general, two-thirds of the total rainfall occurs during the wet season. Average rainfall for Rarotonga is 1292 mm in the wet season and 729 mm in the dry season, representing 64% and 36% of the total annual rainfall, degree of stabilization of reef-top storm deposits and hence their chances of preservation (Scoffin, 1993).

1.3 Geology and Physiography of Rarotonga

Rarotonga is a volcanic island rising 4000 m from the floor of the Pacific Ocean to form peaks, the highest of which is over 650 m above mean sea level. The Island is roughly kidney-shaped measuring approximately 11 km in the east-west direction and 7 km in the north-south direction (Wood and Hay, 1970). Leslie (1980) divided Rarotonga into 2 main physiographic units: the interior uplands and the coastal margin (Fig. 1.7).

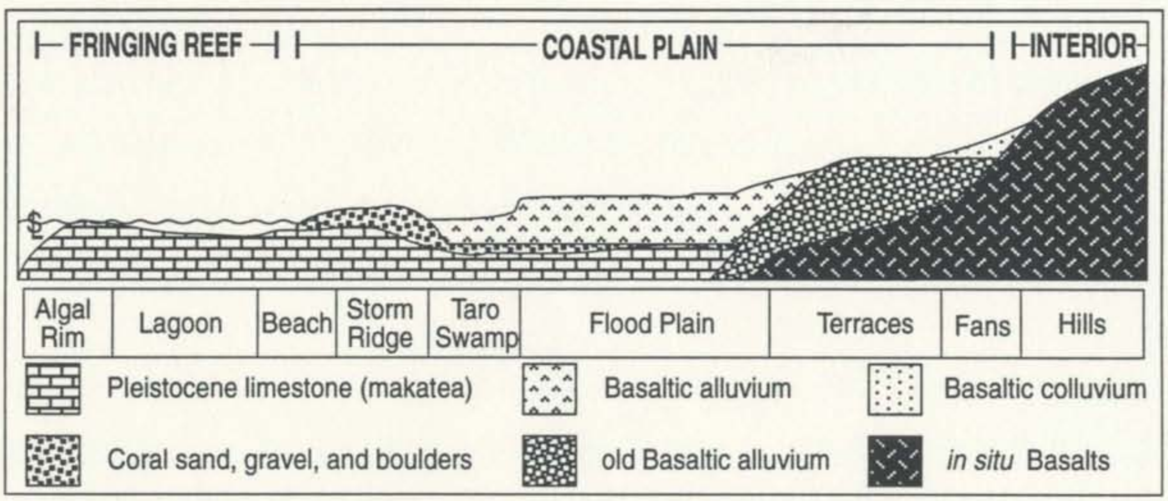

Figure 1.7 Schematic cross section of Rarotonga showing the major physiographic units and lithology (after Leslie, 1980).

The interior uplands exhibit all the features of an extinct Pacific Basin volcano. The razor-backed ridges separating deep valleys result from the erosion of the basement volcanic rocks. The volcanic rocks evolved initially from basaltic eruptions to later eruptions of differentiated lava accompanied by explosive activity and satellite cone formation. The volcanic rocks can be divided into two main

At the Rarotonga International Airport, daily sunshine measurements indicate that during summer, which is the cloudiest time of the year and when the sun is highest, the sun is visible 45% to 50% of the day and during the winter months, with the sun lowest on the horizon, the sun is visible 55% to 60% of the day.

1.2.4 Tropical Storms and Cyclones

Tropical storms and cyclones are extreme storm conditions having sustained wind speeds of greater than 33 kts and 63 kts respectively. Storms are usually confined to the warmer months, November to April. Figure 1.6 shows a comparison of the return periods for sustained cyclonic and non-cyclonic winds.

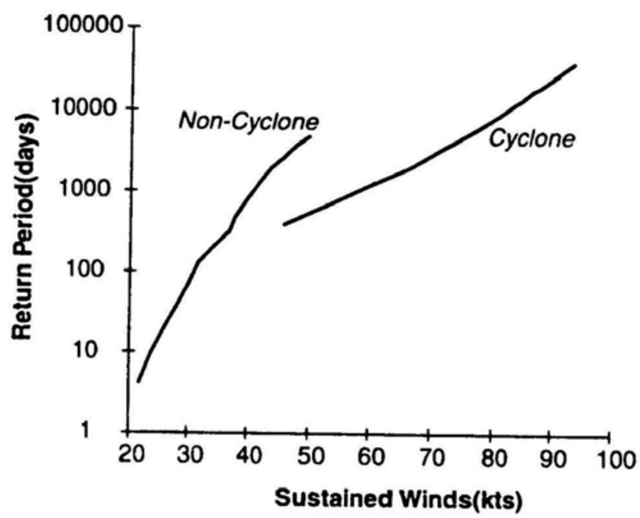

Figure 1.6 Return periods for cyclone and non-cyclone wind (after Carter and Steer, 1984).

It is clear that the most severe winds are associated with cyclonic events. The number of cyclones generated in the South Pacific is 5 to 10 per year (JICA, 1986). The course of cyclones is dependent on the position of the SPCZ, from the east at the beginning of the cyclone season to the west at the end of the season in April. Rarotonga is affected by cyclones mostly in January and February. The Southern Cook Islands, which includes Raroonga, have been affected by 34 cyclones during the past 44 years or 1 cyclone every 1.3 years. Carter and Steer (1984) predicted that a serious storm would hit Rarotonga every 5 or 6 years. The seasonal variability of cyclones is quite high; for example in almost half of the 14 seasons between 1969 and 1983 no cyclones affected the Southern Cook Islands yet between 1976 and 1981 there were three (Thompson, 1986).

1.2.5 Significance of Climate

In general terms, climate has significant effect on the geological processes of the lagoon-channel-harbour system. In this setting, where there are restrictions in the interaction with the open ocean, an excess of fresh water added to the system can influence biological productivity and sediment production (Carpenter and Maragos, 1989). Both meteoric water and the water table influence carbonate sediment diagenesis. Wind and waves significantly affect sediment distribution and coastal morphology. Wind alone exerts an influence through aeolian transport. Air temperature and solar radiation can affect lagoonal water temperature which in turn affects biological productivity and sediment diagenesis.

Extremes of weather such as those experienced during a tropical cyclone can cause catastrophic changes in coastal morphology and sediment distribution. It is clear that these major storms create the most perceptible changes in the natural physical environment of Ngatangiia Harbour and Muri Lagoon. A higher frequency of storms need not result in more reef flat sediments. The violence of storms relative to normal fair-weather conditions influences the extent of damage; the length of time after a cyclone and before a subsequent storm influences the degree of stabilization of reef-top storm deposits and hence their chances of preservation (Scoffin, 1993).

1.3 Geology and Physiography of Rarotonga

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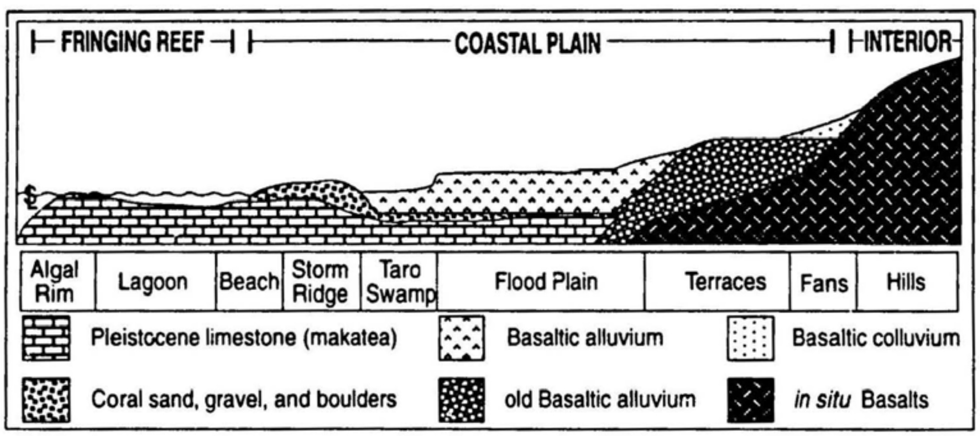

Figure 1.7 Schematic cross section of Rarotonga showing the major physiographic units and lithology (after Leslie, 1980).

The interior uplands exhibit all the features of an extinct Pacific Basin volcano. The razor-backed ridges separating deep valleys result from the erosion of the basement volcanic rocks. The volcanic rocks evolved initially from basaltic eruptions to later eruptions of differentiated lava accompanied by explosive activity and satellite cone formation. The volcanic rocks can be divided into two main eruptive types, basaltic and phonolitic, based on composition, mode of occurrence and age. No remnants of the original cone slope have survived and erosion has reduced the volcano to a residual mountain (Wood and Hay, 1970). Some hills are remnants of satellite cones. One, Raemaru Hill, resulted from a late eruption and quite possibly deflected the Avana River from an initial southern radial course to a transverse easterly course. Other striking examples of Rarotonga's volcanic history are the near vertical crags, pillars and aiguilles which Wood and Hay (1970) suggest were formed because their core of basalt and scoria has been intruded by weather-resistant basaltic dykes.

Alluvial fans and terraces at the base of the interior uplands form from the weathering of the volcanic rocks. Wood and Hay (1970) divided the Niakoa Gravels, consisting of weathered gravel deposits, into an upper and lower terrace and alluvial fan deposits. Both the lower terrace and the fan deposits are commonly truncated at their seaward edge to form steep faces, 7.5 m above swampy depressions known as the Taro Swamps.

The coastal plain is that portion of Rarotonga bounded landward by the alluvial deposits and seaward by the reef flat. Its width varies from 0.5 km on the north and west to 1.5 km on the south and east of the Island. The margin can be subdivided into a coastal plain and a fringing reef (Richmond, 1990). The coastal plain consists of the Taro Swamps and a raised ridge of coral sand and gravel. The fringing reef consists of beach deposits, inner and outer reef flat and the reef crest and fore reef zones.

The Taro Swamps are flat-bottomed areas less than one metre deep and several hundred metres wide. They effectively trap material being shed from the fans and terraces and are generally very poorly drained (Leslie, 1986). It has been reported that a "hard pan" or "hard ground" exists at the base of the Taro Swamps in the vicinity of the airport (Tony Utanga, per. comm., 1991).

A ridge of unconsolidated coral sand, up to 1 m thick with underlying carbonate sand and gravel, is the dominant feature of the coastal plain. The ridge varies in height above the modern storm beach from 1.5 m at Ravera to 2.2 m at Matavera and 4.2 m at Black Rock (Wood and Hay, 1970). It has been modified extensively by human activity. Portions of the main road run along the crest of the ridge which is thought to be a storm-generated rubble bank which sits on older reef flat limestone. Wood and Hay (1970) report C^{14} ages of between 3,510 and 1,235 years before present (yrs B.P.) for this ridge.

Marshall (1930) described the beaches of Rarotonga as dazzling white sand formed of fragments of the various organisms that grow on the reef and in the water outside of it. The beaches are generally composed of carbonate sand with terrigenous clastics near stream mouths and volcanic outcrops. Sediment texture shows a tendency toward finer grain size along the south and west coasts and coarser grain size along the north and east coasts. There is an inverse relationship between grain size and the width of the reef flat (Richmond, 1990). In non-storm conditions the beaches are subject to wave attack during high tides. At one-third plus or minus high tide, the waves are limited by breakage on the reef. Wave energy at the beach is less where the reef flat is widest. The beaches are subject to significant modification during cyclones.

Exposed beachrock was found at a number of locations along the modern strand line. Beachrock is formed in the intertidal to supratidal zone in response to tidal fluctuations by the cementation of clastic material through CO_2 degassing (lowering P_{CO_2}) thus initiating the precipitation of calcium carbonate (Morse and

Mackenzie, 1990). *In situ* beachrock was observed south of Muri Lagoon in the supratidal zone. Weakly cemented, medium grained beach sand was observed just landward of older exposed beachrock.

Richmond (1990) described the development of small flood plains traversed by major streams and the development of small deltas formed at the mouths of larger streams. The deltas generally consisted of terrigenous material and are reworked by longshore currents, resulting in lag gravel deposits.

Richmond (1990) subdivided the reef flat into the inner reef flat and the outer reef flat. The distinction is related to wave energy levels: the inner reef flat is a lower energy environment. Sand sized material, in places up to 1.5 m thick directly overlies algal pavement, but in general the sediment cover is less than 1 m. The sediment is dominated by calcareous algae, mollusc, echinoderm, and coral fragments. The outer reef flat is subjected to higher wave energy levels and commonly consists of an algal pavement with coral debris on top. Sediment cover is generally thin or absent.

Observations over a four week period by the author indicate that water circulation over reef flat areas is likely a direct result of open ocean water being pushed over the reef crest, flowing towards the beach, and being deflected along the shore to flow out the reef passage. Holden (1992) shows that both tides and waves influence reef flat circulation with the latter dominating.

The reef crest consists of encrusting coralline algae with sediment infilling cavities within in the reef framework (Marshall, 1930). The reef crest and portions of the outer reef flat are subaerially exposed during low spring tides.

The reef front is seaward of the reef crest and is populated by massive and branching corals. The fore reef is seaward of the reef front and is characterized by spur and groove topography. A fore reef terrace occurs between 17 and 20 meters water depth. The terrace extends seaward approximately 600 m (Lewis et al., 1980).

The physiography of the Ngatangiia Harbour and Muri Lagoon area is characterized by a significant widening of the reef flat from north of the Avana Passage, where it is less than 100 m wide, to just under 1000 m wide south of the study area (Fig. 1.8; Plate 1.1)(Appendix I). The inner reef flat is bounded to the west by an undulating shoreline broken by two streams, the Avana and the Turangi. Seaward, the Pacific Ocean bounds the reef except for the Avana reef passage. The most prominent land forms in the area are the motus or reef islets. From north to south they decrease in size and are named Motu Tapu, Oneroa, Koromiri, and Taakoka. They are approximately 3 m above mean sea level and are composed of cemented coral block rubble and sand. There are a number of artificial structures including the Ngatangiia seawall and numerous V-shaped fish traps in the harbour and channel.

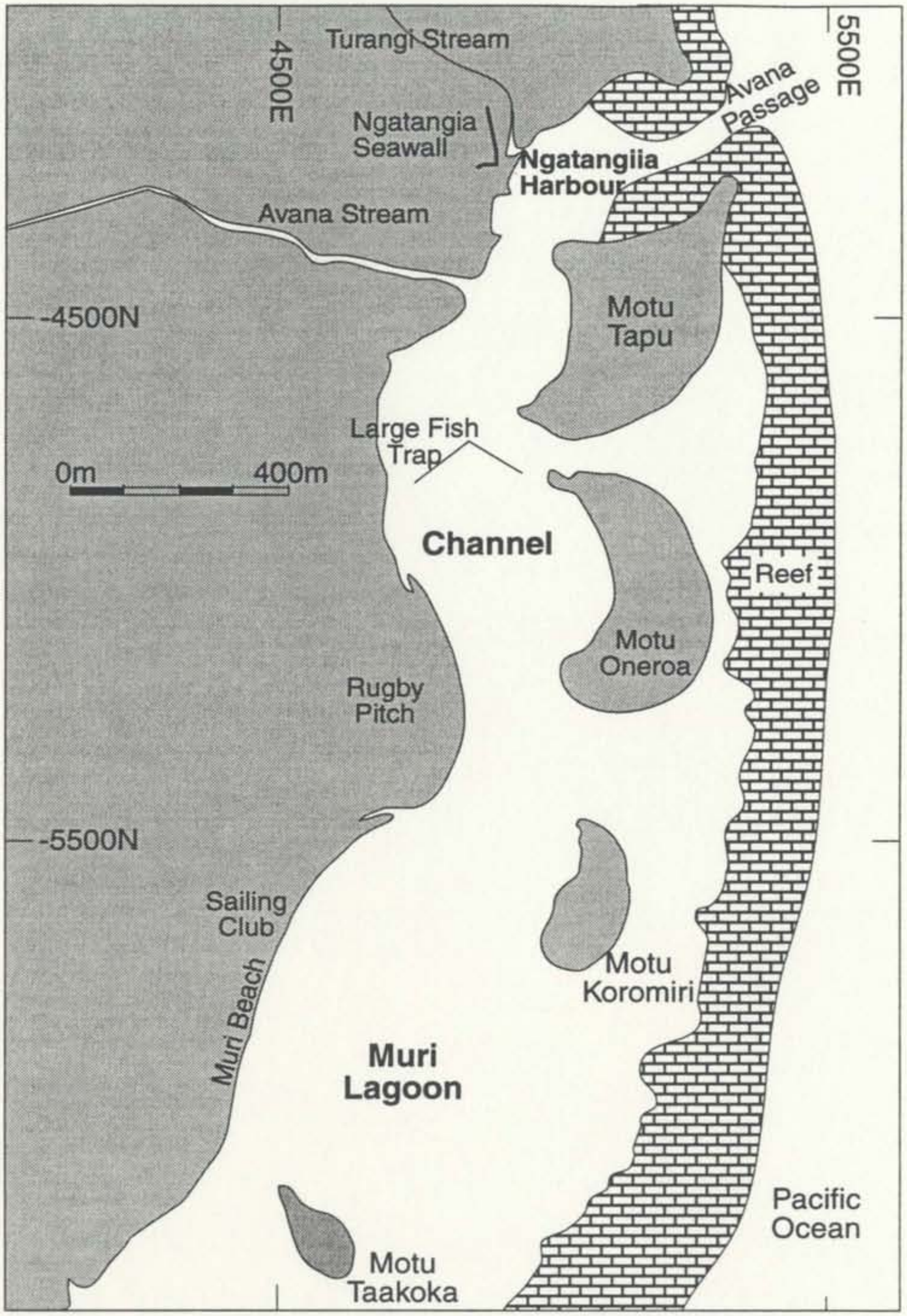

Figure 1.8 Location of the major features of Ngatangiia Harbour and Muri Lagoon.

Plate 1.1 Composite aerial photograph of Ngatangiia Harbour and Muri Lagoon. Scale bar is 200 m.

1.4 Regional Physical Oceanography

1.4.1 Ocean Currents

Rarotonga lies just south of the South Subtropical Current. This results in a southwest or westerly flow at Rarotonga, with current velocities of 0.5 - 1 kts (Thompson, 1986). The average surface water temperature in the vicinity of Rarotonga ranges from 28° C in January and February to 24° C in July and August.

1.4.2 Wave Climate

Predominant wave direction around the Southern Cook Islands is from the east or southeast, with more than 90% of the waves less than 4 m in height (Thompson, 1986). Higher waves are generally associated with storm events and originate to the north or northeast of the island. Wave rider buoy measurements east of Rarotonga recorded between July 1987 and January 1991 indicate that the significant wave height (average height of the highest one-third of all waves measured) was 2.2 m with an average period of 9.4 seconds (Oslen et al., 1991).

1.4.3 Tides

The University of Hawaii Sea Level Centre maintains a tide gauge at Avarua (Wyrtki, 1991). Tide gauge data for December 1990 and January 1991 is shown in Figure 1.9. Tides were semi-diurnal with fourth nightly lunar cycles. The tide had a maximum range of 1 m. Holden (1991) calculated a maximum 1.1 m range for the astronomical tidal cycle of 18.6 years. During this study, tide data was also collected from a water level recorder in Muri Lagoon and showed a tidal range of 0.6 m.

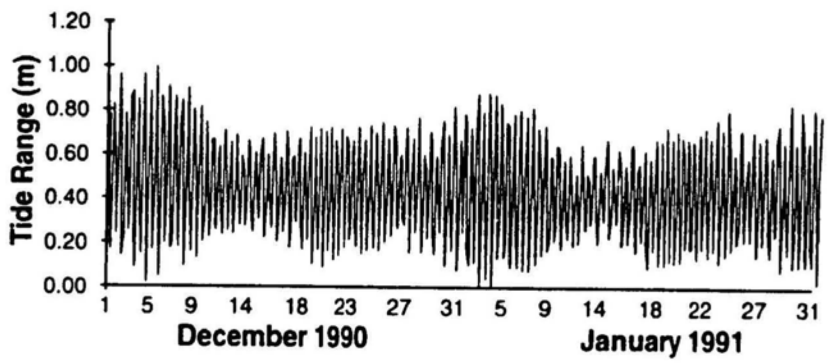

Figure 1.9 Plot of tides for Rarotonga during December 1990 and January 1991 (Wyrtki, 1991).

1.5 Previous Work

1.5.1 Rarotonga

The first geological map of Rarotonga was published by Marshall in 1930. He documented the physiography and geology of the island and the fringing reef. Subsequent geological work describing the physiography, stratigraphy and sediments of the Cook Islands was completed by Wood and Hay of the Geological Survey of New Zealand in 1970. Leslie (1980) published a soil survey which classified the soils of Rarotonga on the basis of underlying rock type and geomorphology. Gary Thompson is preparing a Ph.D. Thesis at Memorial University of Newfoundland on the geology and geochemistry of Rarotonga.

Since 1980, numerous geological studies have focused on the coast. Lewis et al. (1980) documented channel fill sediment for aggregate resource potential. Burne (1983) and Richmond (1990) published surveys on the coastal morphology. Investigations related to sea level change have been completed and most recently Woodroffe et al. (1990) reported on the Holocene emergence of the Cook Islands.

Crossland (1928) described the coral reefs of Rarotonga in comparison to those of Tahiti and Moorea. He noted that the fringing reef of Rarotonga is much narrower than that of either Tahiti or Moorea. He also cited evidence for significant shoreline accretion on the north coast of Rarotonga. Paulay (1985) documented coral reef diversity. Biogeological studies of particular interest to Ngatangiia Harbour and Muri Lagoon include Stoddard and Fosberg (1972) who reported on the flora of the motus and Scoffin et al. (1985) who studied coralline algae in Muri Lagoon.

Two recent programs provide information on oceanographic conditions at Rarotonga. The University of Hawaii's ongoing sea-level program maintains a tide gauge at Avarua, linked via satellite to a main database in Hawaii. A program sponsored by the Government of Norway maintained a wave rider buoy off the coast at Ngatangiia for a period of three years to assess the potential for wave power. Wave data have also been collected by the New Zealand Oceanographic Institute off the north coast of Rarotonga.

1.5.2 Ngatangiia Harbour and Muri Lagoon

The majority of site specific work in the Ngatangiia Harbour and Muri Lagoon area has involved the study of physical environmental parameters (Table 1.2).

Table 1.2 Summary of investigations in Ngatangiia Harbour and Muri Lagoon.

INVESTIGATOR	YEAR	DISCIPLINE	TASK
Shepard	1948	land survey	bathymetry
Stoddard	1972	biogeology	botany, geomorphology
Kirk	1980	geology	bathymetry, sampling, currents
Gauss	1981	geology	bathymetry
Carter and Steer	1984	engineering	bathymetry, oceanography
Brill	1985	land survey	bathymetry
Scoffin et al.	1985	biology	sampling, mapping
Collins	1990	geology	bathymetry, sampling, mapping
Riedel and Byrne	1990	engineering	observation
Holden	1991	engineering	oceanography
Collins and Holden	1991	geology	bathymetry, mapping, sampling

The earliest recorded bathymetric survey of the Harbour was completed in 1948 by a land surveyor named Shepard. He completed 10 survey lines between the village of Ngatangiia and Motu Tapu. Shepard used standard land survey techniques with a compass, chain and sounding line (O. Peyroux, pers. comm., 1990). In 1979 the Government of the Cook Islands and the South Pacific Commission contracted Dr. Bob Kirk of Cantebury University, Christchurch, to investigate beach erosion and sedimentation in Ngatangiia Harbour and Muri

Lagoon. During his investigation echosounding profiles were collected but, due to lack of reliable positioning, a bathymetric map was not published (Kirk, 1980). Bottom samples were also collected and depth to bedrock estimated using a water jet probe. The results of this investigation (Kirk, 1980) indicate that flushing of the lagoon was impaired by the progradation of the Avana Stream delta. This report suggests that delta development was enhanced by poor land use practices in the Avana Stream catchment area, resulting in high soil erosion. The report recommended dredging of the harbour to increase the flushing of the hagoon.

A bathymetric survey of the harbour was completed as part of a larger programme of seabed studies in the nearshore areas of Rarotonga (Gauss, 1981). A total of 21 closely spaced profiles were made in the harbour between the mainland and Motu Tapu and the northern tip of Oneroa. Additional bathymetry and sub-bottom profiles were made offshore of the harbour entrance. No samples were recovered from the harbour.

In February of 1984 a series of 18 lines were surveyed by R. Brill between the mainland, Oneroa, and Koromiri using land survey techniques.

In May 1984 the area was investigated by Carter and Steer, who undertook a baseline study for coastal management. Their report specifically addressed issues of lagoon fishing and coastal erosion (Carter and Steer, 1984). As part of their study an analysis of tropical cyclones, winds, storm surge and reef current was made. A bathymetric survey of the channel and lagoon area was completed and sediment samples were collected. The report concludes that sedimentation in the harbour had contributed to a reduction in the flushing of the lagoon. It suggests that dredging of terrestrial material in the harbour would lower the water level in the lagoon, reduce the wave attack on the lagoon beach and thereby minimize erosion.

Following this investigation the dredging of Ngatangiia Harbour began. A causeway was constructed into the channel between the mainland and Motu Tapu, and used as a platform for the dredging. The causeway appeared to deflect channel waters onto the beach at Motu Tapu causing erosion of the beach (D. Dorrel, per. comm., 1990). Sporadic dredging continued in the harbour area until 1988 when the Conservation Service of the Cook Islands reviewed the dredging site and noted that areas designated as "no dredging" were , in fact, being dredged. Concern was expressed about the potential for sediment instability along the shoreline (V. Tupa, per. comm., 1990).

In August of 1990 the South Pacific Applied Geoscience Commission (SOPAC) contracted G. Byrne of Riedel and Byrne Engineering Consultants of Melbourne, Australia to advise on a number of proposed harbour development schemes (Riedel and Byrne, 1990). The report addressing Ngatangiia Harbour and Muri Lagoon indicated that a reassessment of the recommendations of the Kirk Report was required. In particular, quantitative analysis of the circulation in the Lagoon was needed together with a further study of the extent and nature of the "hard pan". An estimation of the rate of infilling of the Lagoon was also recommended.

Based on the Riedel and Byrne 1990 report a course of action was initiated. The first study was an analysis of the circulation in the lagoon-channel-harbour system to determine the rate of flushing. In December of 1990, current meters were placed in Muri Lagoon and Ngatangiia Harbour to record data simultaneously with a wave rider buoy set approximately 1 km offshore (Collins and Holden, 1991).

The results indicated that there is no restriction in lagoonal flushing (Holden, 1992). The second study was an investigation of the sediments and bathymetry. Both of these investigations provide the data base for this thesis.

1.6 Objectives

Previous scientific and engineering investigations in the Ngatangiia Harbour and Muri Lagoon system have been specific studies designed to address issues related to development. These issues have included harbour development, aggregate dredging, environmental considerations such as pollution, and living resource issues such as the fishery. However, to fully understand the relationships and feed-back mechanisms at work in this environment, an interpretation of a suite geological, oceanographic and biological data is necessary. The purpose of this study is to build upon the previous, more "applied", site-investigations by re-analyzing existing data and incorporating new data. This study is intended to be scientific in nature thereby allowing the results to be scrutinized in the context of the broader scientific literature.

The prime objective is to characterize the sediment dynamics in this tropical coastal lagoon setting. To achieve this objective, knowledge of the changes in sediment distribution through recent time and present distribution patterns in response to prevailing oceanographic conditions are required. The specific objectives are threefold; to investigate record of bathymetric change, to characterize the oceanographic conditions, and to describe the sediments.

- To establish spatial and temporal trends in sediment deposition and/or erosion at Ngatangiia Harbour and Muri Lagoon through the recent past by comparing historical bathymetric records.

- To present the most recent bathymetric data for the area in a form suitable for planning purposes.

- To characterize the wave climate in Muri Lagoon by applying the deep water wave data and bathymetric data from the study area to models developed for the prediction of wave transformation over coral reefs.

- To characterize the unidirectional currents in Muri Lagoon based on data collected from four current meter stations in the lagoon.

- To describe the various depositional environments and the sedimentary units of the Ngatangiia Harbour and Muri Lagoon system.

- To describe the sediment constituents and outline the hydrodynamic controls on their distribution.

- To examine the stability of the sediments in terms of the conditions by which movement is initiated and particles transported, and to determine the frequency and magnitude of movement.

CHAPTER 2 METHODS

2.1 Bathymetry

2.1.1 Data Collection

Table 2.1 is a summary of the survey areas, year, surveyors and methods used to document the changes in bathymetry. All water depths reported in this study are given with respect to mean sea level relative to the tide staff at Avarua Harbour which was established in 1977.

Table 2.1 Summary of the bathymetric surveys used in this study.

Location	Year	Surveyor	Survey Method
Harbour	1948	Shepard	Level, compass
Harbour	1981	Gauss	Echo sounder, microwave positioning
Harbour	1990	Collins	Echo sounder, dead reckoning
Channel	1985	Brill	Level, compass
Channel	1990	Herman	Level, compass
Lagoon	1984	Carter and Steer	Echosounder, sexton
Lagoon	1991	Manuela	Level, compass

2.1.1.1 Harbour 1948

The 1948 survey was completed by the Survey Department, Government of Cook Islands in August 1948 (Shepard, 1948). The original data exist as raw survey field records and a plot of the survey lines drawn at a scale of 1 chain to 1 inch (1:792). Ten lines totaling 2.25 km were surveyed (Fig. 2.1). Coastline information was minimal and consisted of the northwest shore of Motu Tapu and the east shore of the Ngatangiia Harbour. The original survey could not be tied into existing benchmarks so positions were visually scaled using the coastline information on the original plot. A best fit approximation was used to position the data. The lateral error of the data is assessed at approximately 10 m. Spot depths were collected by sounding line (O. Peryoux per. comm.).

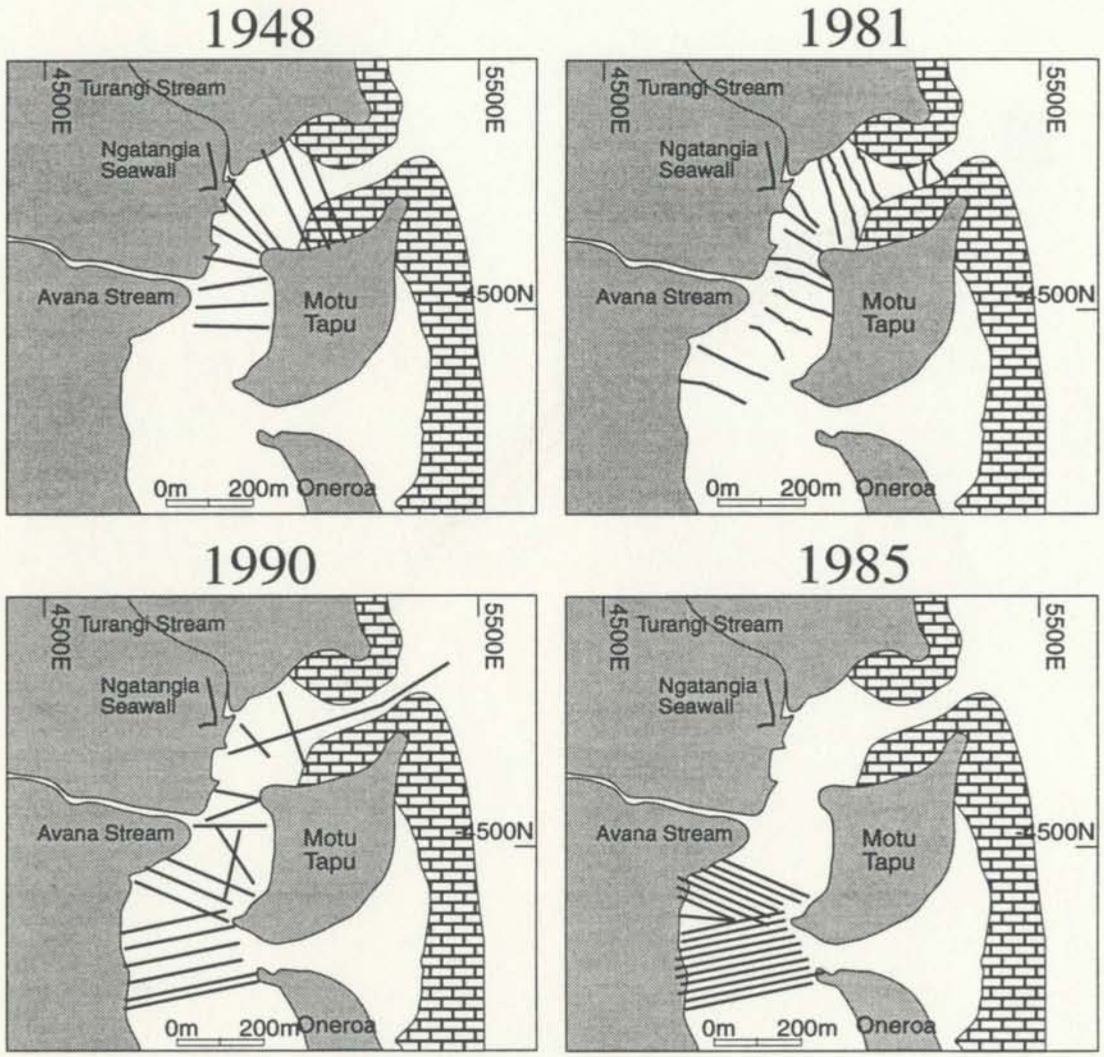

Figure 2.1 Survey lines in the harbour and channel completed during the years 1948, 1981, 1990, and 1985.

The survey datum was the estimated high water mark of spring tide and was given an arbitrary value of 100 feet (30.48 m). Spot depths were reduced to mean sea level under the assumption that there was negligible variation in sea level due to eustatic and isostatic changes over the period 1948 until today and that the high water level for August 1948 was similar to the August 1990 level.

An indication of the precision of bathymetric surface can be obtained by computing the lateral spacing of data points. In this dataset, a total of 130 data points were digitized from a blue line copy of the original map. The spacing was one spot depth for every 17 m.

2.1.1.2 Harbour 1981

This survey was completed April 6 - 26, 1981 as part of a series of nearshore seabed investigations (Gauss, 1981) (Fig 2.1). Positioning was accomplished using a Del Norte trisponder positioning system. The data were collected using a Raytheon DE-719 echosounder with chart recorder (Gauss, 1982). The reported horizontal and vertical error was 3 m and > 1 m respectively. The original datum was the zero mark of the Avarua tide gauge which was reported to be 0.47 m below mean sea level. Twenty-one lines totalling 3.8 km were surveyed. The original depths were plotted at a scale of 4 chains to 1 inch (1:3,168). A total of 180 data points were digitized which averages one data point for each 21 m of survey line.

2.1.1.3 Harbour 1990

Bathymetric data were collected using a Raytheon DE-719 echosounder (Fig. 2.1). The digital data were uploaded into an Apple Macintosh portable computer via an RS-232 and Appletalk cable. The data were presented on paper in metre scale and as an ASCII format file on a 3.5 inch floppy disk. The system was mounted in an open fiberglass boat, 18 feet in length and powered by a 40 horsepower outboard motor. The transducer was secured by means of 1/4 inch rope rigged to a cleat over the port gunwale slightly aft of amidships. The base of the transducer was held by a line to the bow. The system was powered by a 12 volt car battery. Positioning for the survey was by dead reckoning using low level vertical color air photographs (scale 1:3,183). Approximately 2 line kilometers were surveyed. Horizontal and vertical error was estimated to be 10 m and <1 m respectively. The datum used was mean sea level and tidal corrections were applied and tied to mean sea level by the predicted tides for Avarua. Spot depths were picked from the original chart record. 181 data points were digitized representing one depth point for each 11 m of survey line.

Plate 2.1 Echosounder attached to a portable computer in the bow of the small boat used to gather bathymetric data in from Ngatangiia Harbour.

2.1.1.4 Channel 1985

In February 1985 the Cook Islands Survey Department completed a land-based survey of the channel in preparation for dredging. Horizontal control was based on the

Cook Islands geodetic mark OCB 1 and all levels were reduced to mean sea level. The horizontal and vertical error was less than 2m and 0.1m respectively. A total of 18 lines totaling 3.64 line km were run (Fig. 2.1). A total of 217 data points were recorded which represented an average of one point for each 17 m of survey line.

2.1.1.5 Channel 1990

In April 1990 the Cook Islands Department of Trade, Labour and Transport completed a land-based survey of the channel to assess the effects of dredging operations (Fig. 2.1). Every second line, originally surveyed during 1985, was resurveyed. The survey lines coincided with every second line surveyed by Brill in 1985. Levels were tied to the Cook Islands survey peg located near the seawall at Ngatangiia Harbour. The datum used was the Cook Island datum OCB-1 reduced to mean sea level. The horizontal and vertical error was less than 2 m and 0.1 m respectively. A total of 9 profiles were surveyed representing 2.29 line km. A total of 184 data points were recorded for an average of 1 point for each 12 m of survey line.

2.1.1.6 Lagoon 1984

In May and June of 1984, the Committee for the Coordination of Offshore Prospecting - South Pacific (CCOP/SOPAC) completed a bathymetric survey of Muri Lagoon and the channel between the Ngatangiia Harbour and Muri Lagoon (Carter and Steer, 1984). The data were recorded using a Raytheon DE-719 chart recording sounder. Positioning was effected by running lines from marks situated on the west side of Muri Lagoon and positioning along line by sextant readings from a mark on the north side of the lagoon. The survey datum was a Cook Island control point brought forward from a benchmark on the main road. Values were reduced to mean sea level. Estimated horizontal and vertical error was 5m and < 1m respectively. A total of 25 lines equalling 7.66 line km were completed (Fig. 2.2). A total of 357 data points were recorded representing an average of one point for each 21 m of survey line.

Plate 2.2 An example of the land-based compass and level survey technique used to record spot depths from the channel and lagoon.

2.1.1.7 Lagoon 1991

As part of the present study, a bathymetric survey of Muri Lagoon was completed by the Survey Department of the Cook Islands government (Fig. 2.2). The survey covered the same areas as Carter and Steer (1984) using land-based surveying techniques. A baseline was established from control points on the main road. The datum was the Cook Island datum brought forward from Benchmark 12 No. 6 and reduced to mean sea level. Estimated horizontal and vertical error was 2 m and 0.1 m respectively. A total of 13 lines were completed equalling 5.26 line kilometres, and 192 spot depths were recorded representing an average of one point for each 27 m of survey line.

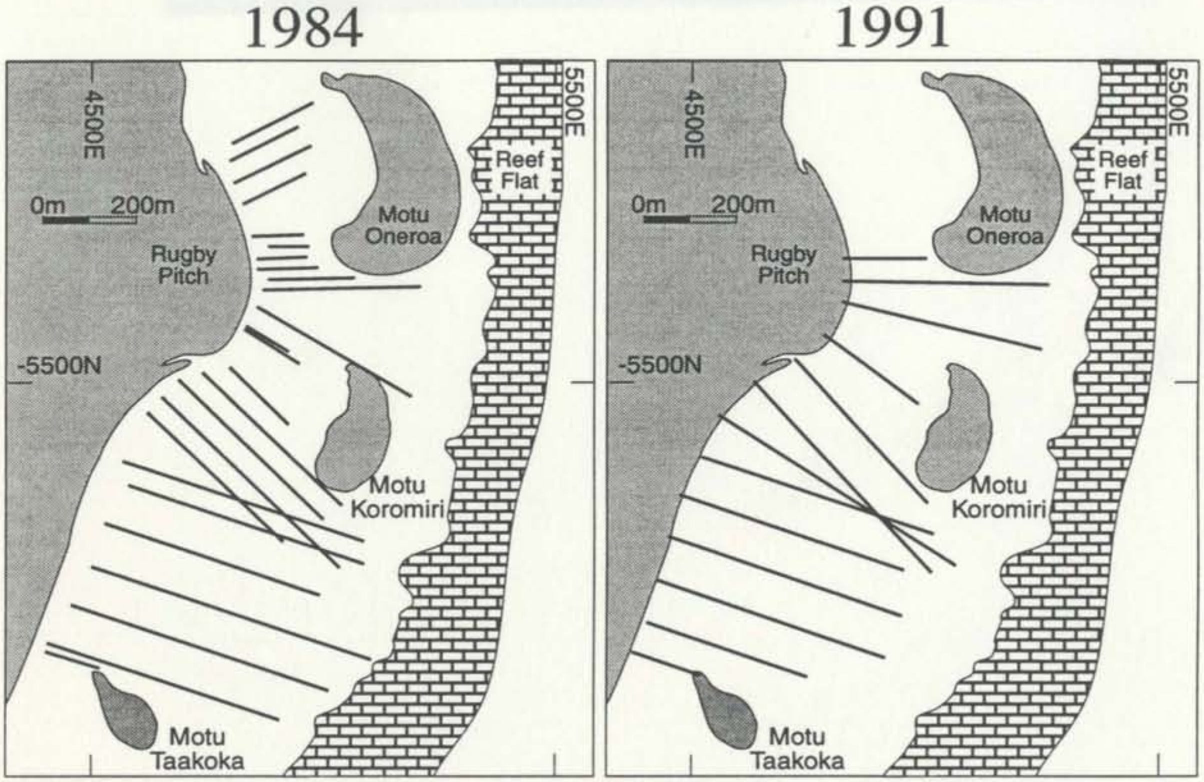

Figure 2.2 Survey lines in the lagoon completed during the years 1984, and 1991.

2.1.2 Data Reduction

Figure 2.3 is a flow-chart summarising the method of data reduction. Raw data, either in the form of survey records, bathymetric maps or echosounder records were digitized to produce data sets containing x, y, and z, where x is the easting, y is the northing (on the Cook Islands local transverse mercator grid) and z is the depth with respect to mean sea level. A digital base map was prepared based on the 1:3,000 UTM cadastral charts G3 and G4 of the Cook Island Survey Department. The grid is local with the origin being 7 654 748.668m N, 419 560.683m E, UTM Zone 4. Portions of the base maps were revised using color air photographs 1 - 6 of run 8/88 and 1-2 of run 91c, Cook Islands Survey Department.

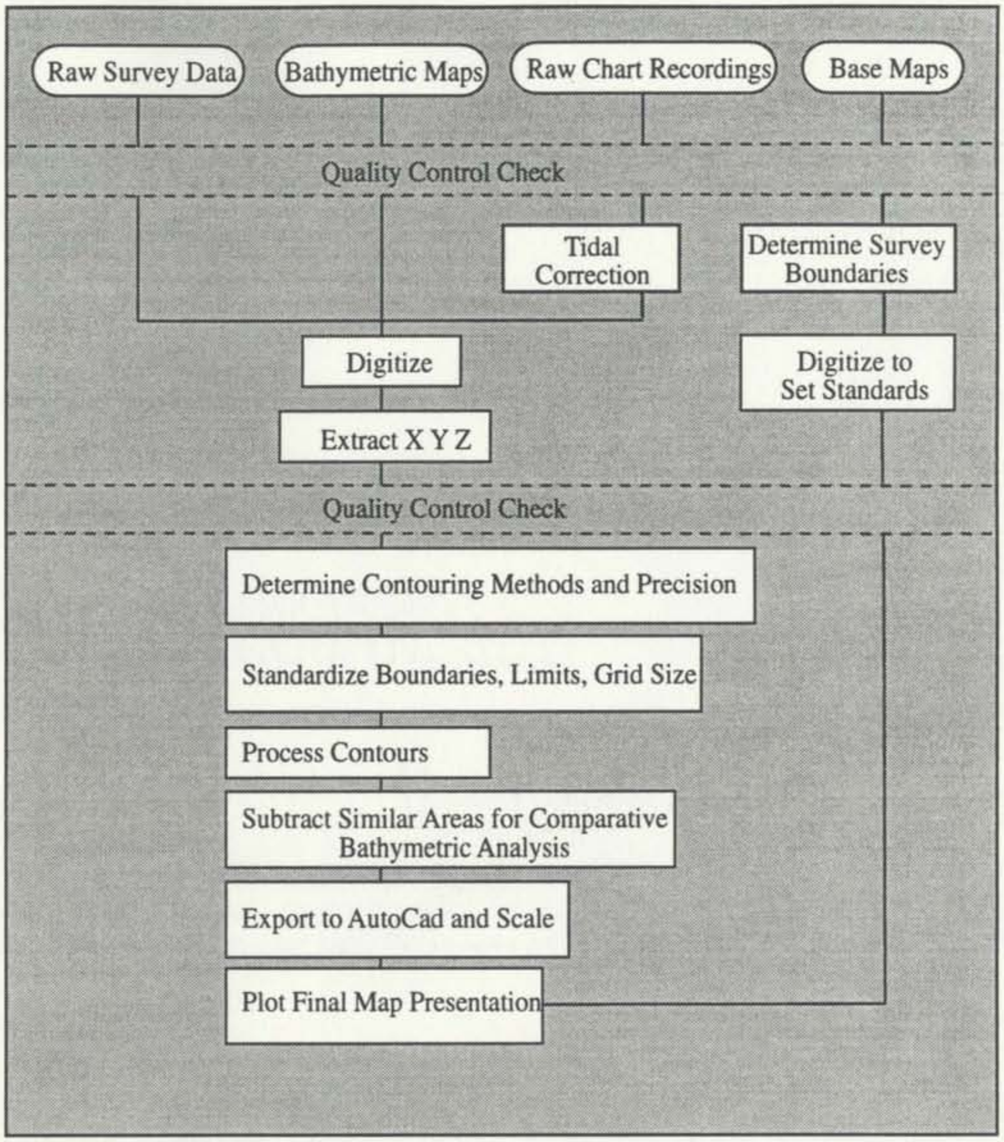

Figure 2.3 Flow chart for the processing of bathymetric data.

Basemaps were digitized to the following standard. The original base was kept in an environmentally controlled space 2 days prior to digitization. Once acclimatized, it was secured to a GTCO 3648 digitizing tablet. The tablet was linked to an IBM compatible 486 PC using AutoCad software. Boundary lines on the cadastral map were digitized at a uniform increment of 1 m. Areas such as reef edge not documented on the cadastral chart were digitized from smaller scale maps at a uniform increment of

3 m. Strand lines from low level air photographs, were digitized at increments of 1 m, generally taken at the mid point between water mark and vegetation line. Artificial features such as sea walls and fish traps were also digitized.

A custom AutoCad LISP (AutoCad's own programming language) was written to allow the spot depths and corresponding locations to be stored and extracted as digital data. The digital survey data were gridded and contoured using a surface modeling software package called Surfer™. A grid of 25 x 25 was used to allow a spacing between 15 and 20 m for each nodal point. Numerous contouring algorithms are available to generate uniform grid points from random data (Banks, 1991). An inverse distance method was used and the nodal value was calculated from the 10 nearest points less than 9.8 m from the node. The method is given by the formula:

$$Z = \frac{\sum_{i-1}^{\eta} Z_i/(\partial i)^2}{\sum_{i-1}^{n} 1/(\partial i)^2} \qquad (2.1),$$

where Z_i is a neighboring point, ∂ is distance, and η is the number of Z elements.

In each case the resulting contour map is adjusted for anomalies such as fish traps and other seabed features. Equivalent gridding parameters must be used to allow comparison of modeled surfaces. This was accomplished by ensuring the number of grid lines and the limits of the grid were equal for each data set. The areas with overlapping data suitable for this analysis are shown in Figure 2.4.

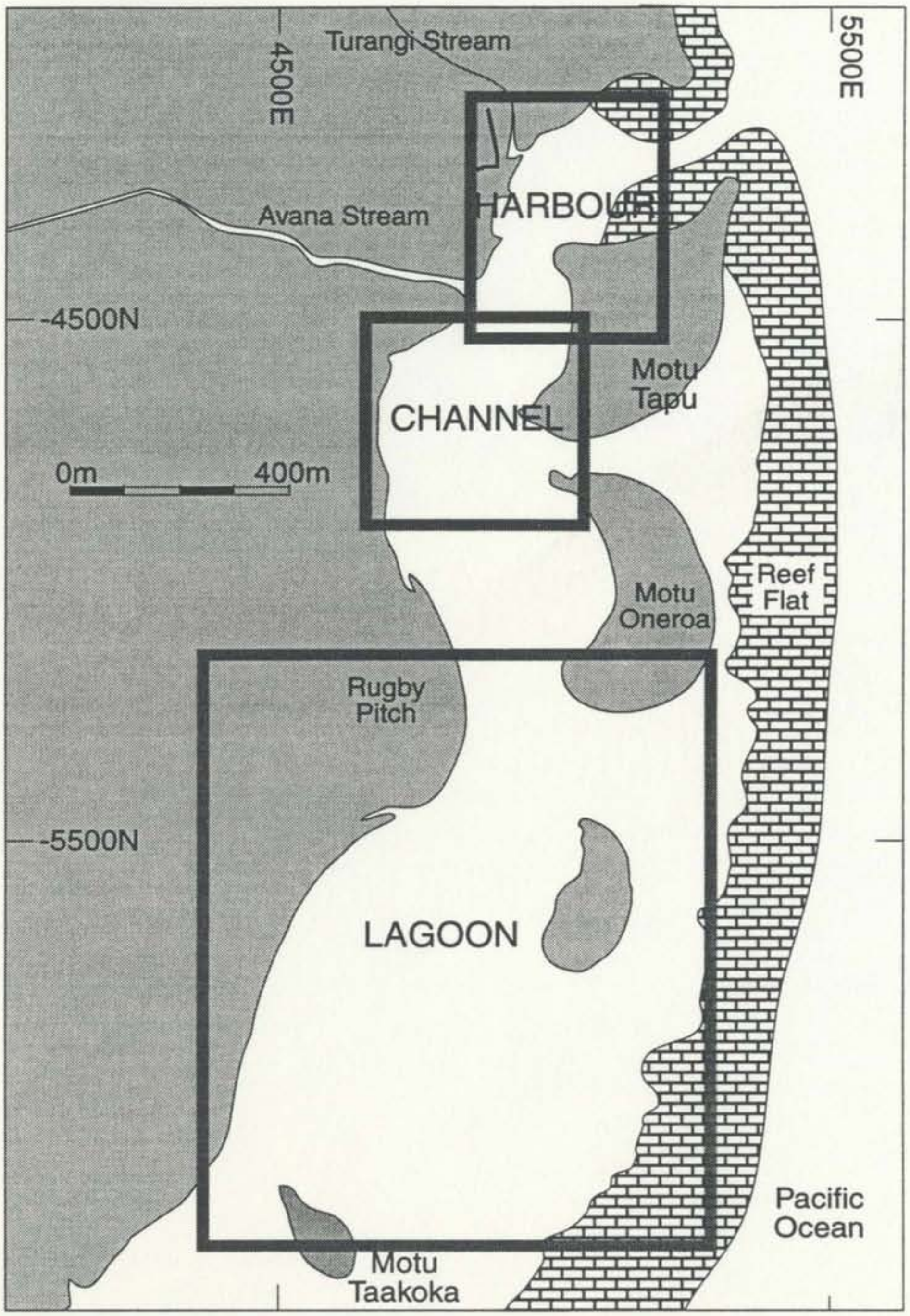

Figure 2.4 Areas of bathymetric comparison.

Once generated, the contour lines were smoothed by a cubic spline method which interpolated data points between grid elements. In addition to the surfaces generated from individual data sets, plots of change in surfaces with time were produced by contouring the difference in bathymetry between the older and younger values at each nodal point.

The resulting plot, therefore, is not a bathymetric surface but a surface of net change from one survey to another. Positive values indicate net deposition and negative values indicate erosion. The contour maps were then exported from Surfer to AutoCad, sized to the appropriate scale, and plotted onto basemaps.

2.2 Physical Oceanography

Physical oceanographic data were collected as part of a multi-faceted study of Muri Lagoon and Ngatangiia Harbour. Wave data were collected as part of a program to assess the potential for wave power generation (Olsen et al., 1991). Current meter data were obtained as part of a program to assess the circulation patterns in the lagoon and harbour. The data were initially processed under contract to the New Zealand Oceanographic Institute. A report specifically addressing the flushing mechanisms was prepared by B. Holden in 1992. During the present study both the raw and processed data were analyzed as a basis for the description of sediment dynamics.

2.2.1 Data Collection

2.2.1.1 Waves

Three years of observations were compiled for a period from 1987 to 1991. A Datawell Waverider buoy was located approximately 1 km southeast of Muri Lagoon in approximately 200 metres water depth at 21° 15.4'S and 159° 42.5'W. The buoy sampled wave amplitude and period at 3 hour intervals. The final waverider deployment specific to this project collected data from November 30, 1990 to January 25, 1991.

2.2.1.2 Unidirectional Currents

Station 1 Ngatangiia Harbour

An Aanderra RCM-4 current meter was moored at the entrance to Ngatangiia Harbour (Fig 2.5). The mooring was set in a depth of 10 m with the current meter 3 m above the bottom (Fig 2.6). The mooring was rigged on the beach and carried out and secured to an anchor block located in 1.5 meters water depth. A line was taken to the anchor block from a 10 meter tug and the mooring was towed into deeper water. Two divers assisted by guiding the meter as it was brought into deeper water. Once in deeper water, the tug moved into position and the current meter assembly was lowered by hand, from the forward bollard, until it was on the bottom.

Plate 2.3 The current meter mooring placed at the entrance to Ngatangiia Harbour. The engine block anchor is at the far left centre; the float, enclosed in netting is at the water's edge and the author is holding the current metre.

A 60 m groundline was secured to the reef on the south side of the channel. The meter included sensors for temperature, conductivity, pressure, direction and speed. It was deployed on December 8, 1990 and retrieved January 23, 1991. The meter collected data from all 5 sensors until December 27, 1990 when the rotor ceased to function due to an entangled fishing net (Holden, 1992).

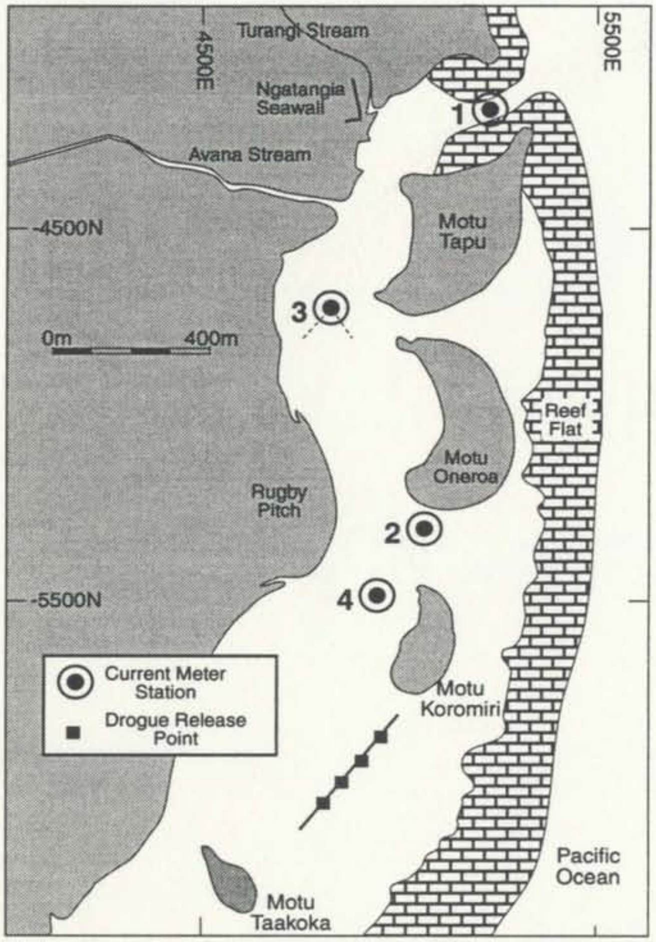

Figure 2.5 Location of current meter stations 1 - 4 (after Holden, 1992)

<u>Station 2</u> **Oneroa/Koromiri Gap**

A second Aanderra RCM-4 current meter assembly on a fixed bottom platform was deployed at station 2 , between Oneroa and Koromiri (Fig. 2.7). The meter was deployed at 2100 Universal Time (UT), December 8, 1990 and retrieved at 0300 UT, December 9, 1990 for a total of 30 hours. The assembly was secured by placing coral blocks on the base. At low tide the rotor of the current meter was 15 cm below the water surface.

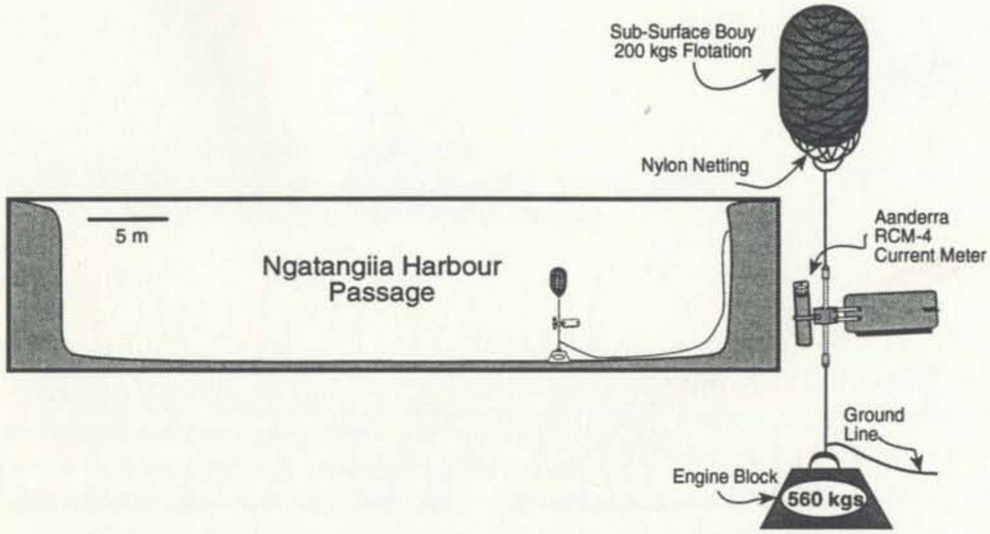

Figure 2.6 Configuration of current meter 1 and approximate location within the passage cross section.

<u>Station 3</u> Fish Trap

Station 3 was located at the weir of a fish trap located in the centre of the channel. The current meter was deployed at 1145 hrs. UT, December 9, 1990. It was recovered at 0345 hrs. UT on December 10, 1990 for a total of 16 hours of recorded data. The fin was removed and the current meter was lashed to an aluminum rod which extended across the head of the trap. At low tide the rotor was approximately 10 cm below water surface. For 2 hours, before and after low tide, the majority of the flow from Muri Lagoon passes through this weir.

<u>Station 4</u> Muri Lagoon

Station 4 was located at the deepest part of the channel between Koromiri and the Rugby Field. The current meter was deployed on 0400 hrs. UT December 10, 1990 and retrieved at 1600 UT on January 25, 1991 for a total of 46.5 days. The platform was held in position by coral blocks on its base. A line was also taken to a nearby coral head. The sensors were approximately 1 m above the channel floor. A float was secured to the platform to mark its position.

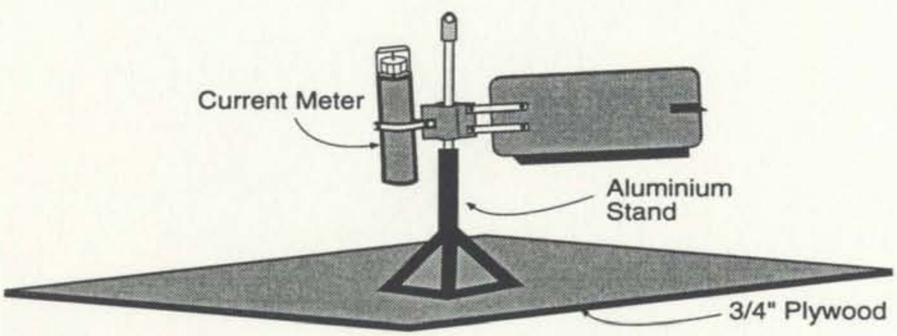

Figure 2.7 Schematic drawing of the platform-mounted current meter.

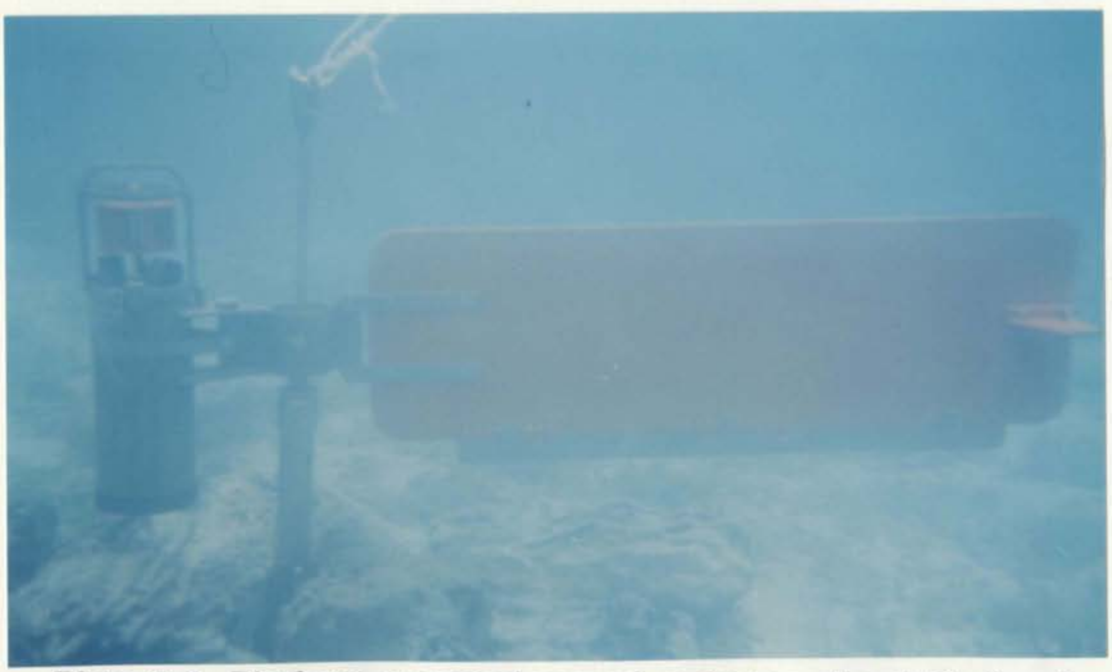

Plate 2.4 Platform-mounted current meter on site at Station 4.

2.2.1.3 Drogues

Window-blind drogues were used to track currents in the Muri Lagoon (Fig. 2.8). A baseline was established between the southeast end of Koromiri and the northeast end of Taakoka. The drogues were released at equidistant points on the line. Their progress was tracked and position determined by triangulation to points onshore. Two runs were made in December, 12/10/90 22:00 UT and 12/11/90 21:00 UT. A third run was made on 01/24/91 21:00 UT.

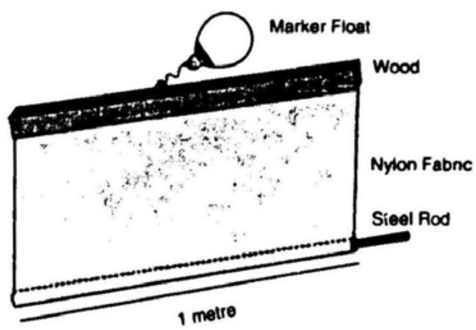

Figure 2.8 Schematic drawing of the "window-blind" drogues used to measure lagoon currents.

2.2.2 Data Reduction

The current meter data were transferred from data tape to a personal computer and preliminary processing was carried out using Aanderra software. The data were then transferred to the New Zealand Oceanographic Institute for further processing including error checking, de-spiking and tidal filtering (Holden, 1991).

2.3 Sedimentary Geology

2.3.1 Data Collection

Sample collection and reconnaissance scale geological mapping were the primary methods used to describe the sedimentary geology of Ngatangiia Harbour and Muri Lagoon. Samples were analyzed to obtain information on sediment composition and texture. This information was used to assess sediment transport. The mapping provided information on the spatial distribution of the sediment.

Sediments were collected from perceived discrete sedimentary units rather than from a random or uniform grid. Stoddart (1978) notes that reef sediments are generally stratified or zoned, and samples are best taken within such already recognized zones. Particular attention was paid to the coverage of the harbour and reef areas.

Sediment samples were collected from a boat using a pipe dredge measuring 45 cm in length by 10 cm diameter. A modified sample bag was mounted on the trailing edge of the pipe to allow capture and retention of fine sediment. The pipe dredge was used in areas where the sediment was less than 10 cm in diameter. Surficial samples were collected by hand in areas too shallow to be navigable by boat. Rock and subsurface samples were collected using a steel spade and rock hammer.

Mapping in submarine areas was accomplished by snorkeling traverses across the lagoon and harbour areas. Photos were obtained using a water-proof camera.

2.3.2 Data Reduction

Techniques used for sediment analysis are shown in Figure 2.9. The sediment was subdivided into respective grainsize classes. There was very little sediment under 0.03 mm (5 ø) so no further classification of this size range was necessary. As no analytical package suitable for statistical analyses of the size data was readily available, one was created using Microsoft Excel 3.0 spreadsheet software. The data were tabulated, and processed to output verbal and numerical description of the sediment sample with a graphical treatment of the data. The statistical parameters defined were: mean grainsize, sorting, skewness, kurtosis, by both graphical and moment methods. The individual sample grainsize information are given in Appendix II. Thin sections of selected rock samples were made. Whole grain mounts were made the of the 0.063 mm (4ø), 0.09 mm (3.5ø), 0.125 mm (3ø), and 0.180 mm (2.5ø) size classes. A minimum of two hundred grains from each sample were point-counted.

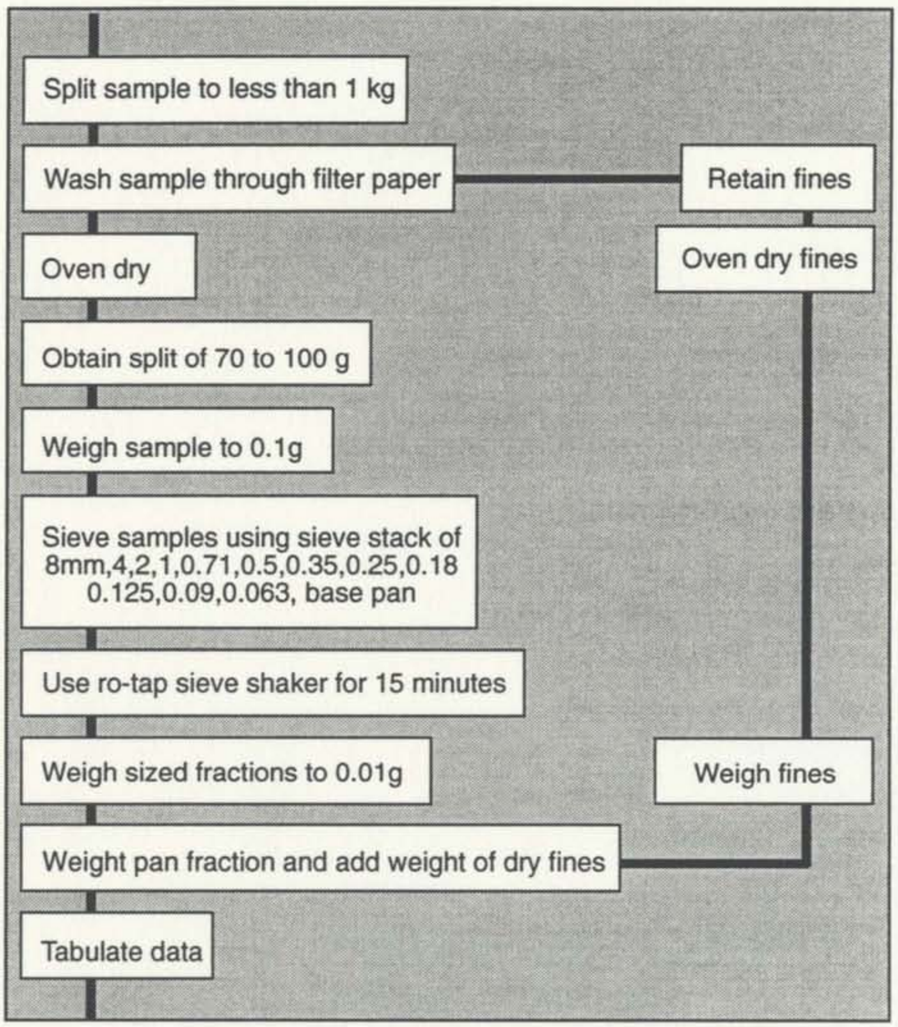

Figure 2.9 Flow chart showing the sample preparation and sieving procedure.

2.3.3 Mapping

Sample location and mapped features were plotted in the field on 1:3183 scale low level color air photographs (Appendix I). In areas where the low level photography were not available 1:50,000 black and white photographs were used. The data were transferred onto the digital base map by a method described in a previous section.

CHAPTER 3 BATHYMETRY

Historical changes in the bathymetry of Ngatangiia Harbour and Muri Lagoon are an important consideration when attempting to establish areas presently prone to erosion and deposition. Fortunately, the number of surveys in the area through the last fifty years provides an adequate data-set to assess such sediment depositional patterns. This chapter describes the bathymetry of the area at specific times and compares the differences in bathymetry over time to show patterns of deposition and erosion.

3.1 Data Reliability

In attempting to compare bathymetric data sets through time consideration must be given to a number of possible sources of error. Inherent in any bathymetric survey where an echosounder is used are errors resulting from the recording equipment and the dynamic sea surface. These errors are minimised by proper calibration of the equipment and accurate measurement of tides. The land survey techniques are generally more precise.

All surveys, with the exception of the Shepard (1948) harbour survey, tied the survey lines to the Cook Island survey datum. This means that comparison of the relative change in the depth of the floor of the lagoon, channel and harbour can be measured with reasonable accuracy. Errors may increase when using mean water level as a datum because this is subject to change through time. The following is a brief description of two phenomena which affect the position of mean water level.

Eustatic sea level refers to the level of a quasi-permanent volume of ocean water, and is distinguished from ephemeral variations associated with oceanic tides and temporal fluctuations due to climatic factors (Peltier, 1988). Presently, there is great debate on whether sea-level is changing and if so, by how much and at what rate. It is clear that the volume of water in the oceans has fluctuated during the Quaternary, mostly due to changes in the volume of continental ice . There have been many estimates of changes in eustatic sea level over the last 100 years with predictions for future sea level. Titus (1987) reports that a weighted average from all tide gauges in the world indicates that over the last 100 years global sea level has risen 10 to 15 cm. If this is true, sea level rise in the past 45 years would create a difference of less than 10 cm when comparing the 1948 and 1990 bathymetry. Peltier (1987) reports a steady increase of eustatic sea level during the Holocene. The rate and amplitude of the rise was probably in the order of 1 mm per 10 years to 8000 yrs B.P. This increase does not, however, represent a significant source of error in this study.

Areas of active tectonism, such as along the Western Pacific arc-trench system, show large variation in relative sea-level (isostatic) as the result of vertical displacement of the land (Woodroffe et al., 1991). Islands in intraplate areas, such as Rarotonga, show less vertical movement than those at plate boundaries. The dominant trend in the Cook Islands, for example, is one of subsidence due to crustal cooling (Woodroffe et al., 1991). The combination of eustatic and isostatic changes causes a transgression or regression of the shoreline. In the ten year period April 1977 to December 1987, the daily and monthly sea-level means for Rarotonga reveal no apparent changes in the reference level suggesting no perceptible change in relative sea-level over the 10 year recording period.

An additional potential source of error in the analysis may result from fluctuations of 15 cm or more in relative sea-level as the result of an El Niño event. Analysis of the timing of El Niño events throughout the last 50 years indicate that none of the surveys from Ngatangiia Harbour or Muri Lagoon coincided with such an event.

3.2 Historical Bathymetry

3.2.1 Harbour

Harbour depths in 1948 data ranged from 0.5 - 4.5 m (Fig. 3.1). Both sides of the reef passage were near vertical coral reefs rising from the passage floor. Two deeper areas existed on the north side of the harbour entrance. The first was over 4.5 m deep and the second, smaller in area, was over 3 m deep. The harbour bottom deepened to the north and west as far as the small delta at the mouth of Turangi stream. The harbour bottom shallowed near the NW point of Motu Tapu. Here the central passage was less than 1.5 m deep. The passage through the harbour and into the channel was everywhere greater than 1 m. The harbour bottom shallowed near the mouth of Avana Stream.

In 1981 data the depth of water in the harbour ranged from over 4 m in the reef passage to less than 0.25 near the mouth of the Avana Stream (Fig. 3.2). There was a pronounced channel, greater than 0.5 m deep, from the centre of the harbour SSE along the tip of Motu Tapu and east of the Avana Stream Delta.

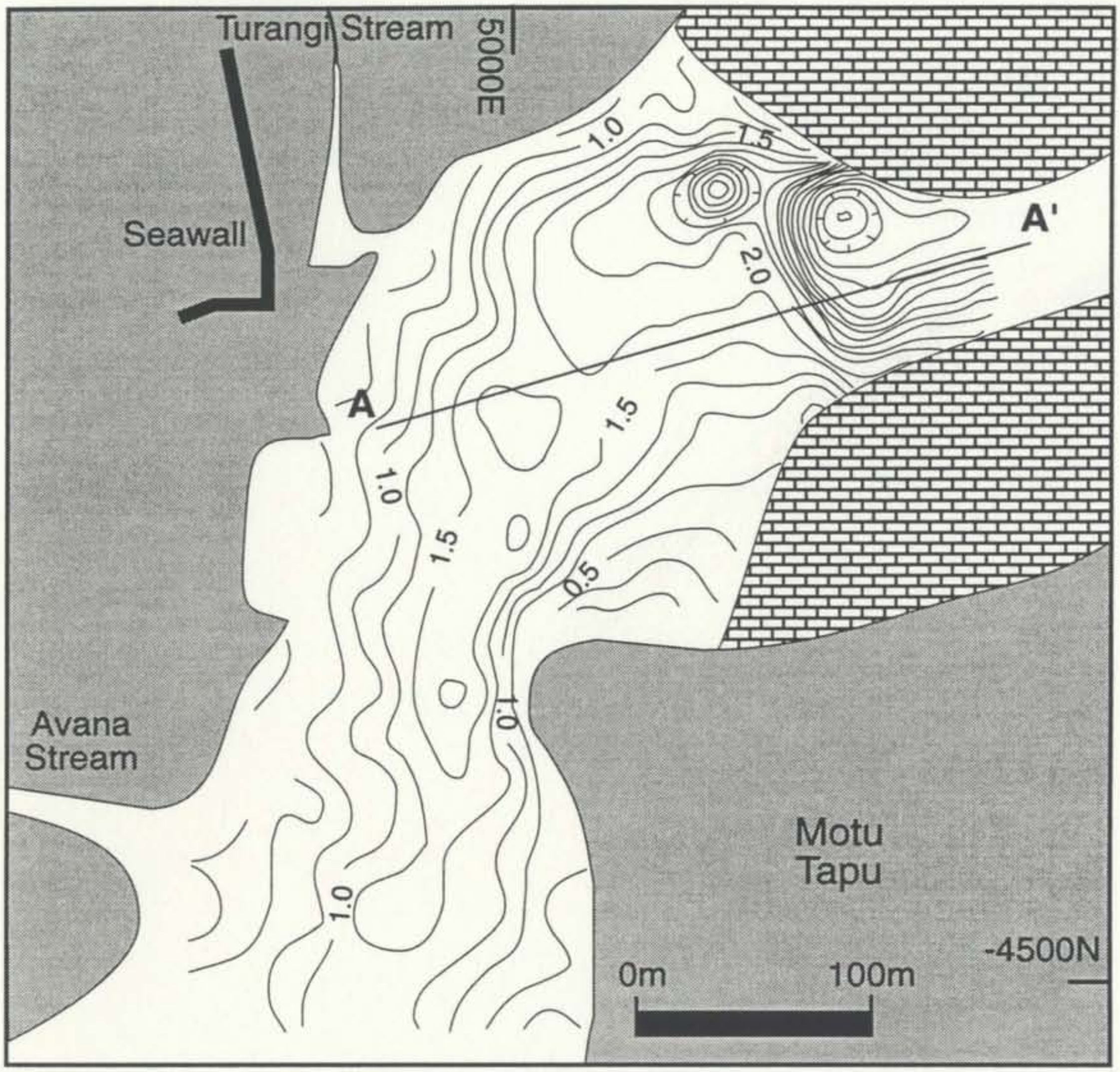

Figure 3.1 Map of harbour bathymetry in 1948. Contours in Metres.

The harbour bottom in 1990 was relatively flat lying. Water depths ranged from greater than 1 m to near mean water level (Fig. 3.3). Two depressions having water depths greater than 1 m existed in the NW area of the harbour. A small delta occured at the mouth of the Turangi Stream. Water depth in the vicinity of the boat basin, south of the seawall, was greater than 0.75 m. The water depth in the harbour shallowed between Motu Tapu and the mainland. The Avana Stream delta was truncated north of the stream-mouth.

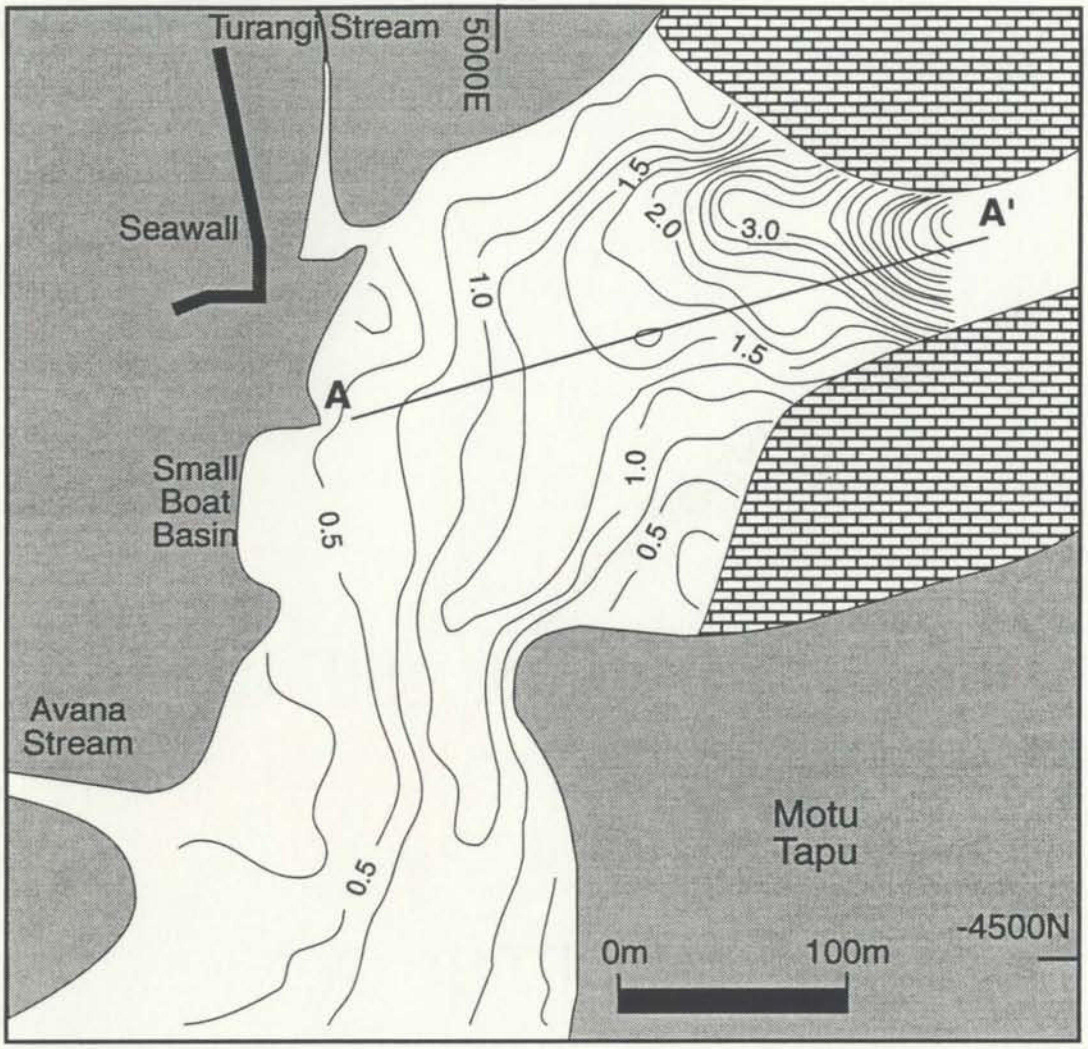

Figure 3.2 Map of harbour bathymetry in 1981. Contours in metres.

Figure 3.4 is a plot of harbour cross sections for 1948, 1981, and 1990. It shows a net deposition between 1948 and 1981 with more than 0.5 m of sediment being deposited in the central harbour basin during this time. A large volume of material has been deposited in the reef passage. From 1981 to 1990 sediment has been deposited throughout most of the harbour with the exception of the inner harbour at the boat basin where approximately 0.5 m of sediment has been removed.

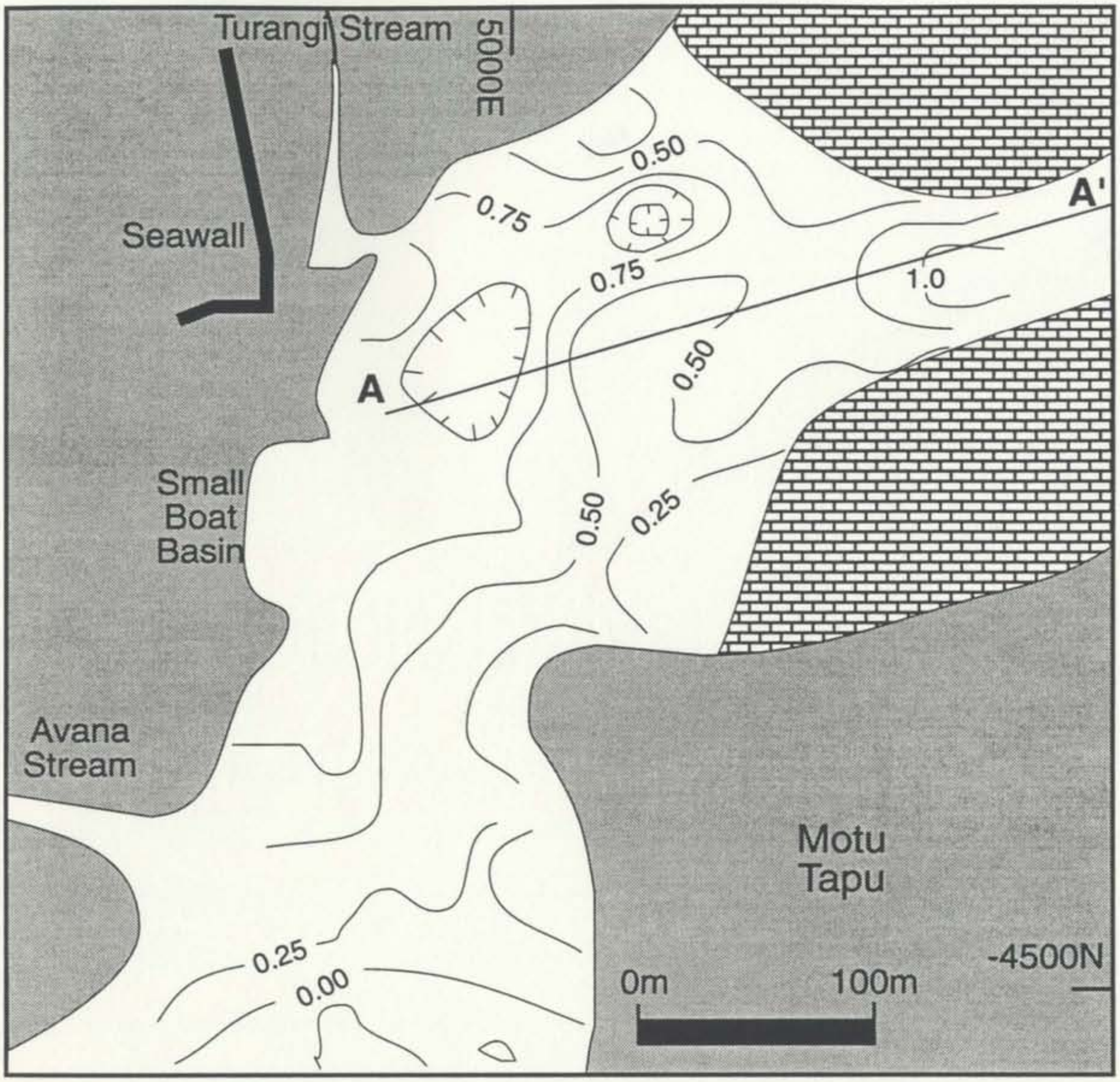

Figure 3.3 Map of harbour bathymetry in 1990. Contours in metres.

Figure 3.5 is a comparison of the bathymetry in the harbour between 1948 and 1990. It was generated, as described earlier, by superimposing the bathymetric maps of the two years and subtracting the data for younger year from that for the older. It is essentially an isopach map with the zero value being the 1948 sea floor. Positive values represent net deposition and negative values represent net erosion.

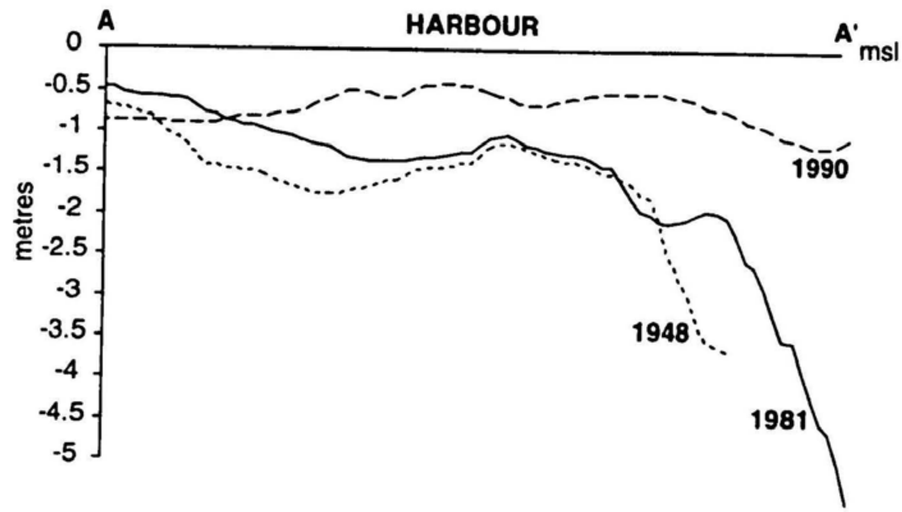

Figure 3.4 Cross sections of the harbour in 1948, 1981, and 1990. Location of cross section is shown on Figure 3.1 to 3.3

The results indicate significant deposition in the harbour. Maximum deposition occurs to the north of the harbour where more than 4 m of sediment infills the former depressions and more than 2 m of sediment has been deposited in the reef passage. More than 1 m of sediment has been deposited in the centre of the harbour. There has been erosion near the seawall and small boat basin. This was likely due to harbour development activities during the 1980's. More than 1.25 m of sediment has been deposited in the central channel just south of the Avana Stream mouth.

Another way to consider changes in the bathymetry through time is to plot the percentage of seabed area below a specific water depth. Such a plot for the harbour is given in Figure 3.6. It shows that most of the sediment infilling occurs in less than 2 m of water corresponding to the central harbour basin. The median isobath, the depth at which 50% of the surface area of the sea floor is deeper and 50% of the surface area is shallower, for 1948, 1989 and 1990 is 1.1 m, 0.9 m and 0.5 m, respectively. As of 1990, most of the harbour was shallower than 0.5 m.

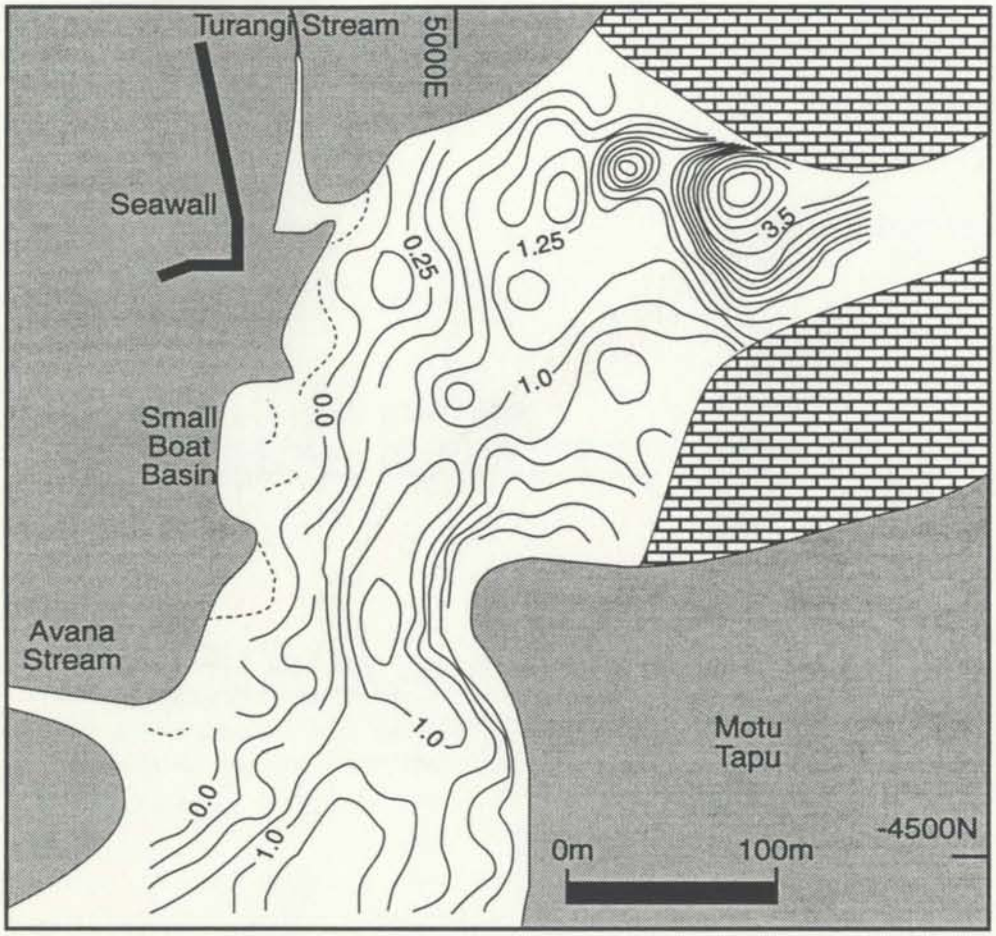

Figure 3.5 Map showing differences in harbour bathymetry in the years 1948 and 1990. Solid contours indicate deposition and dashed contours indicate erosion. Contours in metres.

The total volume of sediment deposited in the harbour between 1948 and 1981 was 20,843 m^3. This represents an average yearly sedimentation rate of 0.07 cm/m^2. Between 1981 and 1990, a total of 57,167 m^3 of sediment has been deposited. This represents an average accumulation rate of 7 cm/yr. Thus 73% of the sedimentation in the harbour since 1948 occurred between 1981 and 1990.

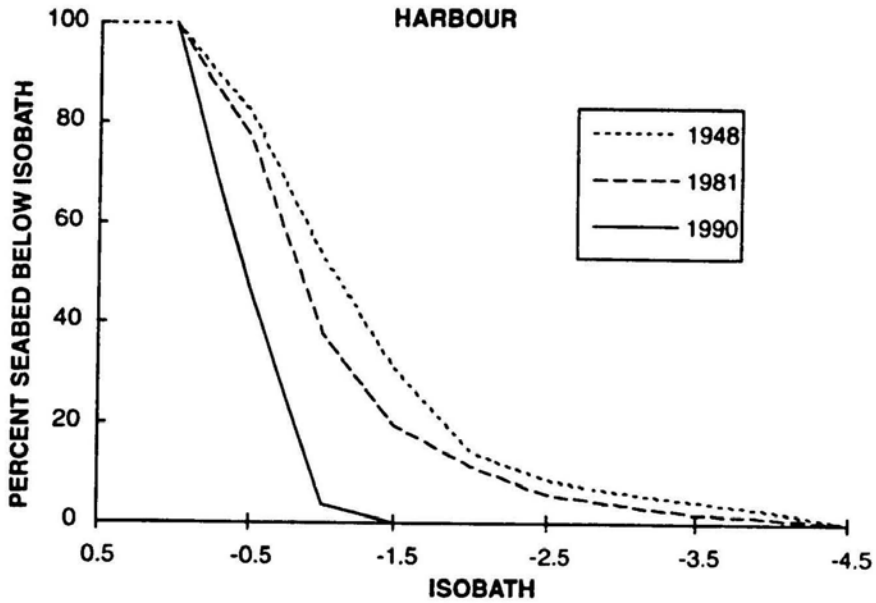

Figure 3.6 Plot of the percentage of harbour floor area below given isobaths.

3.2.2 Channel

The bathymetry of the channel in 1985 showed a broad, central channel shallowing to either side (Fig. 3.7). The water depth ranged from greater than 0.75 m to less than mean water level. The main north-south channel averaged deeper than 0.25 m with a small depression, 0.9 m deep, at its centre off the southwest tip of Motu Tapu. The largest sediment accumulation occurred at the western tip of Motu Tapu. The results of the 1990 survey show little net change in bathymetry from the previous survey (Fig 3.8). The deepest spot in the channel was greater than 0.75 m. The shallowest areas were the southwest tip of Motu Tapu and the northwest tip of Koromiri.

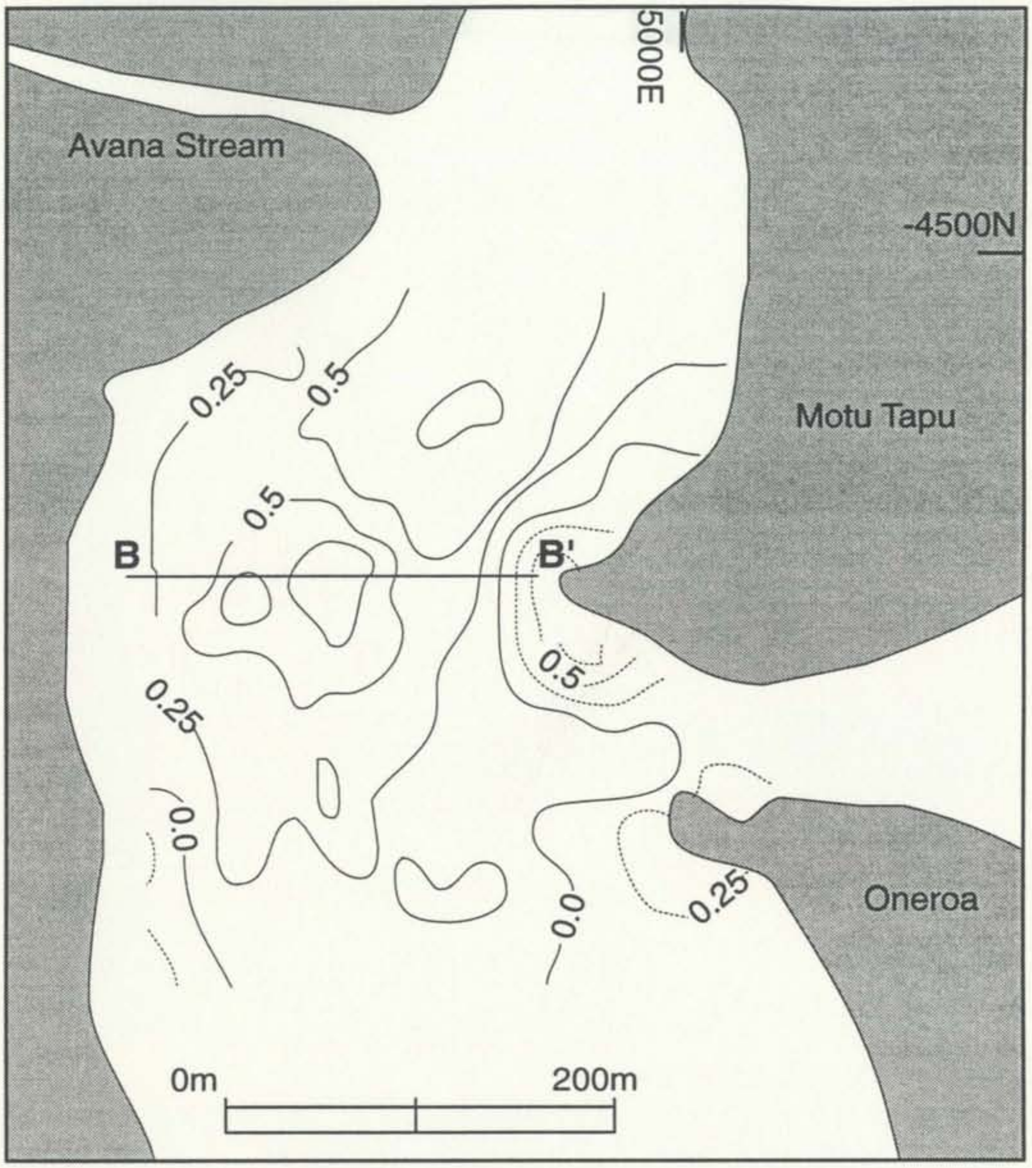

Figure 3.7 Map of channel bathymetry in 1985. Dashed contours indicate level above MSL. Contours in metres.

A cross section through the channel indicates a small amount of deposition, 10 cm to 20 cm at the centre of the channel with erosion at the sides (Fig. 3.9). This is also evident in Figure 3.10, which shows that there was net erosion above the 0.3 m isobath with material deposited in areas deeper than this depth. The median isobath was 0.25 m for both survey years.

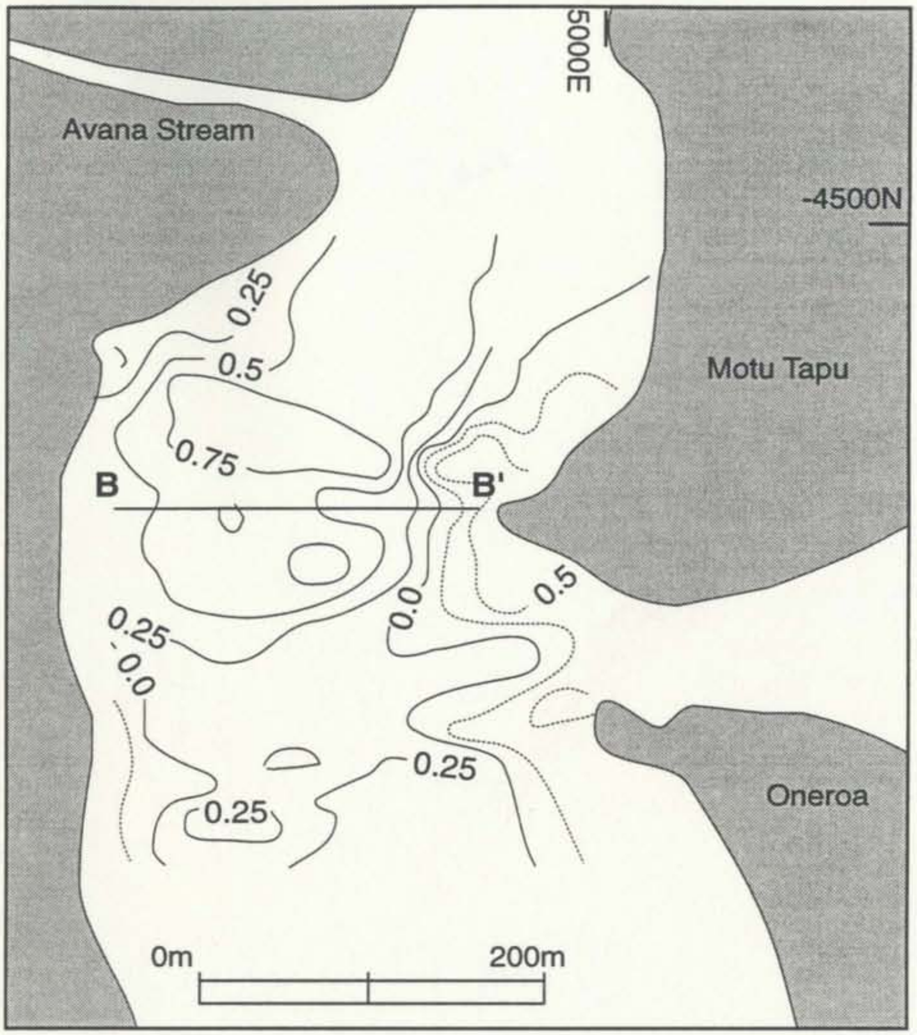

Figure 3.8 Map of channel bathymetry in 1990. Dashed contours indicate level above MSL. Contours in metres.

A plot of the comparison of the bathymetry for 1985 and 1990 indicates that there was little net change (Fig. 3.11). The depression in the centre of the channel has become slightly narrower and deeper. Patchy areas show an accumulation of about 0.25 m and likely represented small sand bodies. A total of 4,571 m^3 of material has been deposited in the channel over this time for an average accumulation rate of 0.08 cm/yr.

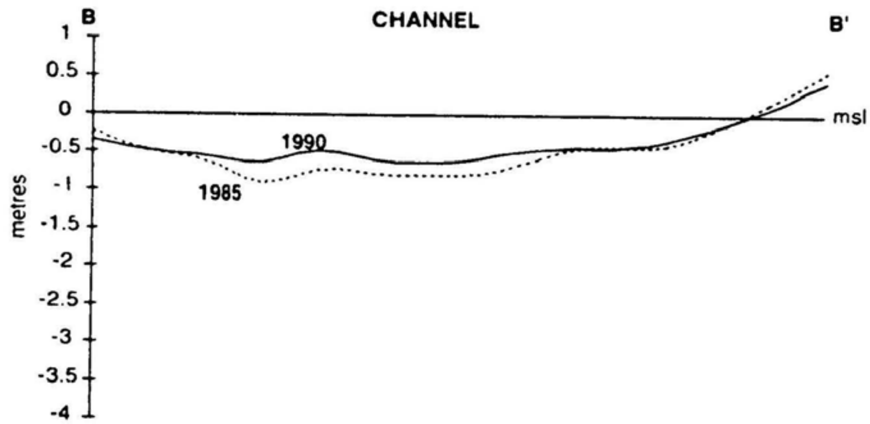

Figure 3.9 Cross sections of the channel in 1985 and 1990. Location of cross section is shown on Figures 3.7 and 3.8.

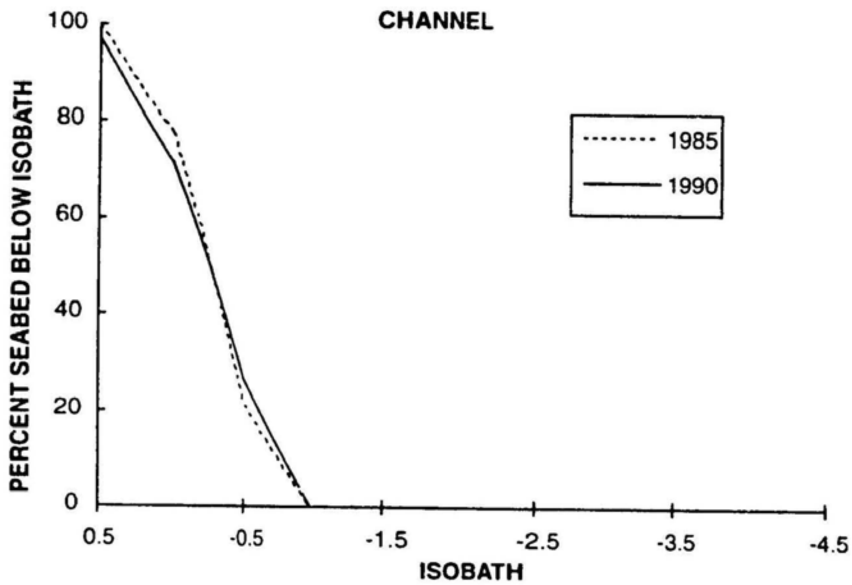

Figure 3.10 Plot of the percentage of channel floor area below given isobaths.

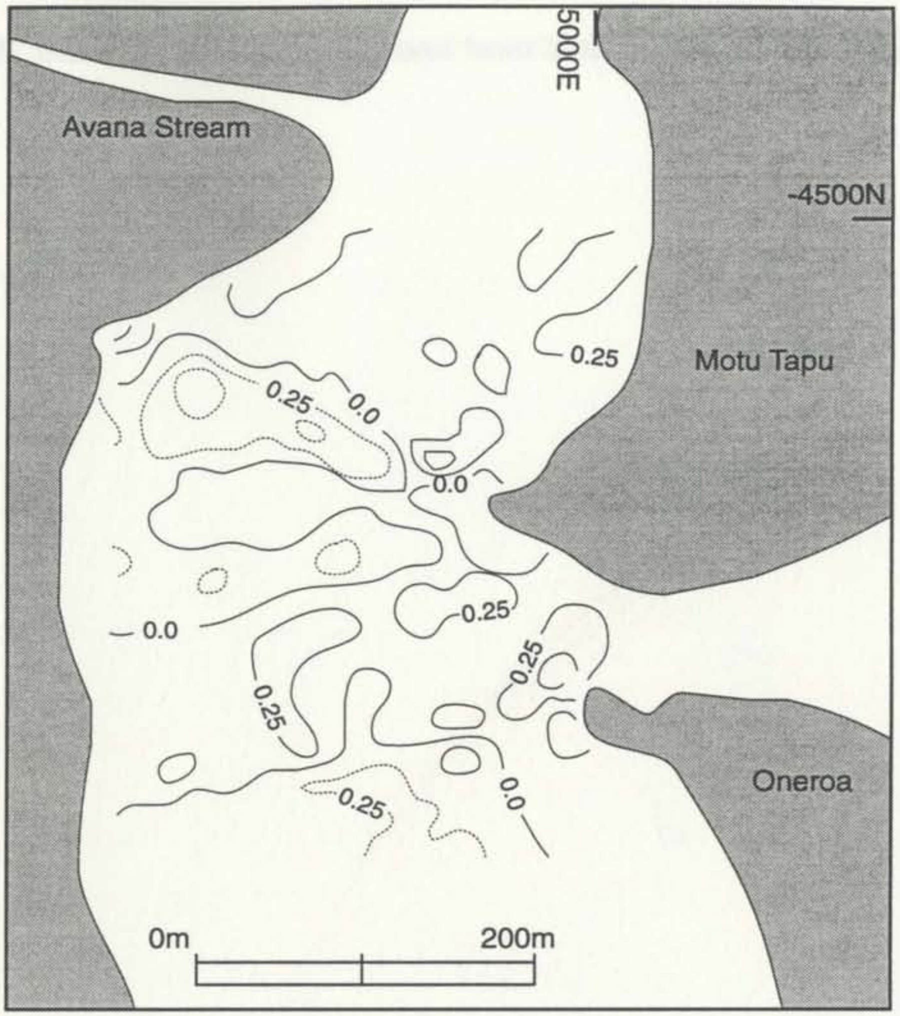

Figure 3.11 Map showing differences in channel bathymetry in the years 1985 and 1990. Solid contours indicate deposition and dashed contours indicate erosion. Contours in metres.

3.2.3 Lagoon

The bathymetry of Muri Lagoon in 1984 exhibited a general west to east deepening with depths ranging from less than 0.25 m at the foreshore of Muri Beach to greater than 1 m at the landward edge of the outer reef flat (Fig 3.12). The lagoon also showed a broad shallowing at its southwest corner.

The 1991 lagoon bathymetry ranged from less than 0.5 m at the mainland beach to greater than 1.25 m in a depression just east of the lagoon centre (Fig 3.13). The beach slope was steeper than the previous survey year.

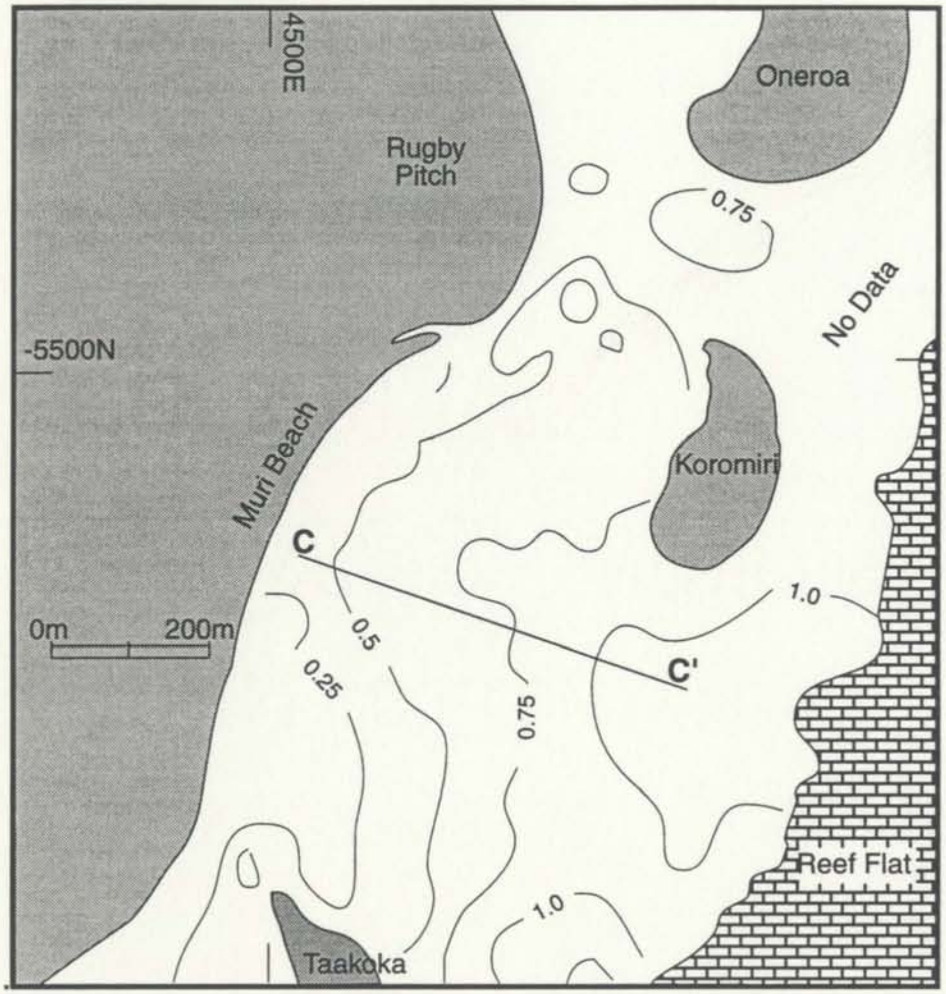

Figure 3.12 Map of lagoon bathymetry in 1984. Contours in metres.

A plot of cross sections of the lagoon normal to the shore from Muri Beach for 1984 and 1991 is given in Figure 3.14. It shows net erosion across the lagoon with approximately 0.5 m of deposition near the foot of the beach. A comparison of the lagoon bathymetry between the years 1984 and 1991 indicates that the greatest erosion has taken place near the south central part of the lagoon (Fig. 3.15). Here a shore-parallel band of erosion has removed 0.5 m of sediment. A smaller zone of erosion occurs mid-way between the southern edge of Koromiri and the mainland. Net deposition occurrs at the southern tip of Koromiri. The greatest amount of sediment has been deposited as a shore-parallel ridge at the Muri Beach front. This is also evident in Figure 3.16 which shows that the majority of deposition occurrs in areas less than 0.5 m deep. Approximately 80,904 m^3 of material has been removed from the lagoon between 1984 and 1991 representing a erosion rate of 0.02 cm/yr.

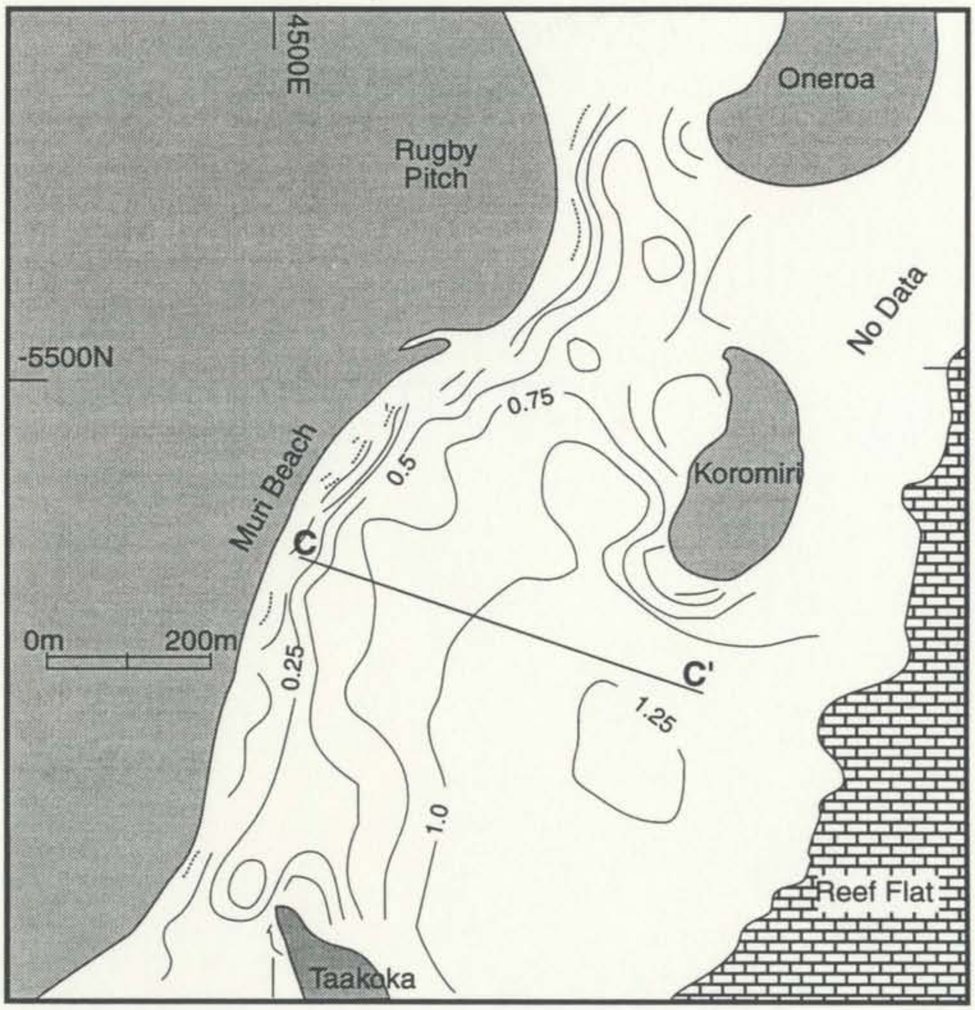

Figure 3.13 Map of lagoon bathymetry in 1991. Dashed contours indicate levels above MSL. Contours in metres.

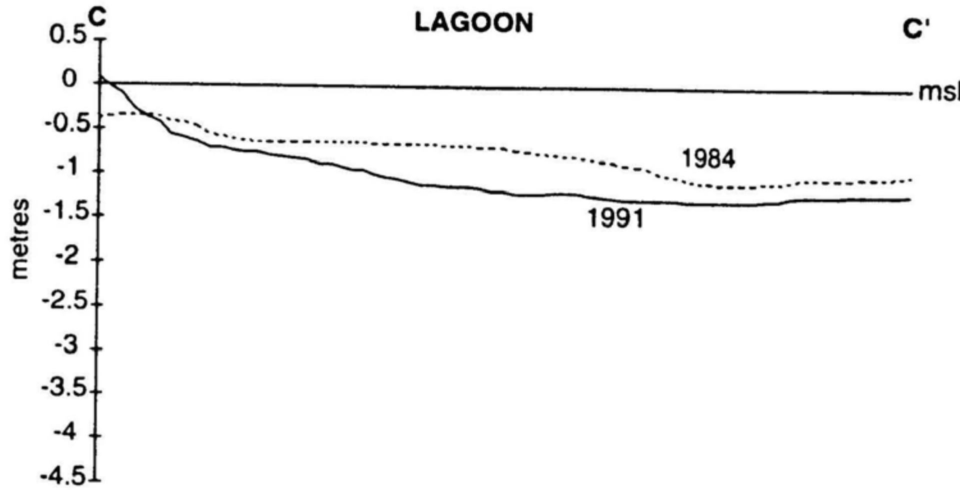

Figure 3.14 Cross sections of the lagoon in 1984 and 1991. Location of cross section is shown on Figures 3.12. and 3.13.

3.3 Modern Bathymetry

Figure 3.17 is a compilation of the most recent bathymetric data available. It uses the 1990 data for the harbour and channel and the 1991 survey for the lagoon. The map shows a relatively broad shallow lagoon bounded on its seaward edge by the outer reef flat. Landward of Oneroa the lagoon narrows and shallows to a broad area between 0 and 0.25 m. Except for a deeper area between the southeastern point of Motu Tapu and the mainland, the lagoon remains shallow until turning northwest into the harbour and through the passage. The maximum depth of the passage is greater than 6.5 m.

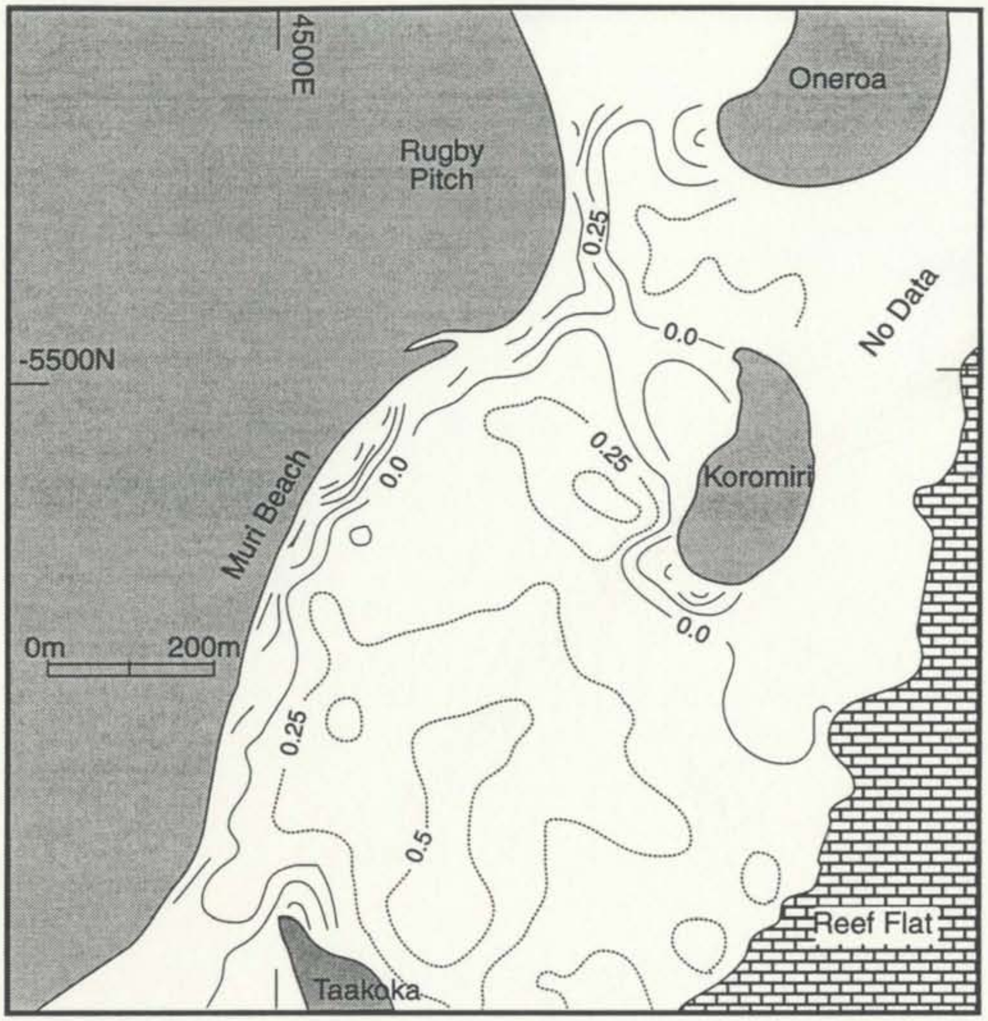

Figure 3.15 Map showing differences in lagoon bathymetry in the years 1984 and 1991. Solid contours indicate deposition and dashed contours indicate erosion.

Figure 3.18 is a north-south cross section of Ngatangiia Harbour and Muri Lagoon. It shows two very shallow areas. The first corresponds to the channel between Oneroa and the mainland and the second occurs near the Avana Stream Delta.

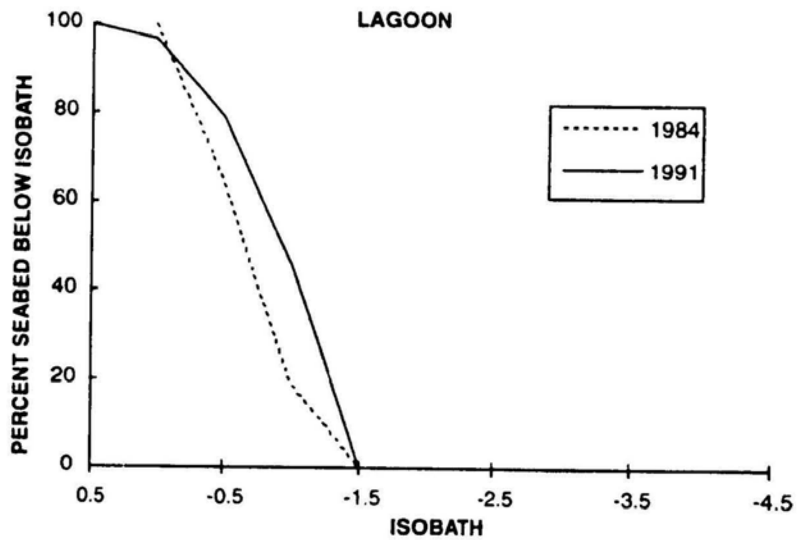

Figure 3.16 Plot of the percentage of lagoon floor area below given isobaths.

3.4 Interpretation

The results of the bathymetric analysis suggest that there was erosion in the lagoon and deposition in the harbour with relatively little net erosion apparent in the channel (Table 3.1). Between 1948 and 1981, 20,873 m^3 of sediment was deposited. A comparison of the cross sections in Figure 3.4 indicates that the sediment has been deposited evenly across the area. During the period 1981 to 1990 sedimentation substantially increased with an almost seven-fold increase in the rate of sediment deposition. In the period 1981 to 1990 the harbour gained 57,167 m^3 of sediment. In a similar time frame the channel gained 4,570 m^3, apparently by erosion at the beach and deposition near the channel axis. From 1984 to 1991 the lagoon lost 80,900 m^3 of sediment representing an erosion rate of 0.02 cm/year with accretion at the beach and the foreshore and erosion at the center of the lagoon.

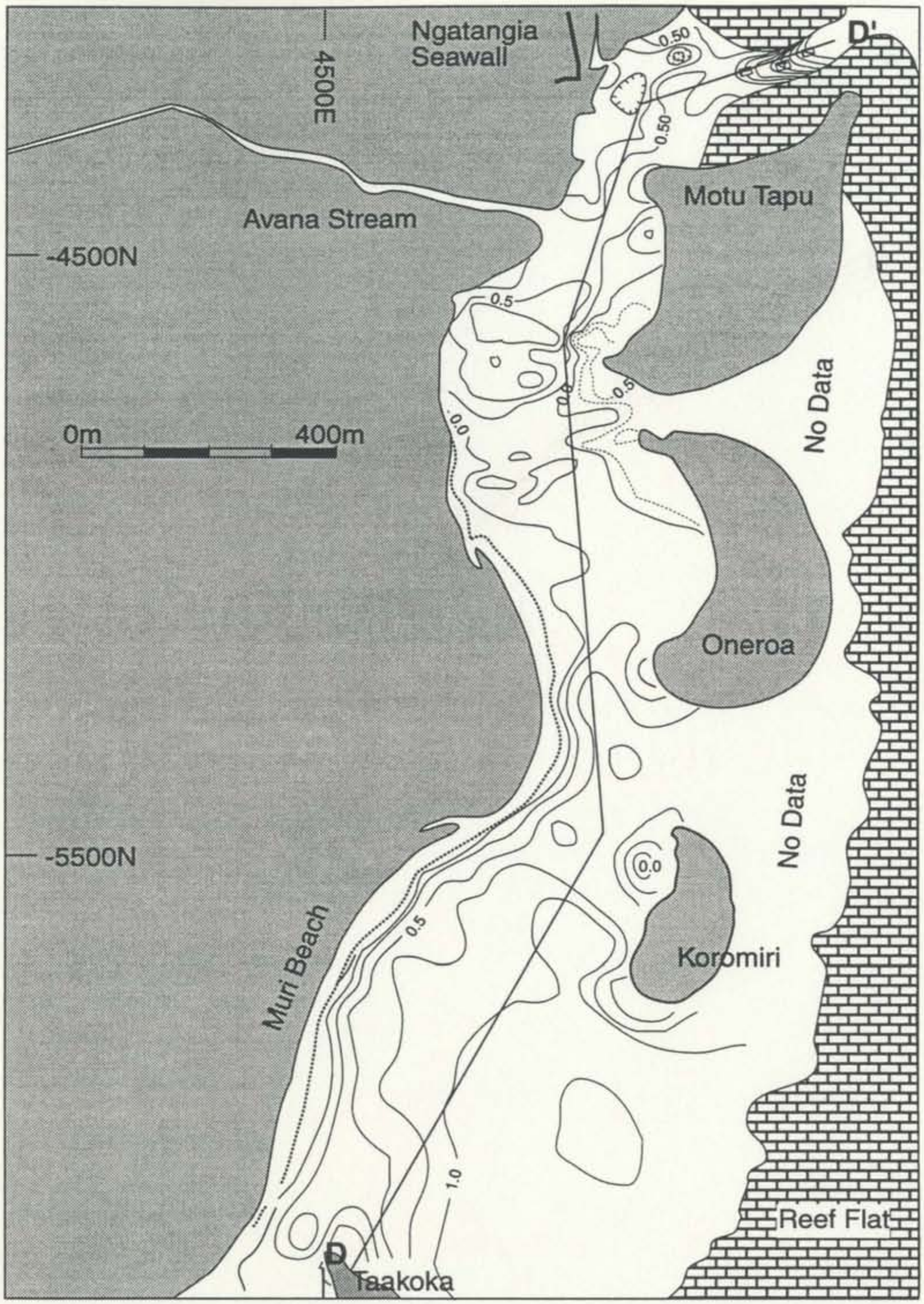

Figure 3.17 Map of a compilation of most recent lagoon bathymetry. Dashed contours indicate levels above MSL.

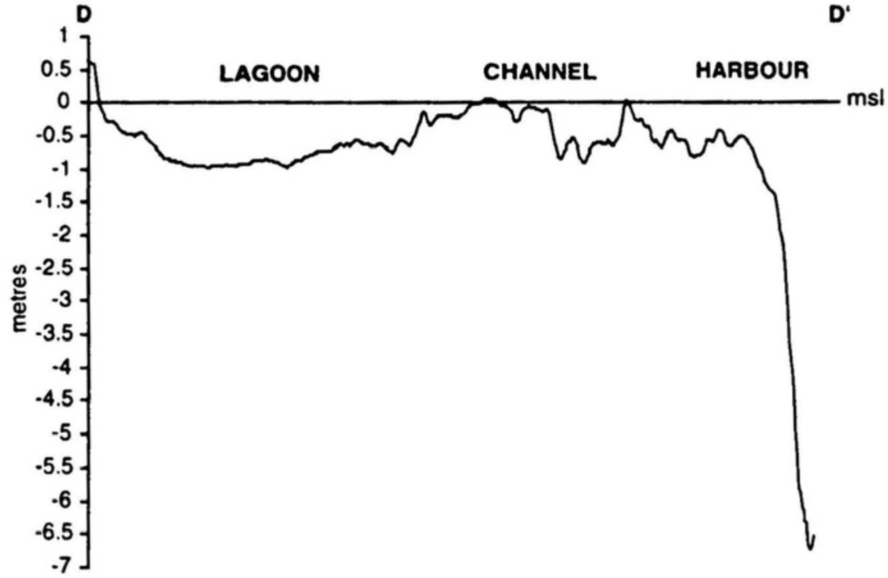

Figure 3.18 Cross section of the modern harbour, channel, and lagoon system. Location of cross section is shown on Figure 3.17.

Table 3.1 Summary of sediment volume calculations.

Area	Period	Surface Area (m^2)	Sediment Displaced (m^3)	Sedimentation Rate (cm/yr)
Harbour	1948-1981	162,050	20,873	0.97
Harbour	1981-1990	162,050	57,167	7.00
Harbour	1948-1990	162,050	78,041	2.00
Channel	1985-1990	160,000	4,571	0.08
Lagoon	1984-1991	1,045,250	-80.904	-0.02

3.5 Summary

1. Ngatangiia Harbour has had a net accumulation of sediment from 1948 to 1990 with an estimated 78,041 m^3 of sediment being deposited since 1948. Sediments have preferentially infilled lower lying depressions in the northern portion of the harbour and at the inner entrance to the reef passage.

2. The channel area has seen a net deposition of 4,571 m^3 of material between 1985 and 1990. There has been relatively little change in the bathymetry of this area.

3. Muri Lagoon has had a net loss of sediment from 1984 to 1991 with an estimated 80,904 m^3 of material being removed. In addition to the loss there has been appreciable redistribution of sediment in the form of a shore-parallel ridge just seaward of the beach.

4. The rate of net accumulation is highly variable in the harbour and of the order of 2 cm/yr. The net deposition in the channel area is approximately 0.08 cm/yr. The net erosion of the lagoon is approximately 0.02 cm/yr.

CHAPTER 4 PHYSICAL OCEANOGRAPHY

The purpose of this chapter is to describe the hydrodynamic conditions which control sedimentation. This description consists of an analysis of waves, both deep ocean waves moving over the reef and those generated locally and by unidirectional currents. In the treatment of waves moving across the reef, an extended effort is made to describe the fundamental relationships. This should provide a more complete understanding of the parameters involved when applying the model to the conditions at Rarotonga.

4.1 Deep-Water Wave Transmission Over Reef

There are a number of considerations when attempting to describe the wave climate in Muri Lagoon. The deep-water wave climate seaward of the lagoon must first be established, followed by a consideration of the modification of the waves as they approach and traverse the reef. Wave transformation over coral reefs has been the focus of study by a number of workers (Young and Hardy, 1993; Young, 1989; Roberts and Suhayda, 1983; Gerritsen, 1981; Roberts et al., 1975).

Roberts et al. (1975) reported an experiment to document the magnitude of waves and currents and their influence on the fringing reef system of Grand Cayman Island, Caribbean Sea. In this experiment, a series of wave sensors aligned normal to the reef crest characterized the transformation of the waves as they moved from deep water onto a 20 metre deep fore-reef terrace and over a reef crest. Fore-reef terrace currents were measured by both *in situ* recording instruments and by deployment of drogues. Roberts et al. concluded that deep-water wave characteristics were modified by reef morphology such that a wave height reduction of 20% occurred on the terrace with a further 75% at the fringing reef crest. They attributed losses on the terrace to the combined effects of friction, scattering and reflection. Losses on the reef crest were attributed to breaking processes. They also noted a substantial modification of the wave spectrum with the introduction of multiple low frequency peaks.

In a Ph.D. thesis published in 1981, Franciscus Gerritsen modeled wave attenuation and set-up on a coastal reef. His experiment involved the measurement of waves in the field by an array of sensors aligned normal to a fringing reef off Ala Moana Park, Hawaii and in an hydraulic model study in a wave tank.

Gerritsen (1981) attributed wave attenuation to the effects of two principal processes: friction with the seabed and the dissipation of energy as turbulence in the breaking wave. Gerritsen proposed that if waves approached a reef in a direction normal to the reef that an equation of the following form could be used to describe the energy losses.

$$\frac{dF}{dx} = -(\mathcal{E}_f + \mathcal{E}_b) \qquad (4.1)$$

where $\frac{dF}{dx}$ is the gradient in energy flux in a direction normal to the reef crest, $\mathcal{E}_f$ is the mean rate of energy dissipation per unit area due to friction with the seabed, and $\mathcal{E}_b$ is the mean rate of energy dissipation per unit area due to breaking. The energy flux for linear waves over a horizontal bottom, F, is given by :

$$F = Enc = \tfrac{1}{8}\rho g H^2 nc \tag{4.2}$$

where E is the energy per unit length along the wave crest and c is the wave speed, n is the fraction of energy advancing with wave velocity, ρ is fluid density, g is the acceleration due to gravity and H is the wave height.

In the development of the term $\mathcal{E}_f$, Gerritsen assumed linear wave theory and a constant period. He reported that the rate of energy dissipation was a function of the instantaneous bottom shear stress, the instantaneous velocity of the main fluid motion near the bottom and an empirically derived bottom friction coefficient. Gerritsen proposed the following equation to describe the energy dissipation:

$$\mathcal{E}f = -\frac{2}{3\pi} f_w \rho \left(\frac{\pi H}{T \sinh \dfrac{2\pi d}{L}} \right)^3 \tag{4.3}$$

where f_w is a dimensionless friction coefficient, T is the wave period, d is water depth, and L is the wavelength.

In defining a term to account for breaking losses, Gerritsen (1981) likened wave breaking to that of a bore. Using this approach, the dissipation of energy due to breaking is a function of wave height, period and a breaking loss coefficient and is given by the following:

$$\varepsilon_b = \frac{\zeta \rho g H^2}{4T\sqrt{2}} \tag{4.4}$$

where ζ is a dimensionless breaking loss coefficient.

In order to apply equation 4.1 it is necessary to make some assumptions as to when the breaking and friction mechanisms will be active (Young, 1989). At this point it may be helpful to summarize the processes that modify a typical wave as it approaches and crosses a fringing coral reef and the relationships that govern such modification. Although waves are three dimensional and can be modified by longshore currents and interaction with other wave trains, only a two-dimensional scenario will be presented here because the data set needed to produce three dimensional analysis does not exist for offshore Muri Lagoon.

A gravity wave approaching a shoreline with a barrier or fringing reef can be described in terms of period (the length of time it takes for two successive wave crests to pass the same point) and height (the distance from the bottom of a wave trough to the top of a wave crest). From these two parameters other wave characteristics such as wavelength and speed can be determined. In deep water, where the relative depth (ratio of water depth to deep-water wavelength) is greater than 0.5 the wavelength can be given by:

$$L_0 = \frac{gT^2}{2\pi} \tag{4.5}$$

Wave speed, c, is given by the following equation:

$$c = \sqrt{\frac{gL}{2\pi} \tanh \frac{2\pi d}{L}} \qquad (4.6).$$

In relatively deep water, d>0.5L, the hyperbolic tangent term tends to unity and the equation becomes:

$$c = \sqrt{\frac{gL}{2\pi}} \qquad (4.7).$$

In the case of relatively shallow water, d<0.05L the hyperbolic tangent term becomes equal to $\frac{2\pi d}{L}$ and the equation becomes:

$$c = \sqrt{gd} \qquad (4.8).$$

From the preceding equations it can be seen that, in relatively deep water, wave speed is a function of wave length or period and, in relatively shallow water, wave speed is a function of water depth. In the transition between relatively deep and relatively shallow water wave speed is a function of both wavelength and water depth, as shown in equation 4.6.

As waves move forward associated energy is carried not as a function of the individual waves but as a function of the wave group (Open University, 1978). The fraction of wave energy that travels forward is given by:

$$n = \frac{1}{2}\left[1 + \frac{4\pi\frac{d}{L}}{\sinh 4\pi\frac{d}{L}}\right] \qquad (4.9).$$

Gerritsen (1981) pointed out that the propagation of energy is given by the product of n and c. This product is also know as the group velocity C_g and even though there may be no groups of waves physically present in the train, the term is maintained and its value used for the determination of energy flux.

As a wave moves into shallcw water it begins to "feel" bottom resulting in a reduction of speed. From equation 4.2 it is shown that energy is proportional to the square of the wave height. In the purely hypothetical case with energy being conserved, a decrease in wave speed results in an increase in wave height. The magnitude of the wave height increase can be defined in terms of a ratio of the shoaled wave height to the corresponding deep-water wave height which is given by the following equation:

$$\frac{H}{H_0} = \sqrt{\frac{1}{2n \tanh \frac{2\pi d}{L}}} \qquad (4.10)$$

As waves move still closer to the shore the process of breaking begins (Plate 4.1). Two basic parameters define the wave breaking process. These are the deep-water wave steepness and the steepness of the reef face or beach slope (Gerritsen, 1981). For the purposes of calculating energy dissipation, it is necessary tc estimate where the breaking process begins and ends. Young (1989) proposed the common depth-limited breaking criterion as suitable for the purposes of defining the zone of wave breaking. The criterion is given as:

$$H_s = 0.78d \tag{4.11}$$,

where H_s refers to the significant wave height or the height of the highest one-third of all waves.

Plate 4.1 Waves breaking on the reef at Muri Lagoon. Approximate field of view is 50m.

A summary of a characteristic wave as it approaches the reef at Muri Lagoon and traverses the reef is shown in Figure 4.1. If a wave approaches the land at an angle normal to the shore at a point defined by $d<0.5L$ the wave begins to "feel" bottom and energy loss due to bottom friction begins. The wave continues to move shoreward and at approximately $d/L_0=0.057$ begins to increase in height. When $H>0.78d$ the wave breaks and energy loss due to turbulence is invoked. The wave continues to move forward with continued friction and breaking losses until the energy losses result in a decrease in wave height such that H<0.78d. The wave then continues forward with energy loss due to bottom friction only.

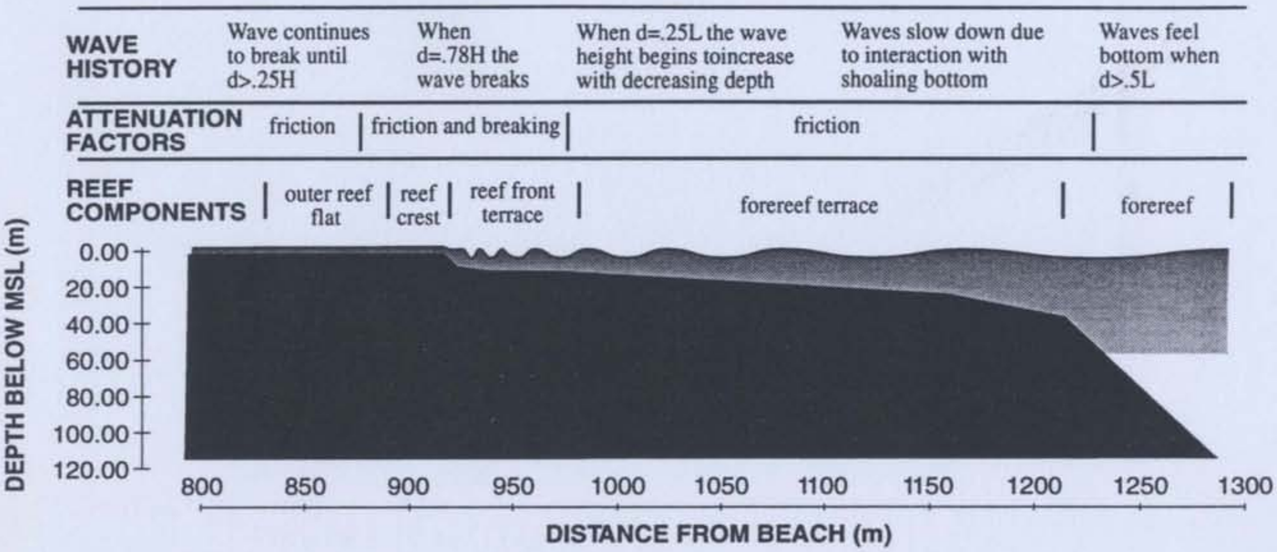

Figure 4.1 Summary of some reef components and processes related to waves approaching and crossing the reef flat.

In the previous oversimplification there is an implied linear relationship in the breaking process. Numerous authors have pointed the out that the wave-breaking process is non-linear. Gerritsen (1981) noted that a solitary wave moving over a uniform depth without changing shape before reaching the shelf would be transformed into a finite number of smaller residual waves or solitons on the shelf (Plate 4.2).

Plate 4.2 Waves transgressing the reef at Ngatangiia Harbour. Approximate width of view is 10m. The wave group in the foreground consists of a series of three solitons

Wave transformation over a reef can be characterized in terms of changes to the energy spectra (Young and Hardy, 1993). In this representation the ocean surface is considered to be composed of a summation of sinusoidal components, each with its own height, period and direction. The spectrum represents energy associated with each wave component of frequency. Typical wave spectra are quite peaked, indicating that the bulk of the energy is concentrated around a single frequency or period. The relationship of frequency to period is given as:

$$f = 1/T \qquad (4.12).$$

As a result , the frequency distribution of waves is often characterized by the frequency, f_P or period, T_P, of the spectral peak.

Figure 4.2 shows the results of three experiments to analyze modification to the wave spectrum over a reef (Roberts et al., 1975; Gerritsen, 1981; Young, 1989). In all cases there is a significant decrease in the energy associated with the peak frequency. Additionally, the remaining energy is uniformly spread across the spectrum with no observable peak frequency at deep-water spectral peak. Detailed analysis of the Gerritsen data indicate that intermediate stations, not shown in Figure 4.2, exhibit a spectral peak at a similar frequency to the deep-water peak. The data from subsequent stations indicate that when waves continue over the reef this energy is apparently transferred to the lower frequencies. Young (1993) attributes the existence of the peaks at these intermediate sites to a less-steep bathymetric gradient. He notes that a steep gradient in the forereef may result in active plunging breakers and a larger redistribution of the energy. While no wave data exist for reef or backreef sites at Muri Lagoon the fore-reef bathymetry is more closely related to sites of Young (1989) and Roberts et al. (1975) and therefore the energy transfer may be similar.

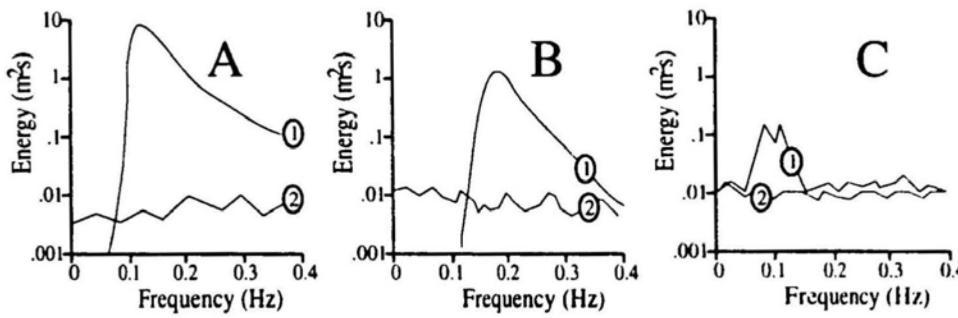

Figure 4.2 Wave spectra plots from three different experiments designed to measure wave attenuation over a coral reef. A is from Young (1989), B is taken from Roberts et al. (1975) and C is from Gerritsen (1981). The label 1 denotes the energy spectrum from the deep-water wave (unbroken) and 2 identifies the energy spectrum following breaking.

4.1.1 Results

The methods developed by Gerritsen (1981) were used to calculate the attenuation of waves over the reef at Muri Lagoon. Wave and bathymetric data from the coast off Muri Lagoon were used as inputs. A two dimensional situation is assumed, meaning no lateral energy was added to the system by wave reflection or refraction and that waves were travelling normal to the reef crest. It was also assumed that there was no percolation into the reef and the interference from unidirectional currents was negligible. Locally generated waves were present in the lagoon and they will be treated separately in a later section.

Using the bathymetric data of Gauss (1982) and bathymetric data collected during this study, a composite cross section of the reef and lagoon at Muri Lagoon can be prepared (Fig. 4.3). For the purposes of the calculation, the reef profile has been divided into nine bathymetric components based on a crude estimate of seabed gradient. The sloping bottom has been divided into a series of horizontal steps. Wave attenuation calculations are made based on a horizontal bottom. At the end of each section a change in wave height due to shoaling is taken into account.

To define an equation to calculate energy loss due to bottom friction and breaking, equations 4.2, 4.3 and 4.4 must be inserted into equation 4.1 (Gerritsen 1981). This yields the expression:

$$\tfrac{1}{8}\rho g H^2 nc = -\frac{2}{3\pi}\mathrm{fw}\rho\left[\frac{\pi \mathrm{H}}{\mathrm{T}\sinh\dfrac{2\pi \mathrm{d}}{\mathrm{L}}}\right]^3 - \frac{\zeta \rho g H^2}{4T\sqrt{2}} \qquad (4.13).$$

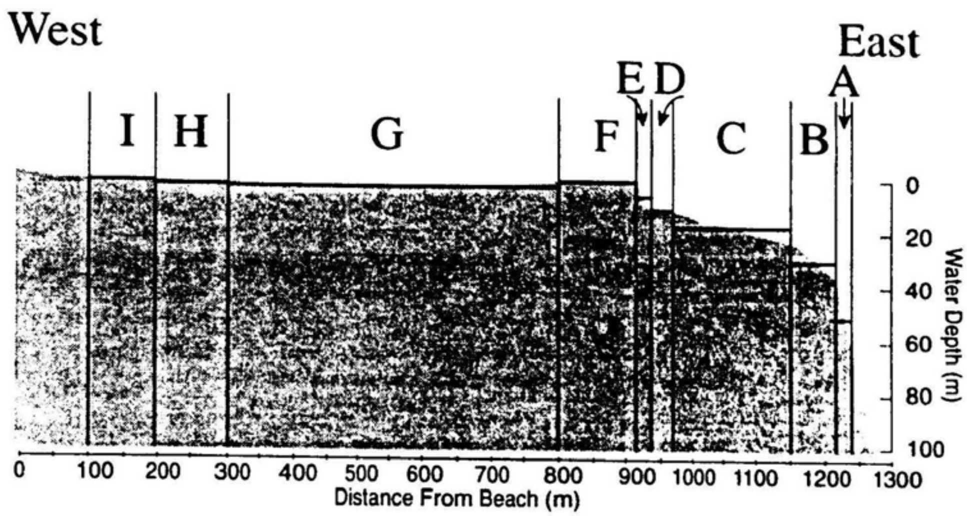

Figure 4.3 Profile of the reef and lagoon section at Muri Lagoon with Zones A-I used to calculate wave attenuation.

Equation 4.13 can then be integrated for a horizontal bottom by setting:

$$\left.\begin{aligned} A &= \tfrac{1}{4}\rho g C g \\ B &= \frac{2\pi^2}{3}\rho \frac{\mathrm{fw}}{\left(\mathrm{T}\sinh\dfrac{2\pi \mathrm{d}}{\mathrm{L}}\right)^3} \\ C &= \frac{\zeta \rho g}{4T\sqrt{2}} \end{aligned}\right\} \qquad (4.14).$$

A, B and C are constants if the bottom is horizontal. Equation 4.14 can be simplified via the following steps:

$$\left.\begin{aligned} &A\frac{dH}{dx} = -BH^2 - CH \\ &\frac{dH}{H(BH+C)} = -\frac{1}{A}dx \\ &\int_{H_0}^{H(x)} \frac{dH}{H(BH+C)} = -\frac{1}{A}\int_{x_0}^{x} dx \end{aligned}\right\} \qquad (4.15).$$

The resulting integral in 4.15 can be solved directly and gives:

$$-\frac{A}{C}\ell n\left(\frac{BH+C}{H}\right)\Bigg|_{H_0}^{H(x)} = -\left(x - x_0\right) \qquad (4.16)$$

If $x_0 = 0$, representing the start of the horizontal section, then $x - x_0 = x$ and

$$\ell n\frac{\left[BH(x)+C\right]}{\left[BH(0)+C\right]}\frac{H(0)}{H(x)} = \frac{C}{A}x \qquad (4.17)$$

which can be algebraically manipulated to give:

$$\frac{1}{H(x)} = \left(\frac{1}{H_0} + \frac{B}{C}\right)e^{\frac{C}{A}x} - \frac{B}{C} \qquad (4.18)$$

where H_0 is the wave height at the start of the section and H is the wave height at the end of the section which is x distance long.

Equations 4.14 and 4.18 were put into a matrix along with the appropriate data from the Muri Lagoon area . Table 4.1 is an example of the calculation based on a deep-water wave height of 2.2 m and a period of 9.4 s.

Table 4.1 A matrix used to calculate wave heights along the Muri Lagoon profile given initial offshore wave data: T=9.4 s and H=2.2 m.

		A	B	C	D	E	F	G	H	I
		Fore Reef Slope		10 m Terrace	Reef Face		Outer Reef Flat	Inner Reef Flat		
		ZONE A	ZONE B	ZONE C	ZONE D	ZONE E	ZONE F	ZONE G	ZONE H	ZONE I
1	x	30	50	190	12	10	110	500	100	100
2	d	50.45	25.45	10.45	5.90	3.40	0.90	1.58	1.33	1.08
3	L	135.33	120.22	88.11	68.98	53.63	27.79	37.21	33.55	30.26
4	H_0	2.20	2.13	1.95	1.81	1.73	1.86	0.40	0.20	0.23
5	H/H_0	0.9682	0.9139	0.9594	1.0493	1.1701	1.5866	1.3893	1.4475	1.5208
6	H	2.13	1.95	1.87	1.90	2.02	2.95	0.56	0.29	0.35
7	c	14.39	12.77	9.32	7.27	5.63	2.95	3.88	3.57	3.22
8	n	0.5433	0.6869	0.8537	0.9153	0.9508	0.9865	0.9772	0.9801	0.9838
9	fw	0.11	0.11	0.11	0.5	0.11	0.15	0.15	0.15	0.15
10	ξ	0.00	0.00	0.00	0.50	0.45	0.00	0.00	0.00	0.00
11	A	19543	21917	19887	16625	13370	7271	9483	8737	7914
12	B	0.0064	0.1634	1.6353	22.5621	12.9934	140.9842	62.1881	76.9438	106.3555
13	C	0.00188	0.00188	0.00188	93.9925	84.5932	0.00019	0.00019	0.00019	0.00019
14	H(m)	2.13	1.95	1.81	1.73	1.86	0.40	0.20	0.23	0.24

The value of x (cell A1) is the horizontal width of the section. The value of d (cell A2) is the depth of the horizontal section which is taken as the water depth at its midpoint. Initial input to the calculation is the deep-water wave height H_0 (cell A4). As described in equation 4.10, the ratio H/H_0, (cell A5), is the shoaling coefficient. This value represents the average shoaling across the section and is multiplied by the wave height at the beginning of the section to give a new value for H, to which the energy losses due to bottom friction and breaking, where appropriate, are applied. The values for the coefficients of bottom friction and breaking, fw and ξ were determined by experiment (Gerritsen, 1981) and applied to the appropriate section.

The values for A, B and C (cell 11-13) in equation 4.14 are then determined. These values were substituted in equation 4.18 to calculate the attenuated wave height (cell A14). This value was then used as the new value for H_0 at the beginning of the next section (cell B4). This process is continued through the entire profile and produced predictions of attenuated wave heights for the end of each zone.

Attenuated wave heights are plotted for each section (Fig. 4.4). At a mean water level (MWL) a 2.2 meter high deep-water wave will be reduced to about 1.86 m at the reef face and further reduced to under 0.5 m as it breaks and crosses the outer reef flat. The wave will continue to lose height until the slope of the bottom changes and the wave begins to shoal at the landward side of the lagoon.

Young and Hardy (1993), in modeling tropical cyclone waves in the Great Barrier Reef, point to the depth of reef submergence as a critical factor in the ability of waves to transgress the reef. Figure 4.4 also shows predicted wave heights along the profile for periods of high and low tide. The result shows that lagoonal waves are predicted to vary as a function of tide. To further illustrate the point, the wave height in the lagoon is plotted against water level above MWL given an initial deep-water wave of 2.2 m and 9.4 s as calculated by the above method (Fig. 4.5). Values for tide level are plotted in 0.05 m intervals to 1 m above mean water level. A value at 1.5 m over mean tide level is also plotted. There is a positive correlation between the height of waves in the lagoon and the tide level above mean water level for the values plotted.

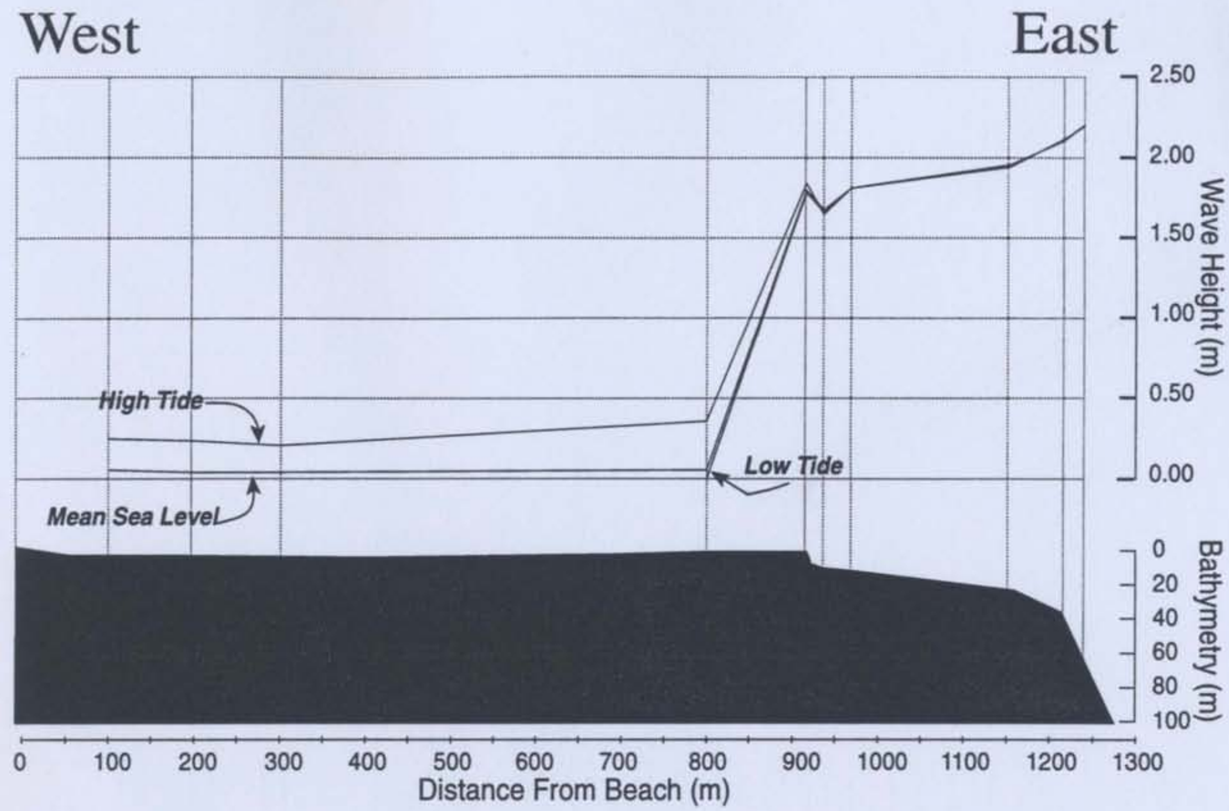

Figure 4.4 Wave height variation across the profile at Muri Lagoon for high tide, mean water level and low tide.

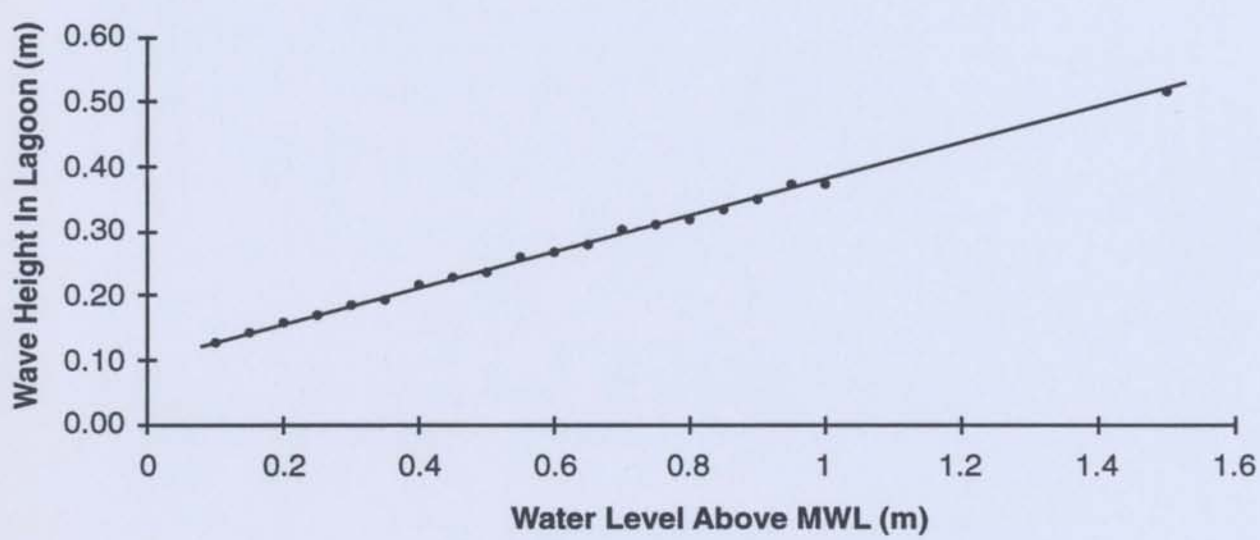

Figure 4.5 Values of lagoon wave height for various water level above mean water level as calculated for the Muri Lagoon profile.

Based on the wave data collected offshore Muri Lagoon from July 1987 until January 1991, the average significant wave height is 2.2 m and the average wave period corresponding to the peak energy is 9.4 s (Olsen, 1991). These waves combined with an average tidal range of 0.9 m will produce waves heights as shown in Table (4.2).

Table 4.2 Summary of wave heights in metres at various sections along the profile at Muri Lagoon for maximum, mean, and minimum tidal levels and average deep-water wave conditions.

Tide (m)	Fore Reef		Fore Reef Terrace	Reef Front Terrace and Reef Crest		Outer Reef Flat	Inner Reef Flat		
	ZONE A	ZONE B	ZONE C	ZONE D	ZONE E	ZONE F	ZONE G	ZONE H	ZONE I
0.45	2.13	1.95	1.81	1.73	1.86	0.40	0.20	0.23	0.24
0.00	2.13	1.94	1.82	1.74	1.91	0.11	0.08	0.10	0.10
-0.45	2.12	1.94	1.82	1.75	1.96	0.00	0.00	0.00	0.01

Holden (1991) pointed out that one of the largest waves recorded at Rarotonga coincided with the passage of Cyclone Peni in February of 1990. The waverider recorded significant wave heights of up to 7.6 m. Maximum wave height at Rarotonga may be assumed to be 1.8 to 1.9 times the significant wave heights with associated periods in the order of 16 s (Holden, 1991). Maximum astronomical tidal range is about 1.1 m. While estimates of maximum wave conditions are often difficult to make, it is reasonable to suggest that waves of the order of 13 m high occurred with associated periods of 16 s. Carter and Steer (1984) estimated that superelevated water in the lagoon due to storm surge could be on the order of 1 m. This is based on a cyclone in 1967 which was considered to have a 25 year return period. The wave heights at various positions along the profile at Muri Lagoon for these maximum wave conditions are calculated and are given in Table 4.3.

Table 4.3 a) Wave heights in meters across the profile based on maximum expected deep-water wave conditions (T=15 s, H_S=13 m), astronomical tide (1.1 m), and storm surge (1 m). b) Wave heights in meters from deep-water wave conditions reported from Cyclone Sally, January 1987 (T=9 s, H_S=8 m), possible astronomical tide (1.1 m), and predicted storm surge (0.71 m).

Zone:	A	B	C	D	E	F	G	H	I
a) Maximum	11.83	8.80	5.08	3.72	3.52	0.84	0.26	0.26	0.25
b) Sally	7.81	7.32	6.52	5.88	6.05	2.29	0.89	0.91	0.91

Wave heights across the profile that would have resulted from deep-water wave conditions such as those reported from Cyclone Sally, January 1987 are also given in Table 4.3. The calculations show that there is significantly less attenuation of the height of deep-water waves with a shorter period. Figure 4.6 is a plot of deep-water wave period vs. lagoon wave height for initial deep-water waves of 1, 2 and 4 m in height. There appears to be an exponential relationship, as the period becomes shorter relative to the wave height, the ensuing lagoon wave becomes larger. The plot shows that deep-water waves with a greater than 9 s period have little effect on wave height in the lagoon. Periods below 9 s have a significant effect on lagoon wave height. This corresponds with the predicted lagoon wave heights during Cyclone Sally and indicates that conditions resulting in maximum lagoon waves are likely to be produced by more locally generated shorter period waves. Lagoon wave heights, on the order of those produced by Sally, probably represent maximum conditions for Muri Lagoon.

Young (1989) compared the method of Gerritsen (1981) to determine wave attenuation over the Great Barrier Reef. He compared the calculated results with the actual measurements of waves both in front and in the lee of the reef. The results compared favourably. The data indicated a 90% loss in wave height across the reef. These losses are similar to the predicted wave height attenuation at Muri Lagoon

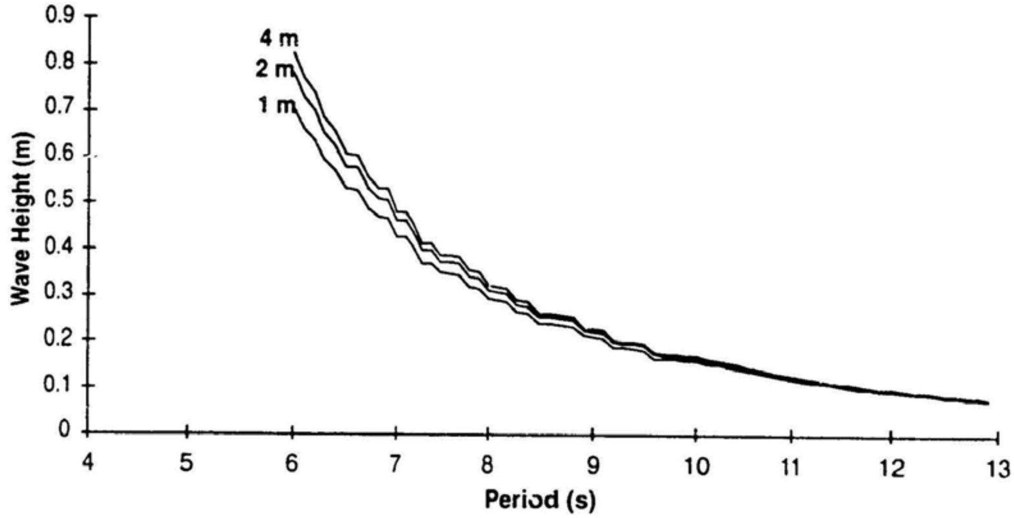

Figure 4.6 Deep-water period versus wave height in the lagoon for deep-water waves of 1, 2, and 4m in height.

4.2 Wind Generated Waves

Carter and Steer (1984) predicted the height and period of wind generated waves in Muri Lagoon. He used wind data collected at Rarotonga from 1958 to 1979. The Carter and Steer (1984) wind data is similar to that given by Thompson (1986) presented in Chapter 1 and shows that average winds at Muri are from the east at approximately 11 kts. Maximum sustained winds are approximately 35 kts. Carter and Steer (1984) calculated the period and height of waves generated from winds with a fetch of 0.5 NM (925 m) in water depths that averaged 2 m. The average condition of winds blowing at approximately 11 kts (5.6 m/s) produces a wave of 1.26 s period and 0.12 m in height. Maximum wind conditions produce a wave having a period of 2.18 s and a height of 0.40 m. These values should be seen as very liberal since the water in the lagoon averages about 1.25 m and the fetch is closer to 700 m.

4.3 Unidirectional Currents

4.3.1 Station 1 Ngatangiia Harbour

Analysis of data from Station 1 indicates that the current direction is predominantly easterly, flowing out of the harbour over 80% of the time (Fig. 4.7), (Holden 1991). There is a strong tidal-induced fluctuation in direction resulting in short periods with a westward flow. Current speed varies with the tidal cycle and reduced speeds occur during rising tides. Current speeds range from a 6.5 to 41.1 cm/s (Table 4.4). The average current velocity is 15.83 cm/s with the modal direction being 91° true. The measured range in water level at this station is 0.75 m. The range in water level is probably due to tidal influence and to a lesser extent to set-up in the lagoon.

Table 4.4 Descriptive statistics from the data collected at Station 1. Data represents one sample every 15 minutes for approximately seven weeks, except for velocity in which the sensor failed after approximately three weeks

	Direction (True)	Velocity (cm/s)	Temp. (°C)	Depth (m)	Salinity (ppt)
Mean	148.19	15.95	26.34	9.01	37.45
Standard Error	1.60	0.15	0.01	0.00	0.04
Median	101.00	13.80	26.34	8.97	35.79
Mode	91.00	12.00	25.40	8.89	35.54
Standard Dev.	107.13	6.46	0.94	0.18	2.54
Range	360.00	34.60	6.33	0.75	11.49
Minimum	0.00	6.50	24.07	8.67	32.26
Maximum	360.00	41.10	30.40	9.42	43.75
Count	4499	1874	4499	4499	4499

The complete record from the current meter at station 1 is presented in Figure 4.8. Average current velocities at December 11 - 14, 1990 were between 12 and 16 cm/s. The average velocity increased to 27 cm/s by December 16 and remained at that figure for two days. The velocities then dropped to 11 cm/s and remained there for the rest of the recording period, except for a spike at December 22 when the 15 cm/s was observed.

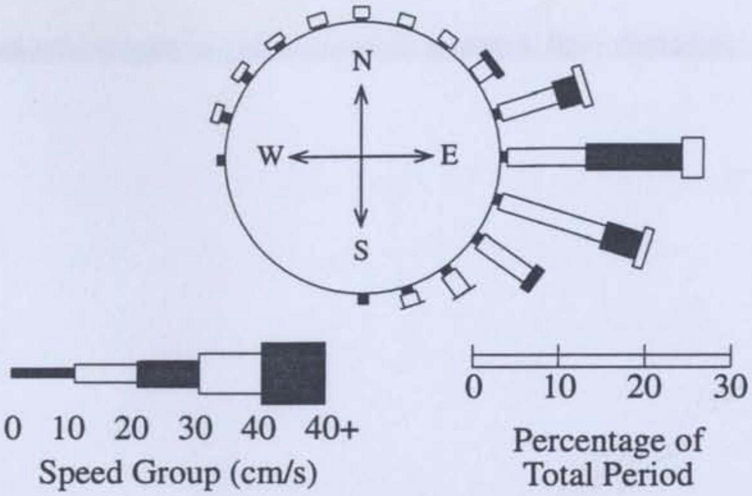

Figure 4.7 Current rose for Ngatangiia Harbour (after Holden 1991).

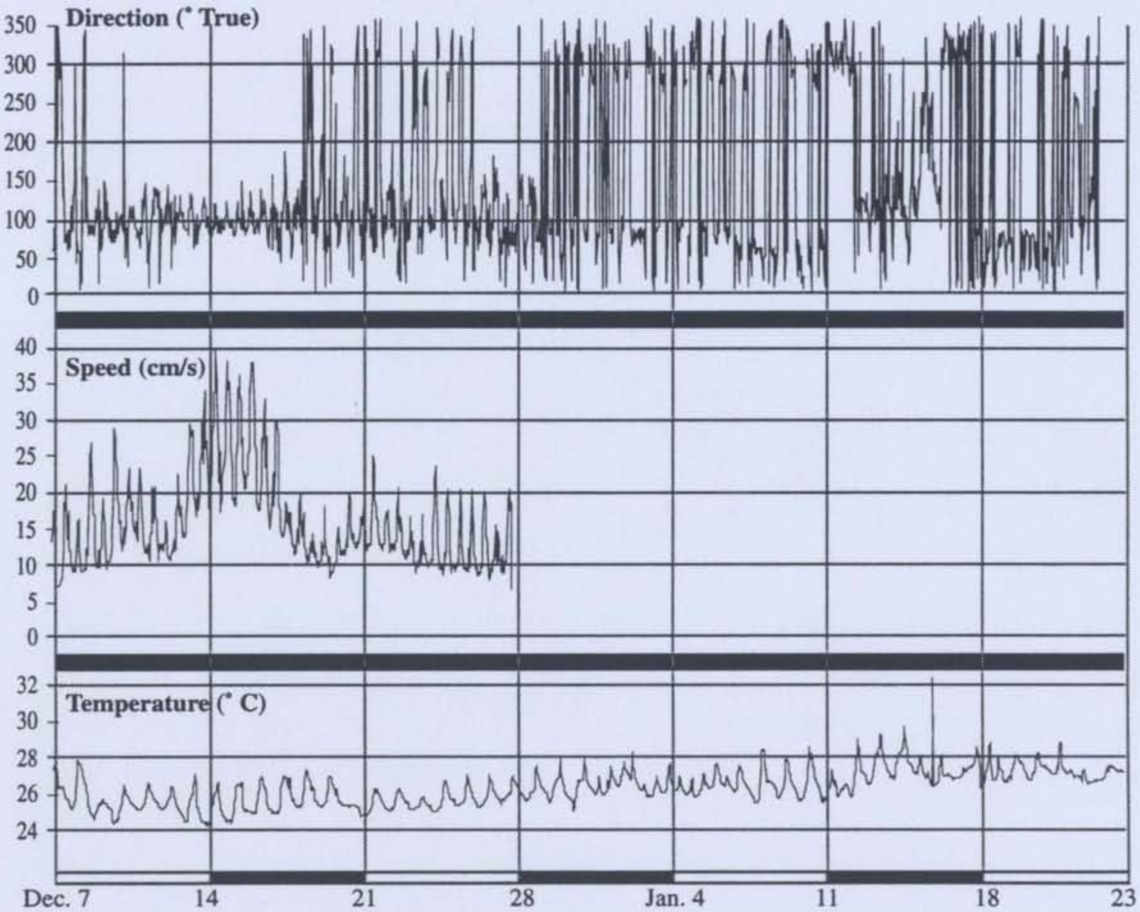

Figure 4.8 Current meter data from Ngatangiia Harbour including salinity, temperature, E-W component of current, speed, and direction.

The current velocity maxima correspond to easterly flow direction. The direction of the highest one third of velocity measurements ranges from 56° to 151° with an average of 90°. The average velocity of the highest one third measured was 32.67 cm/s. These velocities represent approximately 7% of the measurements taken over the recording period but which are concentrated over three days, December 14-17, 1990.

Salinities at Station 1 ranged from approximately 32 ‰ to 44‰ with an average of 37‰. High salinities correspond to ebb tides and the highest one-third of salinities measured correspond with current velocities averaging 15 cm/s in an easterly direction.

Temperatures at Station 1 ranged from 24°C to 30°C with a mean of 26.34° C. Water temperatures in Ngatangiia Harbour showed diurnal heating and cooling with the warmest temperatures in mid-afternoon and the coolest temperatures just before dawn (Holden, 1992). While there were indications of a slight inverse relationship between current speed and temperature, it is clear that temperatures during the December recording period were always less than 26° C when current speeds were over 30 cm/s. There was a seasonal warming trend in the water temperatures measured over the time the instrument was in the water. This was consistent with the regional sea surface temperatures (Thompson, 1986).

4.3.2 Station 2 Oneroa/Koromiri Gap

Station 2 was located between Oneroa and Koromiri. Over the recording period of about 30 hours, the current speed varied with the tide and ranged between 7 cm/s and 28 cm/s with an average speed of 16 cm/s. The direction was predominantly northwest with only 2 records indicating an easterly direction. Salinity was approximately 35‰. The temperature varied from 23°C just before dawn to 27°C in late afternoon.

4.3.3 Station 3 Fish Trap

At Station 3 the current meter was moored in the weir of the fish trap. At high tide the top of the trap was approximately 10 cm below sea level. The trap extended almost completely across the channel and through most of the tidal cycle all the water moving from the lagoon and through the Oneroa - Koromiri gap passed through the trap. Riedel and Byrne (1990) observed that, throughout most of the tidal cycle, there was supercritical flow across the trap evidenced by a 20 cm drop in water level suggesting that the trap controlled the flow from Muri Lagoon (Plate 4.3). During the 16 hour recording period the current speed varied with the tidal cycle between 34 cm/s and 95 cm/s with an average of 65 cm/s. Salinity and temperature average 35‰ and 24.5°C respectively.

4.3.4 Station 4 Muri Lagoon

Descriptive statistics from the current meter record of Station 4 are presented in Table 4.5. The data from Station 4 indicate a predominantly northeastward flowing current as seen on a rose diagram. (Fig. 4.9).

Speed varied diurnally, being reduced on the rising tide (Fig 4.10). Current speed ranged from zero to 38.1 cm/s with a mean value over the entire recording period of 6.72 cm/s. The daily fluctuation in speed reached a maximum of approximately 30 cm/s. "Spikes" of increased current speed on the order of 3 - 10 cm/s were evident in the record and occurred on December 19, 22, 28, 1990 and

January 8, 1991. The current flowed to the north, in the direction of Ngatangiia Harbour, for more than 70% of the time. Current speeds averaged 8.3 cm/s in this direction. Current flowed to the south, into the lagoon, approximately 20 % of the time. The speed in this direction was significantly less, averaging 2 cm/s.

The salinity ranged from 29.34‰ to 40.88‰ with a mean of 35.39‰ . The lagoon became slightly less saline over the recording period. The average salinity of north flowing waters was slightly more than those flowing south.

Plate 4.3 Photo of the large fish trap in the channel between the northern end of Oneroa and the mainland. Channel flow is from right to left.

Table 4.5 Descriptive statistics from the data collected at Station 4. Data represent one sample every 15 minutes for approximately seven weeks.

	Direction (True)	Velocity (cm/s)	Temp. (°C)	Depth (m)	Salinity (ppt)
Mean	88.32	6.72	27.22	0.41	35.39
Standard Error	1.59	0.12	0.03	0.00	0.03
Median	25.00	3.90	27.08	0.41	34.80
Mode	22.00	0.00	26.98	0.41	34.47
Standard Dev.	102.13	7.39	1.74	0.14	1.72
Range	360	38.10	9.62	0.76	11.54
Minimum	0.00	0.00	23.72	-0.04	29.34
Maximum	360.00	38.10	33.34	0.72	40.88
Count	4120	4120	4120	4120	4120

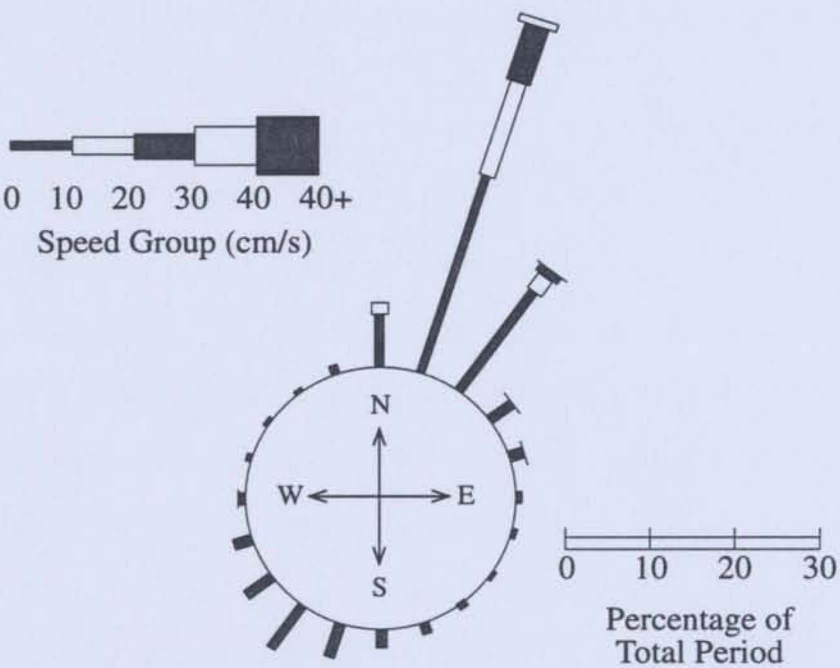

Figure 4.9 Current rose for Station 4, Muri Lagoon (after Holden, 1991).

Water temperatures in the Lagoon showed diurnal heating and cooling with the warmest temperatures in mid-afternoon and the coolest temperatures just before dawn. Average temperatures over the recording period ranged from 23.7°C to 33.4°C with a mean of 27.22°C. This is almost a full degree cooler than at Ngatangiia Harbour. The average temperature of north flowing water was 27.4°C while south flowing waters averaged 26.9°C. Observational evidence at the confluence of waters flowing from the lagoon and those flowing through the gap between Motutapu and Oneroa indicated a distinct temperature difference. Holden (1991) reported an inverse relationship between current speed and temperature at this station. This may be because as the current speeds increased, water in the lagoon would move faster through the lagoon and be less affected by diurnal heating. Water temperature showed a warming trend consistent with seasonal variations (Thompson, 1986).

4.3.5 Drogue Tracking

The drogues were released at low tide, at which time the lowest lagoon current speeds are expected. The drogues released in December drifted west and then north (Fig. 4.11). The three southernmost drogues approached the beach and became grounded. The northernmost drogue passed south of Koromiri, turned to the north and flowed down the channel. Drogue speeds averaged between 2 cm/s upon release and 7 cm/s as they turned to the north and approached the channel. The increase in speed was likely the result of a slightly faster longshore current along the beach and a faster current as the channel becomes constricted between Koromiri and the shore. Both drogues released in January immediately travelled to the north and grounded east of Koromiri.

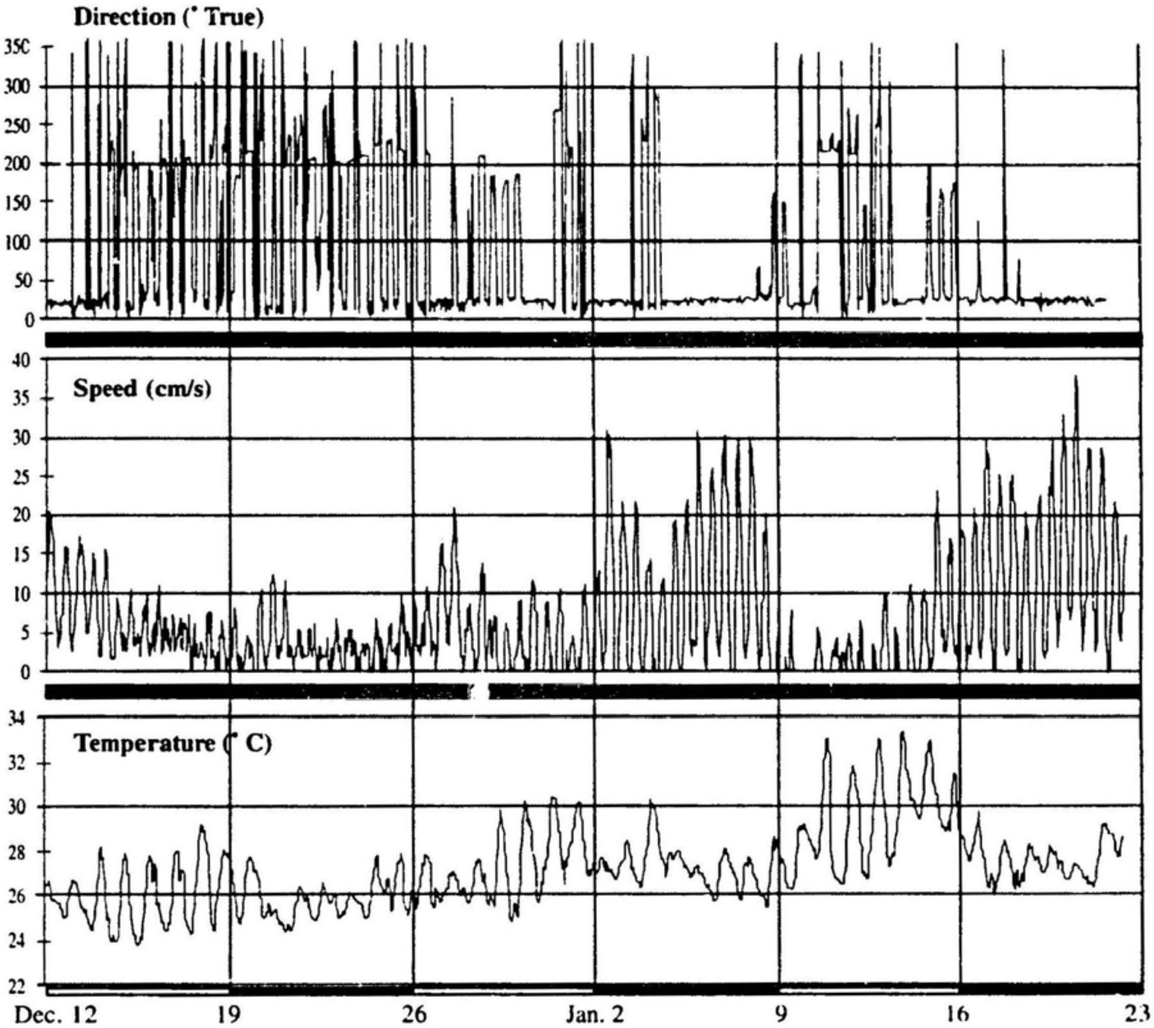

Figure 4.10 Current meter data from Station 4, Muri Lagoon including direction, speed and temperature.

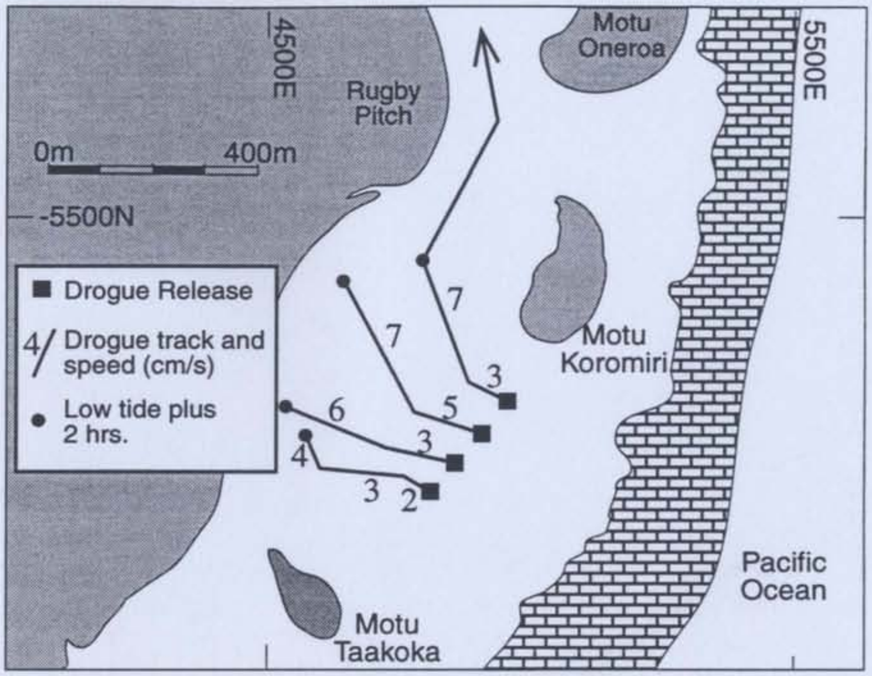

Figure 4.11 Location of drogue drift tracks and times and approximate speeds in Muri Lagoon.

4.4 Interpretation

Circulation in the lagoon and harbour is driven by the interplay of the tide and the set-up caused by water transgressing the reef. These two forcing mechanisms are interdependent. The ability of waves to carry water into the lagoon is to a large extent dependent on the height of water over the reef crest which is a function of tide. The super-elevation of water in the lagoon influences current speeds in the channel and harbour causing almost total one-way flow to the north . On a small scale, relative current velocities vary with the tide. Velocities increase to a maximum during ebb tides and decrease during flood. A detailed view of two different three-day sections taken from Ngatangiia current meter is presented in Figure 4.12.

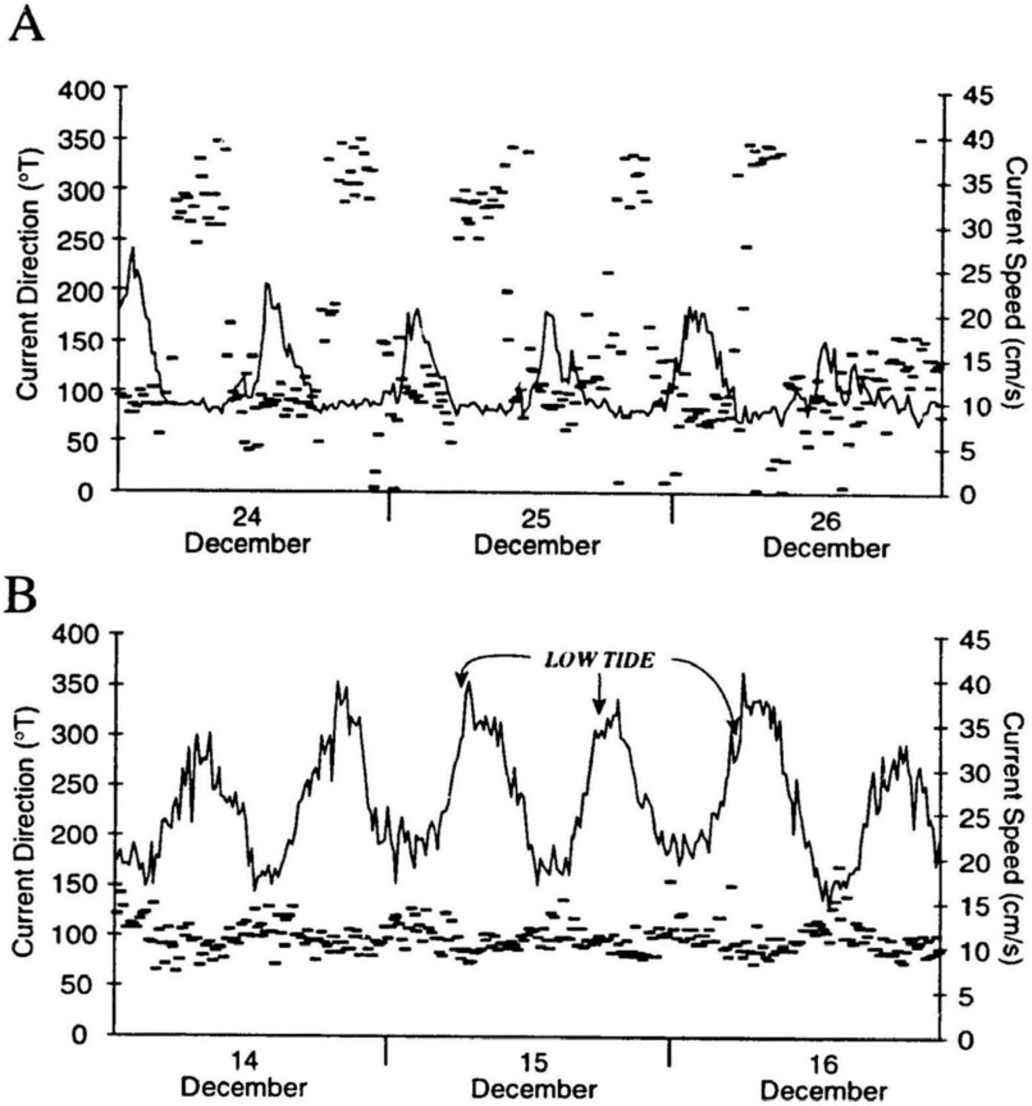

Figure 4.12 A detailed view of two, three day sections from the current meter at Station 1, Ngatangiia Harbour. Section A was recorded between 12/24/90 and 12/26/90; section B was recorded 12/14/90 and 12/16/90.

The peaks on the records correspond generally with the timing of the low tide. When the average current speed is below 20 cm/s (Fig 4.12a) the direction of flow changes with the tide to produce a net westerly direction into the harbour. When the average velocity is greater than 20 cm/s (Fig 4.12b) there is no change in the direction of flow. There is no appreciable difference when comparing the tidal range for these two periods. The current flow in and out of the harbour is likely the result of the interplay between tidal induced flow (in and out) and flow from wave set-up in the Lagoon (out). In the days when there is no change in net flow direction it can be assumed that the flow out through the passage caused by the set-up waters in the Lagoon is always greater than the inward flowing tidal component. The reduction of flow is therefore a result of the incoming tide acting in a direction opposite to the outflow. Over the period 12/14/90 to 12/16/90, the tidal component is between 15-20 cm/s.

Another way to consider expected daily maximums and minimums at Ngatangiia is to plot of the tidal cycle and the cycle of lagoon set-up based on the tides (Fig. 4.13). It is anticipated that there will be a phase lag between tidal level promoting flow over the reef and super-elevated conditions in the lagoon. The phase difference between the two, one quarter of a cycle, suggests that maximum outward flow at Ngatangiia Harbour should occur in the last quarter before low tide. This corresponds with the quarter just after the highest water level in the lagoon. The minimum flow out the harbour is expected to correspond with the quarter of the cycle just before high tide. At this point the lagoon is at its lowest level.

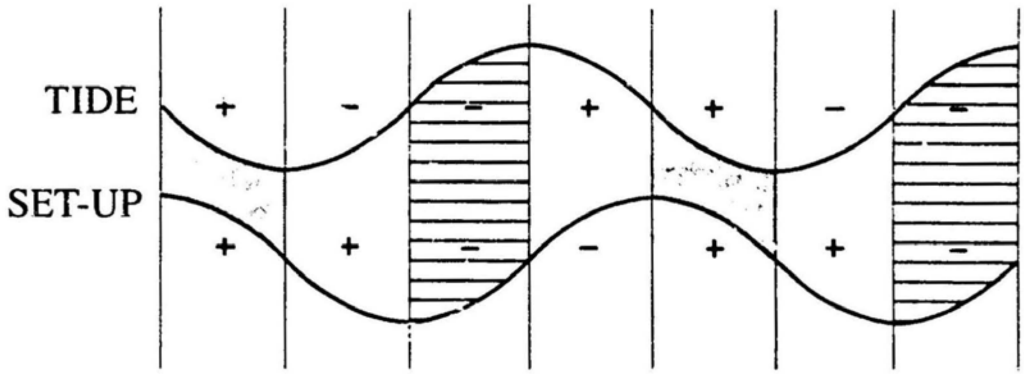

Figure 4.13 Conceptual diagram of expected positive and negative influence on flow out through the reef passage at Ngatangiia Harbour due to tide and set-up in the lagoon. The plus sign indicates an increase in the flow out of the harbour and a minus sign indicates a decrease in the flow out of the harbour.

These expectations appear to be borne out by the data in Figure 4.12b where the maximum recorded flow out of the harbour occurs just before low tide with the corresponding lowest speeds occurring just before high tide.

Holden (1992) noted that the direction given by the Muri Lagoon current meter was out of phase with the expected ebb and flow directions. The data indicate they were out of phase by 6.5 hours with the water level record in Muri lagoon and 4 hours with the predicted tide level. (Muri lagoon was out of phase with the predicted tide by about 2.5 hours). There appears to be good correlation between current velocity and water level.

In terms of absolute current speeds Holden (1992) reported that there is a direct relationship between deep-water wave height and current speed in the lagoon and harbour. Using linear regressive analysis Holden (1992) developd an equation to relate wave height to filtered (tidal component removed) current. This equation is given by:

$$S = 17.3602 * H - 22.3877 \qquad (4.19),$$

Where S is the current speed in cm/s and H is the deep-water wave height in metres.

The maximum significant wave height recorded in the period 1987-1991 was 7.6 m. This value would correspond with a current of 109.05 cm/s.

A further demonstration of the influence of deep-water waves on lagoon circulation comes from a plot of the current meter records of Station 1, Ngatangiia Harbour, and Station 2, Muri Lagoon (Fig. 4.14). The thick grey line is a rough approximation of "Stokes Drift" which is a measure of the amount of water carried forward by each wave and can be given by H_{sig}^2/T. There is a very good correlation between the current meter records and the deep-water wave record.

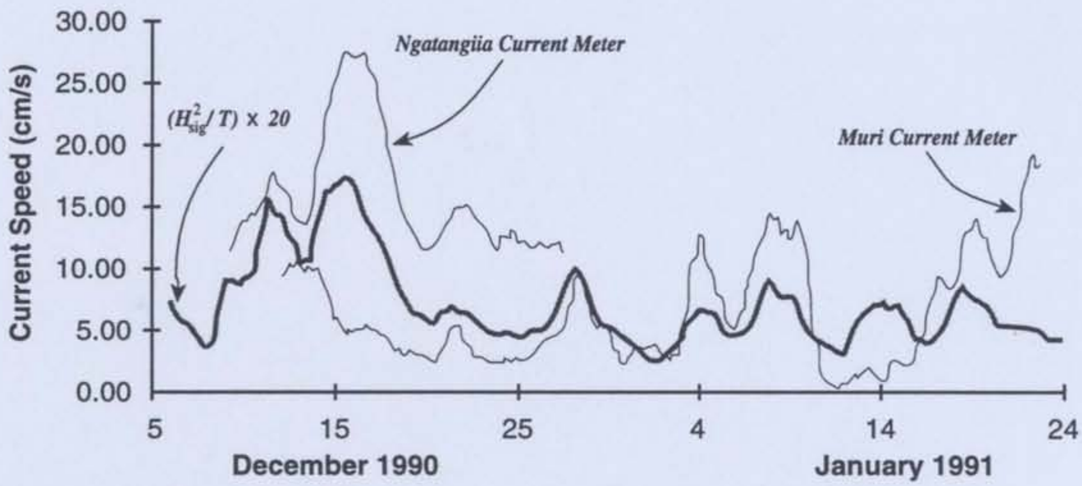

Figure 4.14 Plot showing variation of current speed for Ngatangiia Harbour and Muri Lagoon for the period 12/05/90-01/24/91. The thick grey line is the plot of (H^2_{sig}/T) * 20 for the same period.

4.5 Summary

1. There is a greater than 90% reduction in deep water height as a characteristic wave moves over the reef at Muri Lagoon

2. The submerged height of the reef is a controlling factor in wave height attenuation over the reef.

3. There is a direct correlation between the characteristics of deep water waves and lagoon/harbour circulation.

4. The current flow out Ngatangiia Harbour is primarily a result of superelevated water levels caused by wave set-up.

5. Diurnal variability in current speed and direction related to tides is observable in both the lagoon and harbour.

CHAPTER 5 SEDIMENTARY GEOLOGY

5.1 Physiography and Sedimentary Units

The major physiographic units in Muri Lagoon and Ngatangiia Harbour are the outer reef, inner reef, motus and beaches (Fig. 5.1). Under normal conditions the surficial geology is a reflection of the balance between the input of sediment, in this case largely through the breakdown of reef organisms and the transport of sediment out of the system. Cyclone and other storm events shape macro-features such as motus and redistribute sediment on a large scale. The units identified in this study are a composite of the major physiographic features, depositional environments and sedimentary deposits. Table 5.1 summarizes the major physiographic features of Ngatangiia Harbour and Muri Lagoon and their respective areas.

Table 5.1 Physiographic features of Ngatangiia Harbour and Muri Lagoon.

Feature	**Area (m^3)**
Outer reef	446,039
Inner reef	1,193,073
Motu Tapu	105,024
Motu Oneroa	81,389
Motu Koromiri	29,328
Motu Taakoka	12,657

Seven units are defined for this system. They are outer reef flat, inner reef flat, altered reef flat, lagoon, strand line, river gravel and *Porites* boulder fields. Areas of accumulation of coral boulders, maketea, and vegetation have also been identified.

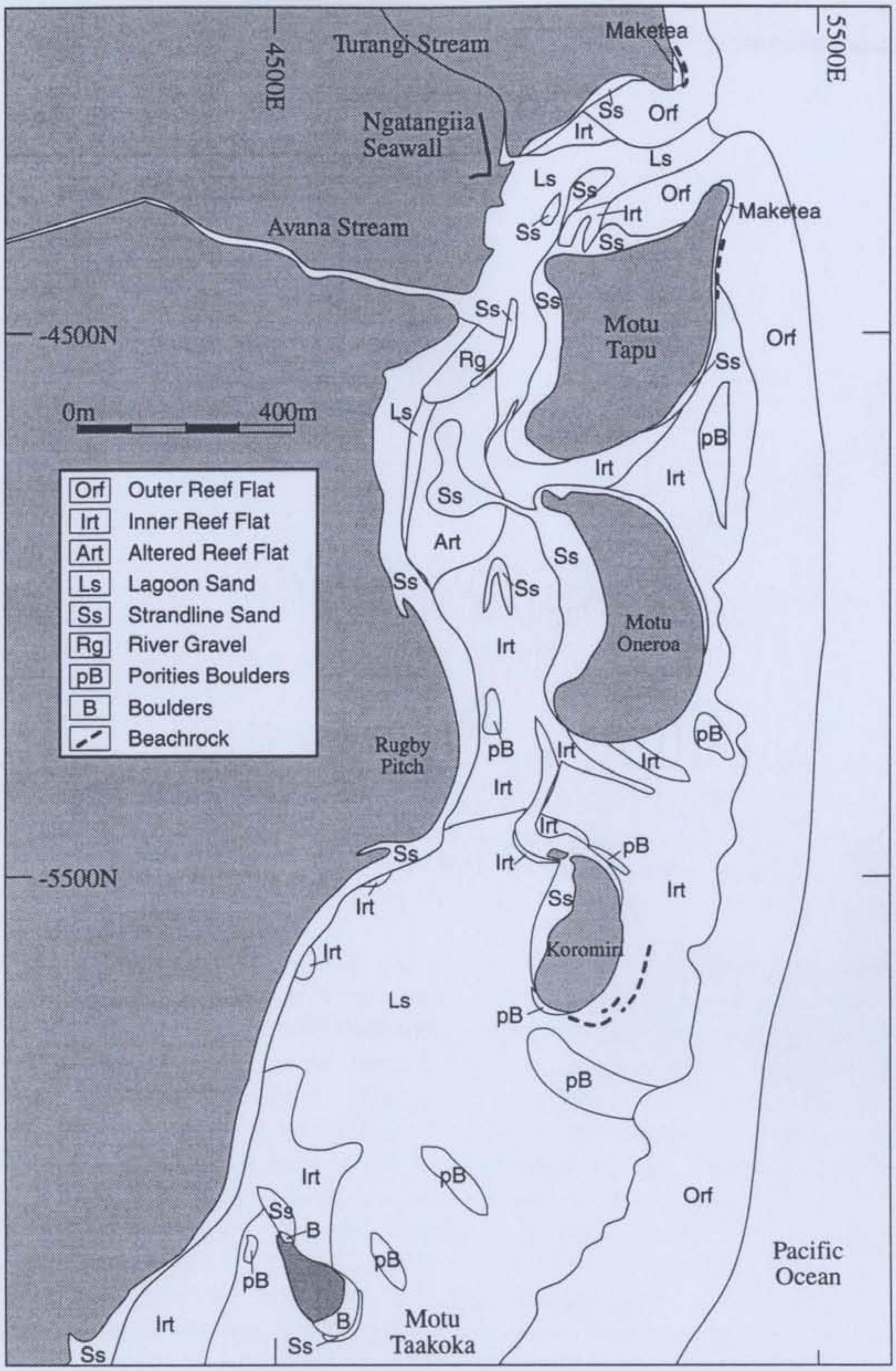

Figure 5.1 Major physiographic and sedimentary units of Ngatangiia Harbour and Muri Lagoon

The outer reef flat occurs from the seaward edge of the reef to the lower lying inner reef flat. The inner reef flat occurs between the outer reef flat and the beach and for the purposes of this study has been subdivided into a number of distinct units. The inner reef flat unit in Figure 5.1 is where algal pavement is exposed. The altered reef flat describes areas where the algal pavement has undergone diagenesis. Overlying the algal pavement on the inner reef flat are various sedimentary units described as lagoon bed sand, strandline sand, river gravel, large boulders of volcanic and biogenic origin and beachrock.

5.1.1 Outer Reef Flat

North of the harbour entrance the outer reef flat is 70 m wide and directly adjacent to the beach. The seaward edge of the outer reef flat parallels the shoreline and extends into the Ngatangiia Harbour. South of the harbour the outer reef flat extends south from the northeast tip of Motu Tapu and ranges between 100 and 250 m in width. It is approximately 0.45 m deep and portions are exposed at low tide (plate 5.1). The landward edge is not uniform but consists of a series of tounges pointing landward. Scoffin (1993) described these features as " toungues of shingle" formed as depositional features following a hurricane. They are best developed seaward of motus Oneroa and Koromiri and consist of coral rubble. The outer reef flat is a high energy environment with coral blocks up to 0.5 m in diameter on an algal pavement. The blocks originated as framework corals living on the reef crest and fore reef. A veneer of biogenic sand up to 30 cm thick in local depressions overlies the pavement.

Plate 5.1 Photograph of a portion of the outer reef flat exposed during low tide. The photo location is just east of Koromiri. Field of view in the immediate foreground is 20 m.

At the seaward edge of the outer reef flat the algal rim or reef crest has a serrated edge with typical spur and groove topography. During periods of high wave activity when water moves through the surge channels, corals are torn from the reef front and deposited on the reef flat. It is probable that a significant cause of coral mortality on Rarotonga is due to hurricane damage (Gibbs et al., 1971). Sediment is produced at the fore reef and reef crest areas through the breakdown of massive and framework coral and coralline algae.

5.1.2 Inner Reef Flat

The inner reef flat has been described by Richmond (1990) as occurring between the outer reef flat and beach. For the purposes of this discussion the inner reef flat defines areas where sediment cover is relatively thin and the algal pavement is exposed. Water depth over the inner reef flat ranges to 0.7 m deep. Portions of the inner reef flat are exposed at spring tide. The inner reef flat in the channel area has a mottled appearance with numerous coral blocks overlying it. Sediment cover is generally less then 5 cm with biogenic sand infilling pockets in the pavement.

Scoffin et al. (1985) documented the existence of free-living Coraliths and Rhodoliths in an area of the channel just south of the large fish traps. Examination in the field indicates their continued existence and abundance.

5.1.3 Altered Reef Flat

The area defined as altered reef flat is essentially a part of the inner reef flat that has been diagenetically altered. This feature has been the focus of much discussion by previous investigators (Kirk, 1980; Carter and Steer, 1984). Kirk described it as hard pan and/or hard coral basement. Carter and Steer (1984) described it as a "crust" or "hard-ground", 15 cm, to 20 cm in thickness underlain by sand and in places by a sticky red brown clay material.

During this investigation several samples of the rock were taken. Probes were made to determine its thickness and underlying substrate. The altered reef flat appears to be continuous with the reef flat to the south and dips under the river gravel to the north (Fig 5.1). It also appears to be continuous on a cross section between the mainland and Oneroa. This is contrary to the suggestion of Carter and Steer (1984) that a 10 m wide channel existed parallel to the shore of Oneroa. Bathymetric surveys indicate that the area is, in fact, hummocky with a series of small east-west ridges. The surface of the altered reef flat is not as smooth as the other exposed inner reef flat areas. It contains many cavities and depressions.

The substrate consists of an algal pavement with cemented biogenic sand grains, mollusc shell and cobble size coral fragments. Terrigenous sediment accounts for less than 5% of the total composition. In places, dead coral appears to be in original growth position. Cavities have been filled with sand. There is evidence for both dissolution and cementation.

Meniscus cement binding of sand grains seen in thin sections of samples of the altered reef flat are evidence of cementation during sub-aerial exposure. Larger sized coral fragments have also been cemented. In one case a mollusc shell was found cemented to a dead coral in apparent original growth position.

Diagenetic alteration of the rocks may be caused by a high groundwater table. This section of reef flat is sub-aerially exposed at spring tide and likely influenced by meteoric waters. Leslie (1980) indicates that soils directly adjacent to the area are very poorly drained.

An attempt was made to determine the existence of the hard-pan over unconsolidated material as suggested by Carter and Steer (1984). A hole was cut through the surface layer into unconsolidated sand, but it is not clear if the crust is continuous or if the sand is just infilling a cavity in the reef flat. It seems likely that this portion of the reef flat is undergoing relative rapid cementation similar to that described by Meyers (1987) who described the precipitation of Mg-calcite through the degassing of CO_2.

5.1.4 Lagoon Sand

Lagoon sand is the sediment overlying the inner reef flat in the lagoon channel and harbour. In the lagoon and channel these deposits are generally less than 2m thick. Distinct zones of dark material are observed on both black and white and colour air photographs (Plate 5.2). These are aligned parallel to current direction and measure up to 30m in width. Close inspection of these areas indicate that they correspond to a high density of living Holothurians.

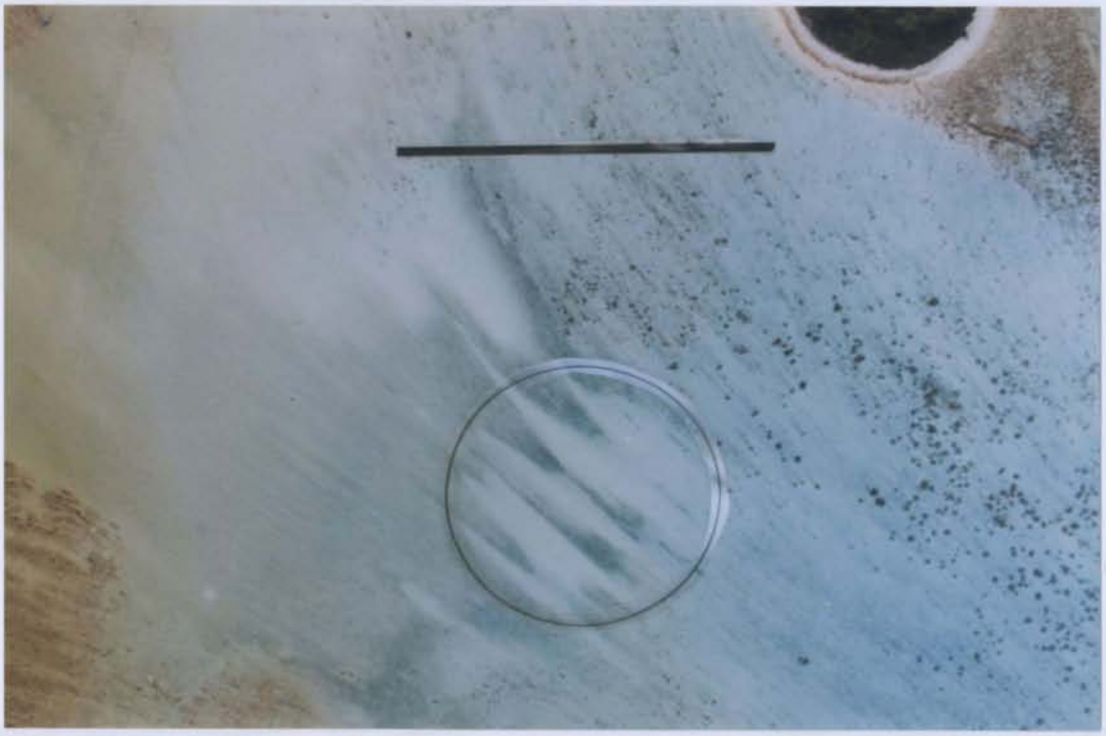

Plate 5.2 Photograph of the center of Muri Lagoon just south of Koromroi showing dark patches (circled) corresponding to high densities of Holothurians. Scale bar is 150 m.

Gibbs et al. (1971) reported densities of Holothurians up to 10 per m^2 on the reef flat of Rarotonga. Large quantities of sediment are ingested by certain Holothurians, which digest the adhering particles of food and excrete the sediment. Examination of the sediment processed by these organisms shows that it is an olive-green colour which may account for the dark zones on the air photographs. The olive-green colour is most noticeable in the 1 mm and 2 mm grain-size fractions. Lagoon sand deposits on the floor of the harbour are considerably thicker than those of the lagoon. Kirk (1980) reports thicknesses of greater than 3 m at the entrance to the reef passage. Subsurface sediment consists of coral sand and river gravel.

5.1.5 *Porites* Boulders

Abundant *Porites* boulders exist in the area, ranging in size from 0.5 m in diameter to over 2 m in diameter. Areas defined as *Porites* boulder fields occur in the lagoon and inner reef flat areas, particular near the landward edge of the outer reef. In these areas the abundance is generally greater than 1 boulder for every 5 m^2. A review of air photographs taken in 1954, 1979 and 1990 indicates little change in the distribution or abundance of the boulders. In a number of cases the same boulder can be identified on the three photographic data sets.

5.1.6 Strandline Sand

These shoreline and associated deposits are sand-sized material forming beaches and spits along the shoreline of the mainland and motus. Sand accumulations are also associated with fish traps in the channel and harbour.

The mainland beach sands are continuous from Taakoka to the Avana Stream (Plate 5.3). The beaches are generally less than 50 m wide except for a somewhat broader section just south of the rugby field. On the west side of the harbour they are unique in that they are mixed sand and gravel containing significant volcanic material. These beach deposits have been extensively artificially reworked and are classed as reclaimed areas.

Plate 5.3 Photograph of the beach along the west side of Muri Lagoon.

Beach deposits developed on the landward side of Koromiri and Oneroa measure a maximum of 40 m and 80 m wide respectively. The landward beach on Motu Tapu is somewhat narrower than on Oneroa, measuring a maximum of 50 m. The beach is anomalously narrow opposite the Avana Stream mouth. The seaward edges of all motus have narrow beaches.

Substantial spit development has occurred. On the west tip of Taakoka a straight sand spit greater than 100 m in length and 50 m wide has developed. This spit appears to be a continuation of a narrow beach deposit on the north side of the motu.

A long sinuous spit has developed from the northern tip of Koromiri (Plate 5.4). The spit is a continuation of the beaches to the east and west of the motu. It is formed as a result the interaction of currents flowing north from the lagoon and east from the outer reef flat between motus Oneroa and Koromiri. The spit is a maximum of 1.2 m in relief.

Plate 5.4 Photograph of the spit at the northern tip of Koromiri motu. Scale bar is 200 m.

All the fish traps in the area are associated with sediment accumulations (Plate 5.5). The largest fish trap has up to 1 m sediment at its centre with a 60 m spit at its apex. A narrow sand bar occurs between a fish trap in the channel and Oneroa.

There are at least two narrow sand spits at the northwest tip of Motu Tapu. The spit closest to the reef flat was first documented by Shepard in 1948, and is observable on the photograph from 1954 (Plate 5.6).

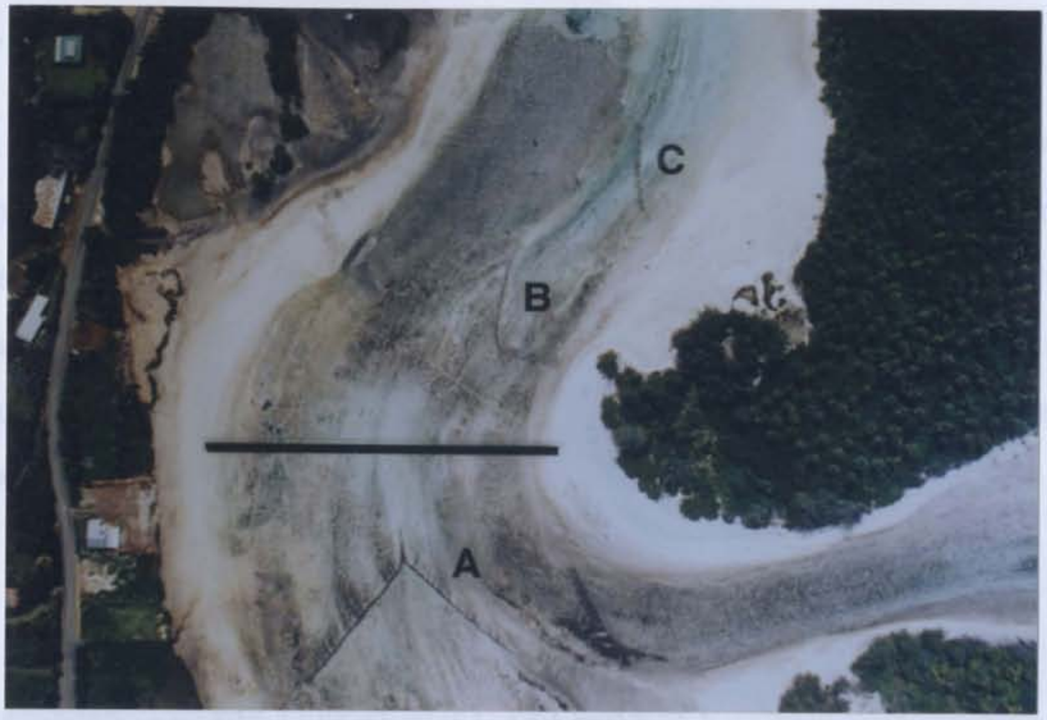

Plate 5.5 Aerial photograph of fish traps in the channel (**A**, **B**, **C**) showing associated accumulations of sediment (lighter areas at the apex of each trap). Scale bar is 200 m.

Plate 5.6 Aerial photograph of Ngatangiia Harbour taken in 1954 showing the spit developed (**A**) at the northwest tip of Motu Tapu. North is to the top of the photo and the scale bar is 100 m.

5.1.7 River Gravels

A delta formed by sediment from the Avana Stream was partially excavated during the mid 1980's. The remaining portion is just south of the present stream mouth and consists of a pebble and cobble armouring overlying sandy gravel with clasts. The clasts range up to 10 cm in diameter and are well rounded (Plate 5.7). The matrix is a mixture of terrestrial sand from the Avana Stream and coral sand from the lagoon. The river gravels are at least 2.1m in thickness (Kirk, 1980).

Plate 5.7 Photograph of the river gravel deposited at the mouth of the Avana Stream. The field notebook is used for scale.

5.1.8 Motus

The three northernmost motus : Motu Tapu, Oneroa and Koromiri, are composed of weakly cemented coral rubble with a sand matrix. They directly overlie reef flat limestone. Lewis (1978) suggested that they formed as the result of deposition of a storm ridge or large rubble bank which was modified by wave action. Modification probably continues today as material is eroded at the seaward edge and transported to the leeward edge. Taakoka is volcanic in composition, probably related to late stage volcanism. Large basaltic boulders surround the motu.

5.1.9 Beachrock

Beachrock is cemented beach material usually consisting of biogenic sand but possibly including other material such as shells, coral pebbles and cobbles. It generally forms 10 - 20 cm below the beach surface from the supersaturation and precipitation of calcite resulting from CO_2 degassing during falling tide (Meyers, 1987). Extensive areas of exposed beach rocks occur south cf Muri Lagoon (Plate 5.8). A small pit was excavated near the high water mark on a beach just south of Muri Lagoon. Weakly cemented sand was evident suggesting active beachrock formation. In the lagoon area beach rock is exposed seaward of Koromiri and is oriented such that it describes an outline that could represent a former beach.

5.1.10 Maketea

Maketea, or raised Cenozoic limestone, occurs in two places at the entrance to the harbour. Wood and Hay (1970) mapped maketea on the east sides of Oneroa and Koromiri and dated a 3 m raised platform at 28,200 yrs BP. Stoddard and Fosberg (1972) claim that this date and other dates on similar raised rocks are suspect and that the raised deposits are more likely to be associated with the maketea of Mangia which was dated at 110,000 ± 50,000 yrs B.P. The makateas represent a former coral reef that was living at a time when sea level relative to the reef was higher likely due to lithoshperic flexure (Woodroffe et al., 1991)

Plate 5.8 Photograph of exposed beachrock located along the beach approximately 100 m south of the study area. The field of view across the centre of the photo is approximately 5 m.

5.1.11 Boulders

Boulders of coral debris are seen in many areas of Muri Lagoon and Ngatangiia Harbour. Where abundant, such as on the northern seaward tip of Motu Tapu, they have been mapped separately. On the north landward edge of Oneroa, the boulders seem to have influenced spit development. This area shows a high density of boulders ranging up to 0.5 m in diameter which were probably moved from the reef during storms. Boulders on the southern end of Koromiri are probably clasts derived from the motu.

5.2 Sediment Composition

The majority of sediments are biogenic in origin. Sediment particles are primarily calcareous algae with Halimeda being dominant. Secondary constituents include molluscs, echinoderms, foraminifera, and coral fragments (Scoffin et al., 1985).

Basalt fragments, which account for most of the non-biogenic material, originate in the hinterland and are transported to the sea by the Avana Stream. The amount of this material ranges from less than 3% in the lagoon and south channel areas to an average of 15% in the harbour to greater than 80% at the mouth of the Avana Stream.

5.3 Sediment Texture

The results of grain-size analysis on 51 samples from the lagoon, channel, and harbour are given in Appendix II. The locations of the samples are shown in Figure 5.2. A broad description in terms of mud, sand, and gravel , shows that all samples contain less than 2% mud. Samples from the harbour and lagoon generally contain over 80% sand. Samples in the channel contain significantly more gravel.

Harbour sediment grain-size statistics are given in Table 5.2. Harbour sediments are unimodal with means ranging between 0.25 and 0.5 mm. The sediment sorting ranges from poor to moderate with a mean value of ø0.82 indicating a moderate sorting. Grain-size curves exhibit a range of symmetry from being near symmetrical to negatively skewed with a mean value for skewness ø-0.04 suggesting a slight negative skewness. Kurtosis, the measure of peakedness of the distribution, has a mean value of ø1.04 indicating a near normal to slightly leptokurtic distribution.

Table 5.2 Mean values for harbour sediment grain-size, sorting, skewness and kurtosis.

Mean Grain Size	0.35 mm
Sorting	0.82
Skewness	-0.04
Kurtosis	1.04

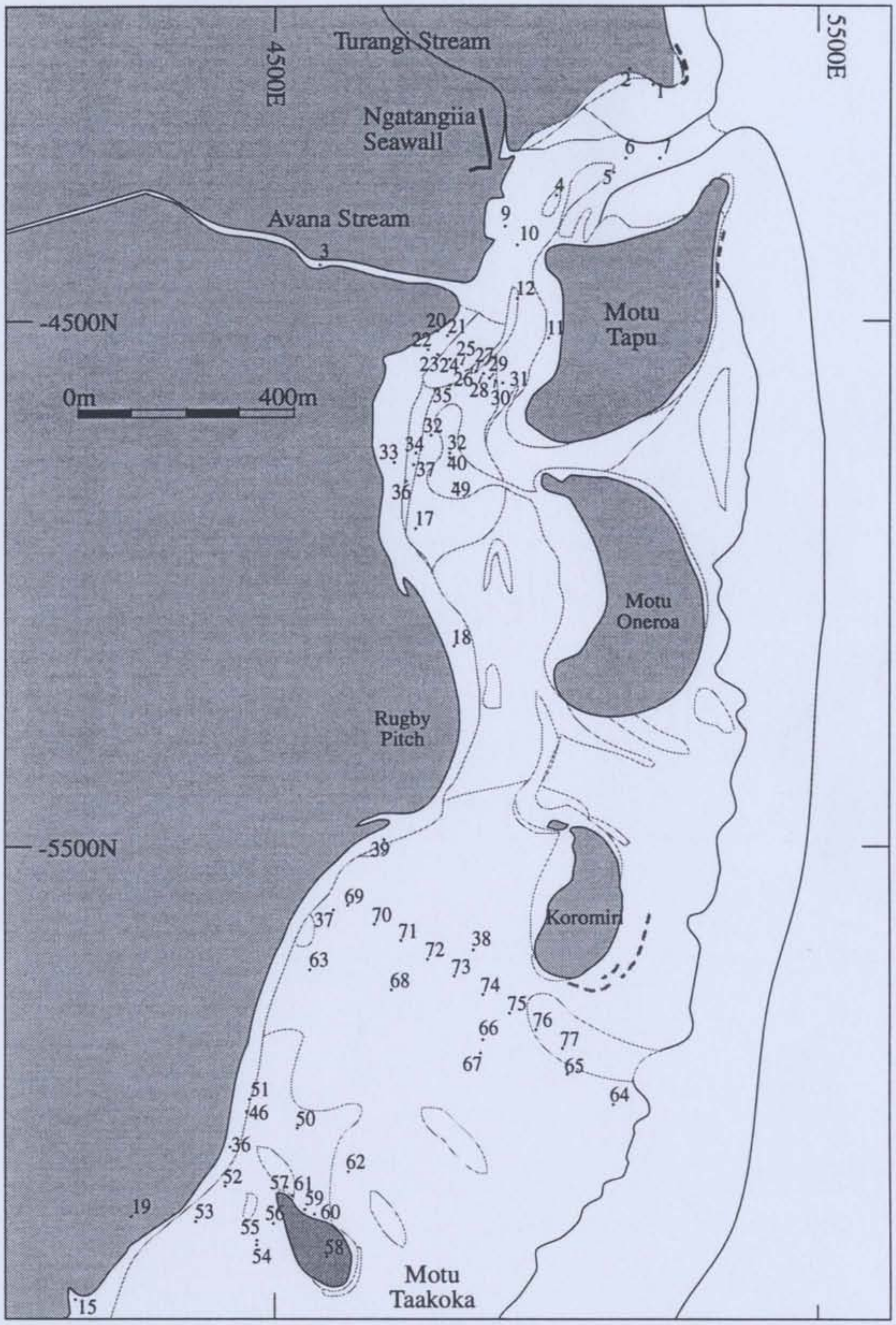

Figure 5.2 Map of sample locations in the study area superimposed on the surficial units described in Figure 5.1.

Grain-size distribution plots of selected samples from the harbour and lower channel are presented in Figure 5.3. Sample 7 is near symmetrical with a mean and mode approximately 0.5 mm and is located in the most constricted point in the reef passage. Samples 6 through 4 are located in the broad channel at the centre of harbour. Mean grain size for sample 6 is slightly more coarse than samples 4 or 5. Samples 4 and 5 have slightly coarse tails. Sample 10 is located in the centre of the channel between Motu Tapu and the mainland. It has a mode of 0.35 mm and a coarse tail.

Samples 12, 21 and 11 are located at the north end of the channel between Muri Lagoon and Ngatangiia Harbour. Sample 12 is from the channel in close proximity to the mouth of the Avana Stream and its gravel delta. It is distinct from the sediments of the harbour by having significantly increased amounts of sediment over 1 mm and less than 0.09 mm. The very coarse fraction, ≥4 mm, was removed from this plot and the distribution recast for the fraction ≥1 mm in diameter. Sample 11, is from the foot of the beach on the inside of Motu Tapu is similar to sample 4 except for a slightly coarser tail. Sample 21 is located in a strandline sand deposit overlying river gravel. It has a distribution similar to sample 10 which is from the centre of the channel.

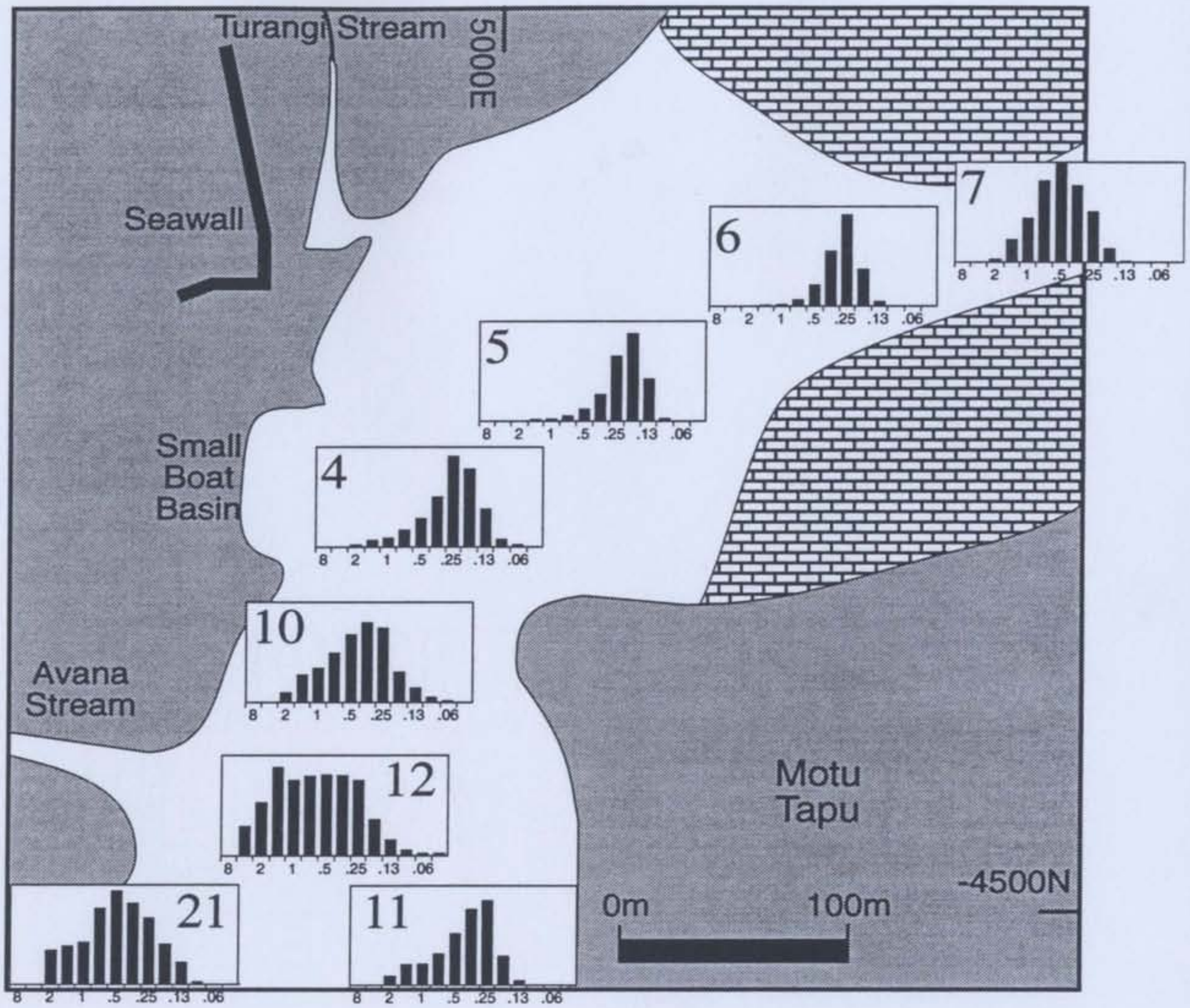

Figure 5.3 Grain-size distributions of selected samples from Ngatangiia Harbour and the northern part of the channel. Grain size in millimetres.

Samples 20, 25, 27, 28 , and 31 represent an E-W transect across the channel at the south end of Motu Tapu (Figure 5.4). Sediment particles over 4 mm in size account for almost 50% of all samples from the channel. For the purposes of this figure the 8 mm and 4 mm size fractions have been removed and the distribution recast. The location of sample 20 is close to the edge of the channel in the vicinity of the gravel delta at the mouth of the Avana Stream. The distribution of the sand fraction is near symmetrical. The mode is 0.35 mm and the mean is slightly coarser at 0.38 mm. Samples 25-28 show a high percentage of coarse material in the 2 mm and 1.41 mm fraction. The fine sizes are bimodal with peaks at 0.71 mm and 0.35 mm . Sample 31 is located near the edge of the channel and shows a similar distribution. Sediment less than 0.13 mm account for less than 2% of the total sand size fraction.

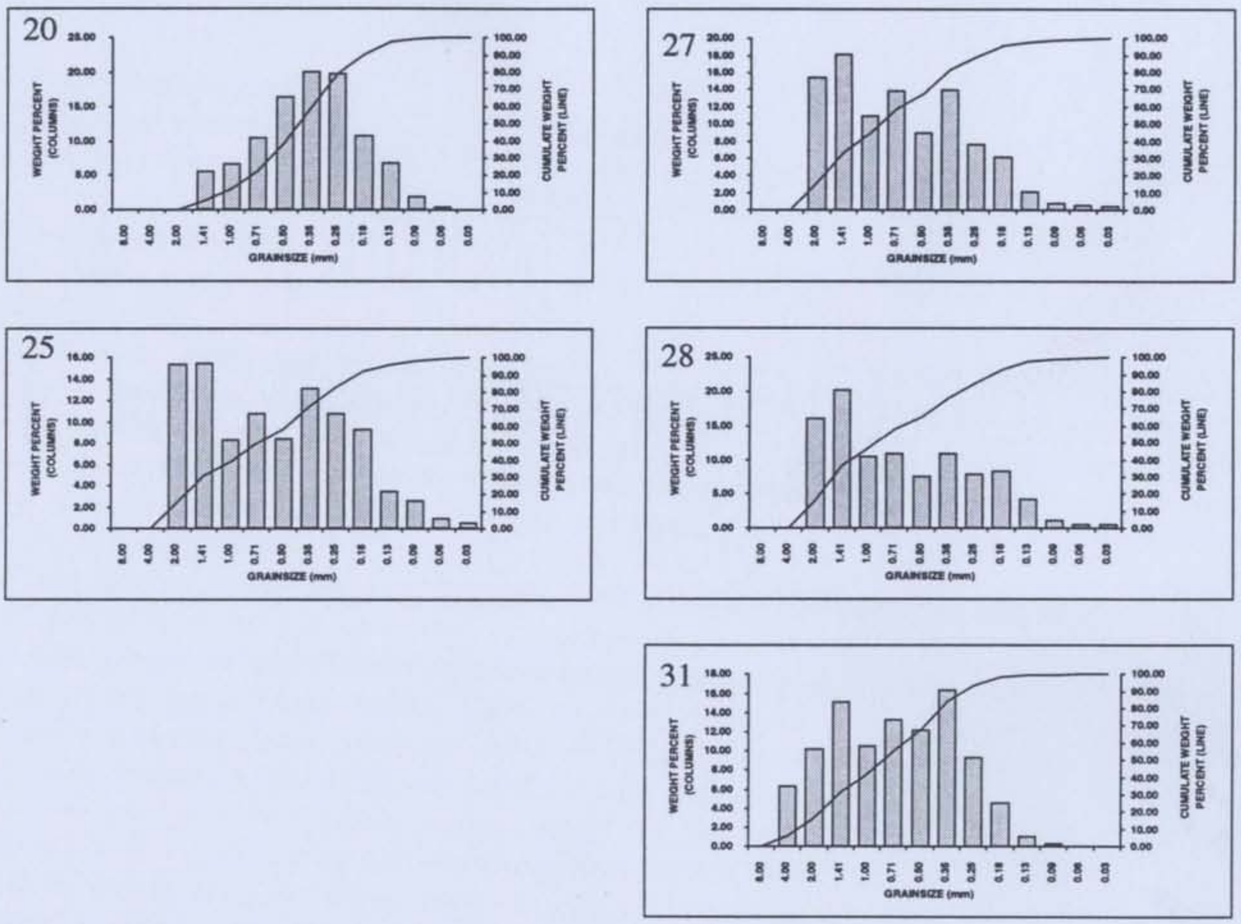

Figure 5.4 Grain-size distributions from selected channel samples. Samples from top to bottom represent a transect across the channel between Motu Tapu and the mainland.

Selected samples from the lagoon are shown in Figure 5.5. Over 95% of the sediments are between 0.13 mm and 2 mm with mean grain sizes ranging from 0.31 mm to 0.91 mm. Grain-size distributions vary but in general are poorly sorted. There is very little symmetry in any of the lagoon samples. The distributions are platykurtic. The grain-size distributions of individual lagoon samples appear to be bathymetrically controlled. Samples located in greater than 1m water depth at MWL are bimodal. Samples 65, 66 and 75 have a primary mode at 0.18 mm and a secondary mode at about 1.41 mm. Sample 62, located approximately 100 m north of Taakoka, is bimodal with the primary mode at 0.5 mm. Sample 64, located close to the shoreward edge of the outer reef flat, has a mean of 0.88 mm with no clear mode. Samples 68 and 71 are in water depths between 0.75 m and 1 m at MWL. They are unimodal with peaks at 1.41 mm and are positively skewed. Samples 63 and 70, are located in less than 0.75 m of water, show no clear mode and are quite platykurtic.

Samples from the lagoon, channel and harbour were plotted on a probability scale (Fig. 5.6). The plot exhibits a significant variability in maximum grain size. The fraction less than 0.25 mm appears similar throughout the samples. The fine sediments are cut-off at between 0.09 mm and 0.06 mm.

The diversity in this plot is likely a function of sediment provenance and hydrodynamic conditions. Grain size in biogenic sediments is limited at the coarse end by the contributing organism. Folk and Robles (1964) noted that, in size vs. sorting curves of carbonate sediments, a number of slightly overlapping distributions corresponding to discrete sediment distributions can be distinguished. They pointed out that mollusc and echinoderm fragments exhibit a normal gaussian distribution with a peak at 4 mm, Halimeda peaks at just less than 1 mm and coral grit (detritus from the breakdown of coral blocks and sticks) peak at 0.25 mm. Their study was based on the collection of beach samples.

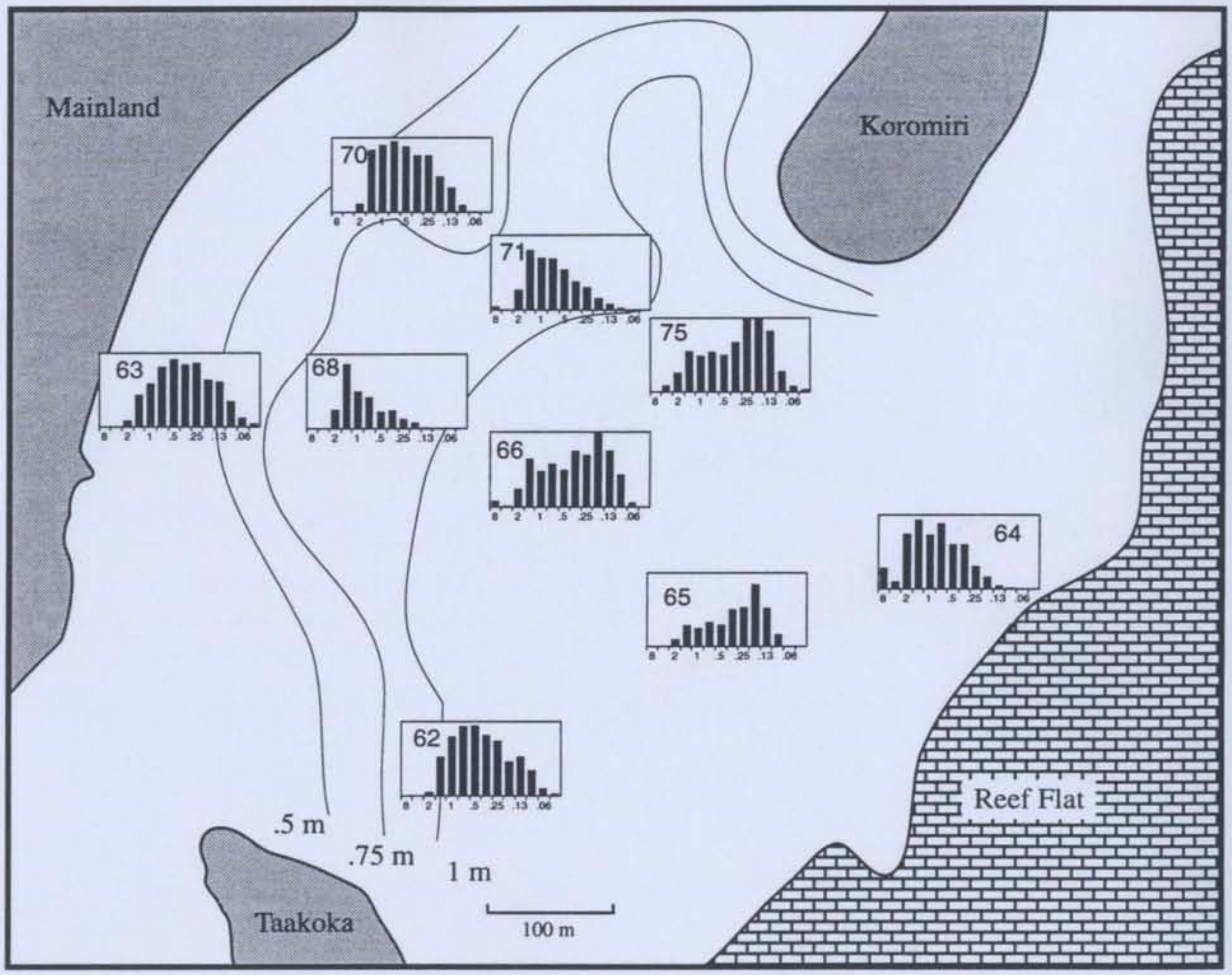

Figure 5.5 Grain-size distributions from selected samples in Muri Lagoon. Grain size in millimetres.

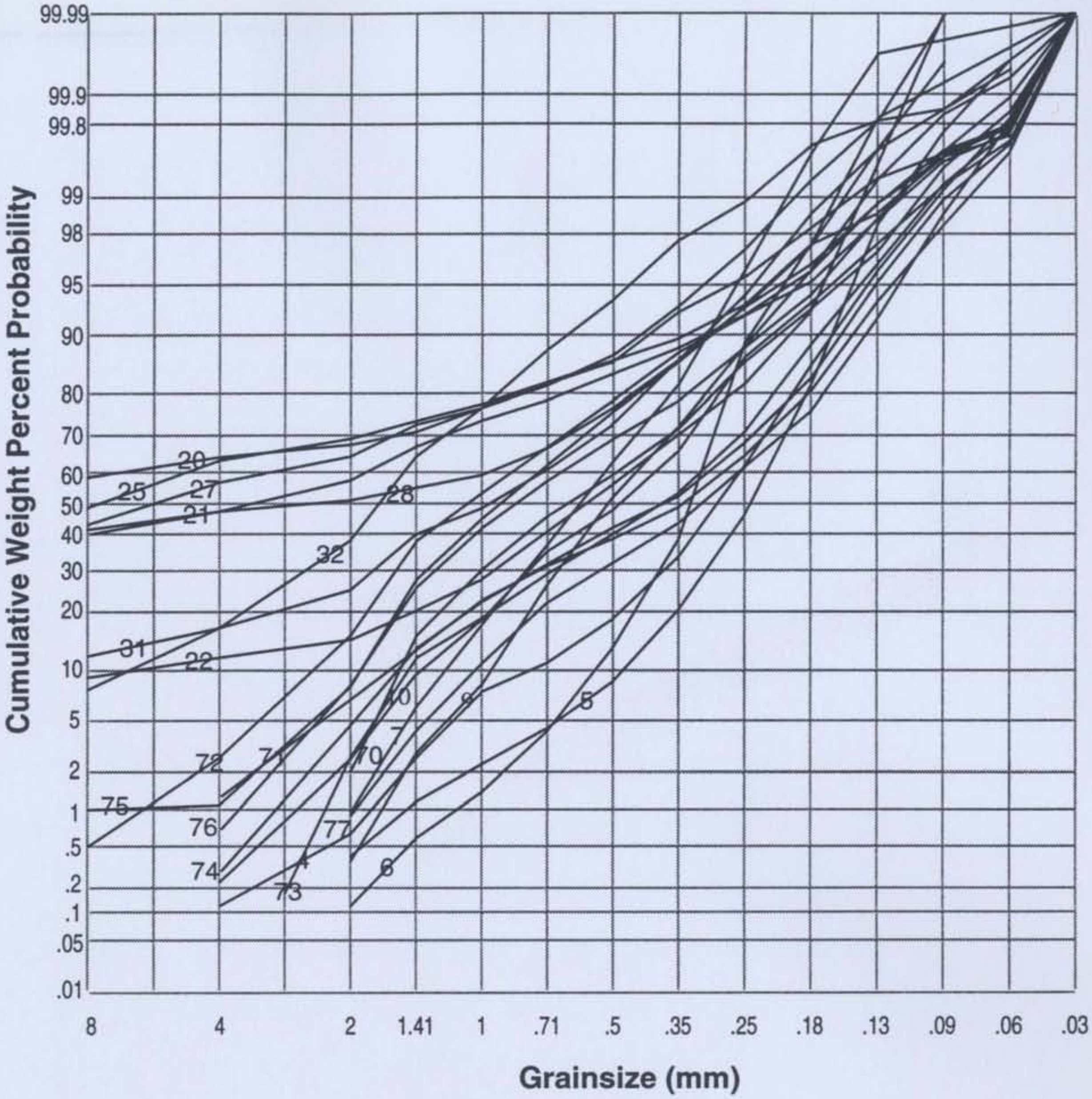

Figure 5.6 Cumulative frequency probability plotted against grain size for samples from the harbour, channel and lagoon.

The biogenic sediments in Muri Lagoon and Ngatangiia Harbour consist mainly of Halimeda, calcareous red algae, mollusc, echinoderm, and coral fragments (Scoffin et al., 1985). Maximum grain size of skeletal carbonate from this area is estimated from examination of living organisms. Halimeda flakes or segments are approximately

5mm, calcareous red algae such as the Rhodoliths have branches that can be 1 cm long and 3 mm in diameter. Echinoderm, mollusc and coral fragments can range in size to tens of centimeters.

Stoddard (1978) noted that it is not only the grain size originally produced by the organism that influences the distribution but how the skeleton breaks down. He pointd out that the coral *Acropora cervicornis* first yields a population of sticks and then coral grit. Halimeda produces flakes which break down into silt size material. A plot of grain size and sorting was constructed to identify any possible correlation (Fig. 5.7). The plot shows a reasonable correlation between better sorted sediments and smaller grain size. However there is little evidence of better sorting at specific grain sizes, as might be expected given the dominant sediment producing organisms present.

The influence of sediment provenance on grain-size distribution is apparent where the input of clastic material is predominant, such as near the stream mouths and where volcanic bedrock outcrops at the shore. Correlation beyond that is obscured by the fact that new sediment is being introduced into the system at most points along the transport path. Examples include material being produced along the reef and brought in through gaps in the motus. Further biogenic sediment is produced by organisms such as the Coraliths and Rhodoliths in the channel, identified by Scoffin et al. (1985).

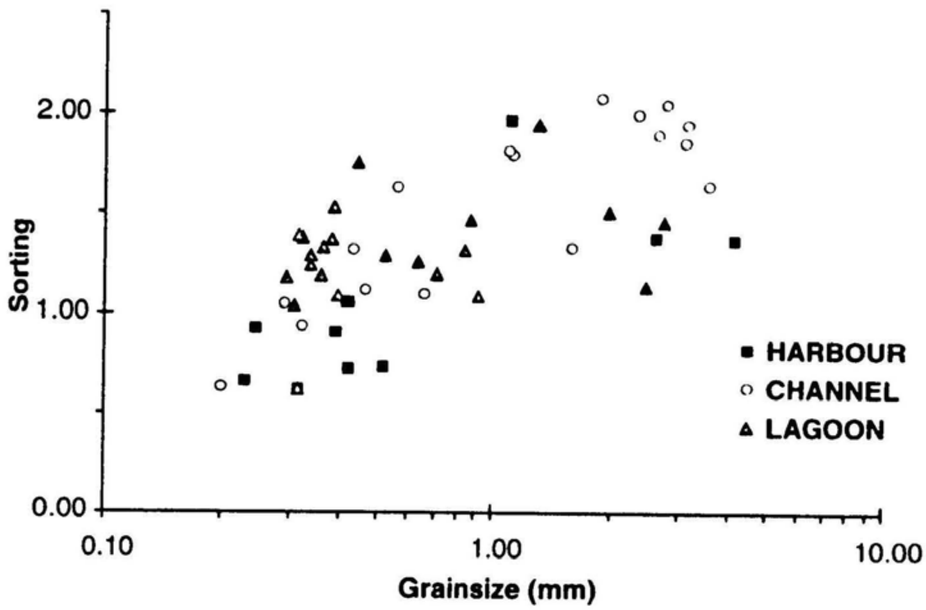

Figure 5.7 Plot of grain size versus sorting for samples from the harbour, channel, and lagoon.

Hydrodynamic conditions are likely the dominant factor in controlling the sediment distribution in this system. Sample distributions shown in Figure 5.6 were grouped based on the sample location and redrawn in Figure 5.8. Harbour and lagoon sediments have similar grain-size ranges but differ in that those from the harbour are slightly better sorted. There is a difference in distribution between lagoon sediments from greater than 1 m of water at MWL and less than 1 m of water at MWL. Those sediments in less than 1 m are slightly coarser and more poorly sorted. Channel sediments are significantly more coarse and less well sorted. The bimodal distribution of channel sediments greater than 1.41 mm (-0.5ø) is the result of a bias in sampling. Samples taken at the centre of the channel have a higher percentage of coarse material than those taken near the channel edge which is close to thicker accumulations of sand.

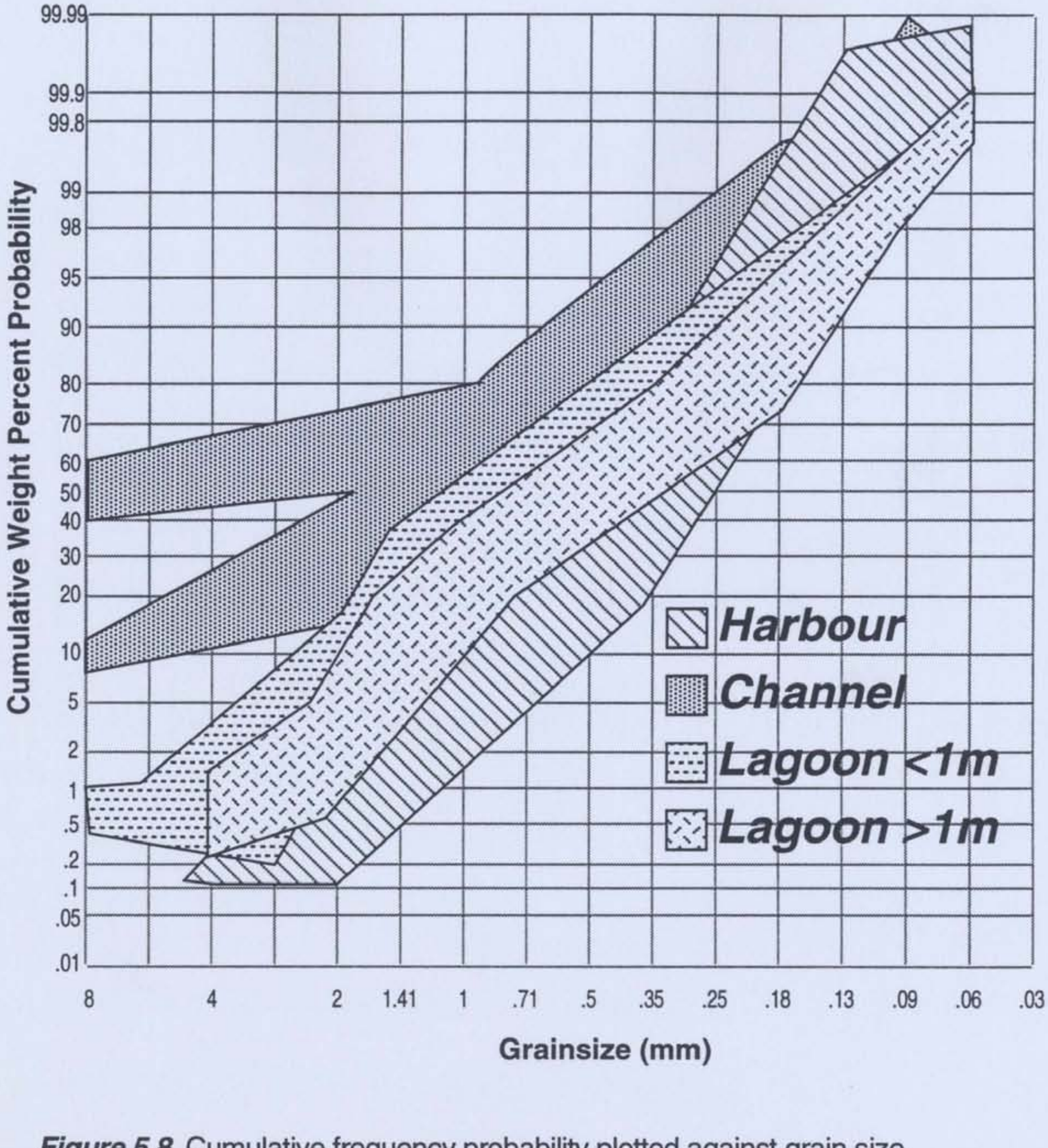

Figure 5.8 Cumulative frequency probability plotted against grain size for sample grouping from the harbour, channel, lagoon samples < 1m water depth and > 1m water depth.

5.4 Sediment Stability

The distribution of the sediments in Muri Lagoon and Ngatangiia Harbour is a function of the source (terrestrial clastic or marine biogenic) and the physical forcing mechanisms (waves and currents). On a larger scale, bedrock topography and macrofeatures such as motus also influence sediment distribution. The previous section presented the relative importance of the volcanic material versus reef and lagoon organisms as a sediment source and the sections on sedimentary facies and texture presented data on the present distribution and size of sedimentary particles. The purpose of the present section is to provide an evaluation of the physical processes by which sediment grains in Muri Lagoon and Ngatangiia Harbour are put in motion and transported through the reef, lagoon, channel, and harbour system. The goal here is to describe the controls on sediment distribution.

Sediment transport is the movement of sediment from sources to sinks. To maintain a dynamic stability in the lagoon-channel-harbour system the sediment input must equal the sediment lost. Observational evidence from the channel indicates that material is being moved from the source, primarily on the reef front, outer reef flat, lagoon and channel areas to the harbour and eventually out onto the 10 m terrace and deeper (Gauss, 1981). This evidence includes ripples measuring 1 m in wavelength and 10 cm in amplitude located 100 m seaward of Muri Beach. The evidence suggests that sediment transport is toward the mainland from the reef edge.

Numerous authors have noted "striations" on the floor of the lagoon and channel as indicating current direction (Lewis et al., 1980; Kirk, 1980; Scoffin et al., 1985). When observed in detail, these striations are sediment deposits in the lee of obstructions such as boulders (Plate 5.9). Sediment grains in motion have been observed in the channel. A small fan deposit at the outflow of the fish trap is indirect evidence of sediment having been transported. The leading edge of a sand spit projecting into the harbour is also evidence for transport as is the rippled sedimentfloored channel east of the harbour entrance. The changes in bathymetry over time as presented in Chapter 3 provide evidence that material is being moved.

Plate 5.9 Aerial photograph of apparent striations in the channel between Oneroa and the mainland. They are formed as sand is deposited in the lee of large cobbles and boulders. Scale bar is 200 m.

To estimate the volume of sediment being transported through the system it is first necessary to describe the hydrodynamic conditions by which the sediments of Muri Lagoon and Ngatangiia Harbour are put in motion. Then it is necessary to determine whether those conditions occur, and if so, what is the frequency and magnitude of the occurrences.

5.4.1 Oscillatory versus Unidirectional Currents

There are two major forcing mechanisms causing the sediment to be transported in this system, oscillatory and unidirectional currents. While both are present throughout the system, the relative importance of oscillatory and unidirectional currents is variable and dependent on location. Sediments in the lagoon are subject to oscillatory currents produced by waves and unidirectional currents produced by fluid movement driven by gravity.

5.4.1.1 Lagoon

In the lagoon, waves are either deepwater waves transgressing the reef or waves generated within the lagoon. As wind waves in the lagoon are limited by fetch, their influence is greater closest to the beach. Unidirectional currents in the lagoon are likely forced by gravity, influenced by a super-elevation of water in the lagoon due to open ocean water overtopping the reef, and flow in the direction of the harbour. Tidally-induced currents, considered unidirectional as their period is long in relation to their amplitude, also influence sediment transport. In the lagoon, unidirectional current speeds generally increase in a direction away from the reef.

5.4.1.2 Channel

Currents in the channel are mostly unidirectional and driven by tides and wave set-up in the lagoon. Oscillatory currents from waves that transgress the reef and pass through the gaps in the motus exist but do not appear to be significant as compared to the magnitude of the unidirectional currents and are not considered here.

5.4.1.3 Harbour

Unidirectional currents in the harbour are the result of tide, which is of such long period it is considered unidirectional for the purposes of this study, and set-up induced flow from the lagoon through the channel. Waves from the east can pass through the reef passage and enter the harbour. Indirect evidence of waves entering the harbour through the reef passage is seen in an aerial photograph dating from 1954 in which an arcuate beach lies directly in line with the reef passage on the opposite side of the harbour (Plate 5.10).

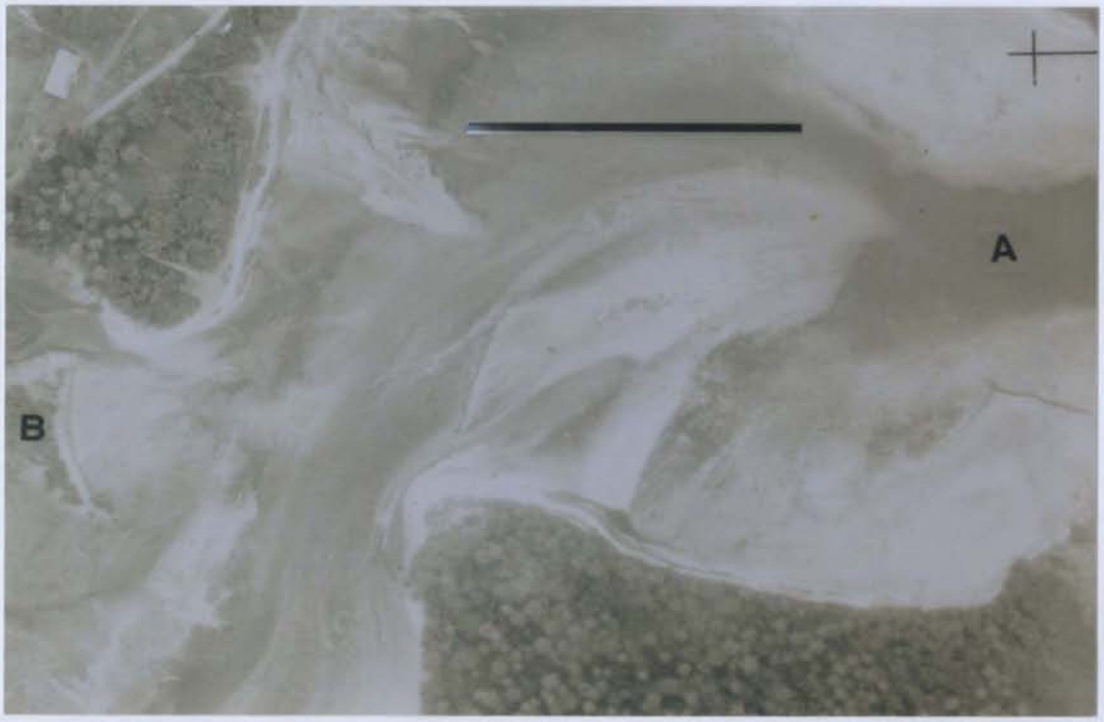

Plate 5.10 Aerial photograph of Ngatangiia Harbour taken in 1954 showing an arcuate beach (**B**) formed by waves entering the harbour at the reef pasage (**A**). Scale bar is 100 m.

In both the lagoon and the harbour oscillatory currents alone account for little net transport of sediment because the oscillatory motion of waves causes a back and forth motion of particles at the bed with little net transport (Komar, 1976). However, when even weak unidirectional currents are superimposed, net transport results because particles are put in motion by the wave but are carried by the unidirectional current. Furthermore, ocean waves that have transgressed the reef have likely been transformed into long period, low amplitude shallow waves which are generally considered constructional and will move sediment in the direction of propagation, i.e. towards the beach (Carter and Steer, 1984).

5.4.2 Sediment Threshold

As the velocity of fluid flow over a bed of sediment is increased, there comes a point at which the sediment grains begin to move. This is known as the threshold of sediment movement or threshold of exceedence (Komar, 1976a). This is the critical stage for erosion or transportation. Curves for the prediction of threshold values, based mostly on flume data, have been developed and usually denote some combination of grain diameter and density, water velocity and stress.

Sediments on the reef crest and outer reef flat are subject to a complex mixture of currents having various intensities and duration (Roberts and Suhayda, 1983). When considering transport processes in this area, two fundamental velocities are involved. These are threshold and particle settling velocities. While threshold velocity for fine grained sands is greater than that for coarse sand, once in suspension the fine travels farther (Roberts and Suhayda, 1983). In a study of wave height and current associated with normal trade wind conditions, Roberts and Suhayda (1983) reported that average reef-normal flow was between 10 to 20 cm/s and individual wave surges reached values of up to 180 cm/s. They concluded that the mean data alone would suggest that there is not sufficient velocity to transport coarse material over the reef crest and outer reef flat. However, these high velocity bursts, associated with individual waves, are sufficient to initiate transport. Thus, although storm events are generally considered to be the principal agent for moving material in this area, the data of Roberts and Suhayda (1983) suggest that normal reef-crest processes are sufficient to transport coarse sediment to the immediate back reef.

5.4.2.1 Lagoon

The threshold for sediment movement under oscillatory currents in Muri lagoon is calculated using the method of Komar and Miller (1973). They note that, near the seabed, the elliptical motion of a wave is reduced to the to-and-fro horizontal motion. The orbital diameter, d_0 , of the motion is given by:

$$d_0 = \frac{H}{\sinh\left(2\pi d/L\right)} \tag{5.1}$$

where d is the water depth, H is the wave height, and L is the wavelength.

The maximum horizontal velocity, U_m, associated with this motion is:

$$U_m = \frac{\pi d_0}{T} = \frac{\pi H}{T\sinh\left(2\pi d/L\right)} \tag{5.2}$$

From this equation the velocity of the near-bottom motion can be calculated if wave period and height , and depth of water are known.

Komar and Miller (1973) further point out that to calculate the threshold of sediment movement , the fluid motion must be related to the physical properties of the sediment. They report that for sediment diameters less than 0.5 mm the equation:

$$\frac{\rho U_m^2}{(\rho_s - \rho)gD} = 0.3(d_0/D)^{0.5} \tag{5.3}$$

is appropriate. Here D is the diameter of the grain and ρ_s is its density. In a later paper by Komar and Miller (1975), a value of 0.21 for the constant was found to be more appropriate.

To better relate the hydrodynamic conditions to the sediments the equation is solved for D. In that way the range of hydrodynamic conditions measured and expected at Muri Lagoon and Ngatangiia Harbour can be expressed in terms of their ability to move sediment of a certain grain size. Equation 5.3, with 0.21 substituted for 0.3, was solved for D with the following result:

$$D = \left(\frac{\rho U_m^2}{0.21(\rho_s - \rho) g d_0} \right)^2 \qquad (5.4).$$

From equation 5.4, a matrix is developed whereby initiation of motion of grains of specific diameter, at specific lagoon depths , can be estimated by using recorded and predicted wave periods and heights outside the reef as input values (Table 5.3).

Results of the calculations show that average deepwater wave conditions external to the lagoon produce horizontal oscillatory velocities near the lagoon bed of over 10 cm/s at some time during the tidal cycle and likely produce minimum velocities of over 20 cm/s throughout most of the lagoon at high tide. Maximum velocities near the bed are over 30 cm/s in the shallowest portions of the lagoon at high tides and during extreme events velocities of almost 70 cm/s can be reached.

Table 5.3 Table of values used for the calculation of maximum grain size moved at specific water depths in the lagoon; (a) during average deepwater wave conditions at mean water level, MWL and at high tide, HT; (b) expected values given conditions such as those during Cyclone Sally.

(a)

T	9.4	density (fluid) (kg/m^3)	1020
H(SIG)	2.2	gravitational const. (m/s^2)	9.81
density (sand) (kg/m^3)	2480*	constant	0.21

Location	Outer Reef Flat		Inner Reef Flat (lagoon)					
Depth at mwl.	**< 0.45 m**		**1.25 - 1.00 m**		**1.00 - 0.75 m**		**0.75 - 0.50 m**	
	MWL	**HT**	**MWL**	**HT**	**MWL**	**HT**	**MWL**	**HT**
H (cm)	10.54	34.09	8.00	18.55	10.11	21.72	10.24	22.88
T (s)	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40
d_0 (cm)	73.87	166.41	34.85	68.94	50.15	86.64	60.29	101.65
U_m,(cm/s)	24.69	55.62	11.65	23.04	16.76	28.95	20.15	33.97
Threshold Diameter (mm)	0.56	6.43	0.06	0.46	0.18	0.91	0.31	1.47

* Density of sand as determined by Gauss (1982)on a sample located just seaward of the Ngatangiia Harbour.

(b)

T	9	density (fluid) (kg/m^3)	1020
H(SIG)	8	gravitational const. (m/s^2)	9.81
density (sand) (kg/m^3)	2480*	constant	0.21

Location	Outer Reef Flat		Inner Reef Flat (lagoon)					
Depth at mwl.	**< 0.45 m**		**1.25 - 1.00 m**		**1.00 - 0.75 m**		**0.75 - 0.50 m**	
	MWL	**HT**	**MWL**	**HT**	**MWL**	**HT**	**MWL**	**HT**
H (cm)	80.98	152.52	33.18	56.77	36.49	59.77	36.76	59.99
T (s)	9	9	9	9	9	9	9	9
d_0 (cm)	332.21	519.02	108.58	162.43	129.52	182.18	143.57	196.31
U_m,(cm/s)	115.96	181.17	37.90	56.70	45.21	63.59	50.12	68.53
Threshold Diameter (mm)	60.92	232.32	2.13	7.12	3.61	10.05	4.92	12.57

* Density of sand as determined by Gauss (1982)on a sample located just seaward of the Ngatangiia Harbour.

The above values from the various water depths indicate that sediment stability in the lagoon is depth dependent. Following the same zonation used to establish the heights of waves transgressing the reef, the sediment stability can be described in terms of depth at mean water level (MWL). In lagoon water depths greater than 1 m the results indicate that, during average external wave conditions, sediment less than 0.06 mm in diameter is predicted to be in motion at times when the water level is greater than the mid-point in the tidal cycle (i.e. for about 12 hours). This is evident in the grain-size plots for the lagoon samples which have a fines cut-off at about 0.06 mm. It is further predicted that grains as large as 0.46 mm will be set in motion during high tide. During extreme events, such as conditions similar to Cyclone Sally , the threshold diameter is 2.13 mm which means the majority of sediment in water depths greater than 1 m is likely to be in motion.

In areas where MWL depth is between 0.75 m and 1.00 m sediment less than 0.18 mm in diameter is in motion for water levels greater than mid-tide. At high tides, sediments less than 0.91 mm are in motion. During extreme events sediments up to 1 cm are in motion. Between depths of 0.5 m and 0.75 m sediment between 0.31 mm and 1.47 mm are in motion at least some portion of the tidal cycle during average deepwater wave conditions.

To estimate the percentage of time the threshold was exceeded, the threshold grain diameter was calculated for each waverider buoy sample for lagoon depths of > 1 m, 0.75 - 1 m, and 0.5 - 0.75 m. The number of wave rider samples causing threshold values greater than a specific grain size are plotted as a percentage of the total number of wave rider samples (Fig. 5.9). The result shows that the finer material, 0.06 mm, in the lagoon is expected to be in motion almost 25 % of the time. The same size sediments in less than 0.5 m of water were likely to be in motion almost 50% of the time. Furthermore most material in water depths greater than 1 m was likely be moving about 10% of the time while most sediment in water depths between 0.75 m and 1 m was moving about 12% of the time over the recording period. In depths less than 0.5 m at mean water level most sediment is moving about 25% of the time.

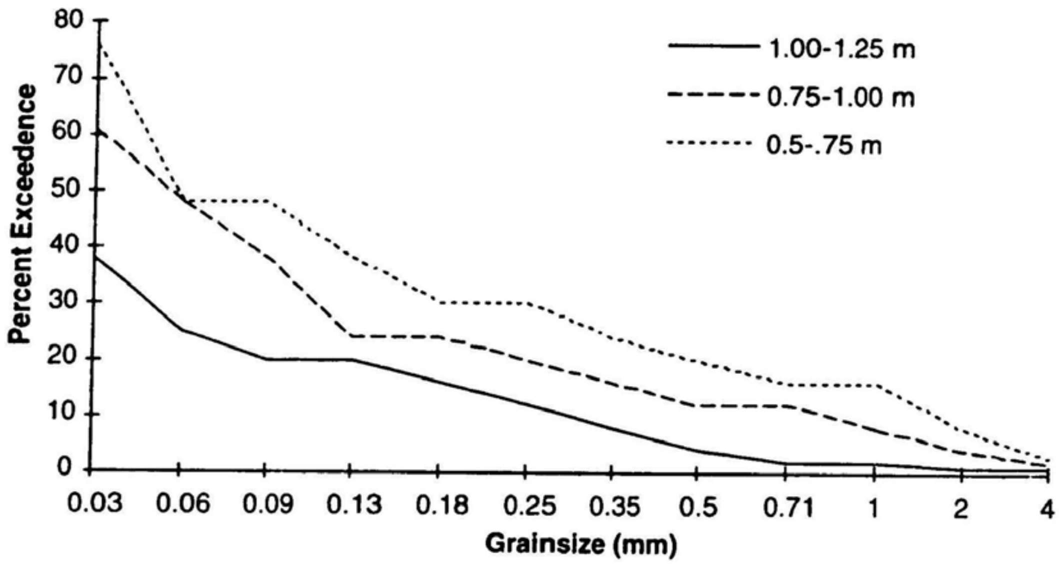

Figure 5.9 Plot of cumulative percent exceedence versus grain size for various lagoon water depths.

<u>5.4.2.2 Channel and Harbour</u>

Threshold calculation for sediment in the channel and harbour involves analysis of the unidirectional currents. Miller et al. (1977) evaluated a number of empirical curves for the threshold of sediment movement under unidirectional flow. They filtered the data sets, concentrating only on open channel flumes with parallel sidewalls where flows were uniformly steady over flattened beds of unigranular, rounded sediment. Using these data they developed curves relating the diameter of quartz-density sand, D, to threshold conditions of bottom stress, τ_c, friction velocity, μ_*, and current velocity 100 cm above the bed, u_{100}. They produced the following equations to describe the best fit curve of threshold velocity 100 cm off the bed, u_{100c} and D:

$$u_{100c} = 122.6D^{0.29} \text{ for D} < 0.02,$$
$$u_{100c} = 160.0D^{0.45} \text{ for D} > 0.02 \quad (5.5).$$

Once u_{100c} is known, values for u_{*c} and τ_c can be calculated using the following equations:

$$u_{*c} = .0547\bar{u}_{100c},$$
$$t_c = \rho u_{*c}^2 \quad (5.6).$$

Values for u_{100c}, u_{*c} and, τ_c are summarized in Table 5.5. The results indicate that the threshold velocities for the sediments in Muri Lagoon and Ngatangiia Harbour range from 22.74 cm/s for 0.03 mm diameter sand to over 140 cm/s for sand of 8 mm.

It should be remembered that these are values for quartz, density (2.65 g/cm^3) in water. The threshold for skeletal carbonate material of similar origin was studied by Young and Mann (1985). They obtained u_{100c} values as low as 18 cm/s from field experiments in the Caribbean. In their calculations they assumed a density of 1.5 g/cm^3 for the skeletal carbonate. The density of the sand sampled from just outside Ngatangiia Harbour was 2.48 g/cm^3 (Gauss 1982). The reasons for the difference in density of similar material from the Caribbean and Ngatangiia Harbour is not known. The values for quartz density material and summarized in Table 5.4 will be used here although it should be realized that the threshold velocities are likely to be somewhat high.

Table 5.4 Summary of the values of u_{100c}(cm/s), u_{*c}, (cm/s) and, τ_c, (dynes/cm^2) for threshold conditions and indicated grain sizes (mm).

D	u_{100c}	u_{*c}	τ_c
0.03	22.74	1.24	1.58
0.06	27.81	1.52	2.36
0.09	31.28	1.71	2.99
0.13	34.80	1.90	3.70
0.18	38.24	2.09	4.46
0.25	42.06	2.30	5.40
0.35	46.37	2.54	6.56
0.5	51.43	2.81	8.07
0.71	56.93	3.11	9.89
1	62.88	3.44	12.07
1.41	69.46	3.80	14.73
2	77.55	4.24	18.35
4	105.9	5.79	34.25
8	144.7	7.92	63.91

The values for threshold velocities at 100 cm off the seabed are compared to the velocities from the current record at Station 1, Ngatangiia Harbour, and Station 4, Muri Lagoon to determine the percentage of time threshold is exceeded. A direct comparison could be made from Station 4 as the current meter was set at 100 cm off the seabed. At Station 1 the current meter is 3 m off the seabed, so the values had to be scaled according to a typical velocity profile with a roughness length of 0.1 cm. (Sternberg, 1972). The values are for currents flowing in a direction to the North in the case of Station 4 and to the east at Station 1. At no time is the threshold for sediment motion exceeded in a direction flowing in the reef passage at Ngatangiia or from the channel into the Lagoon. An analysis of the current meter data from Stations 1 and 4 indicate that during the vast majority of time there is not enough current to move sediment (Fig. 5.10). In fact, the data indicate that over the recording period only sediment as large as fine sand would have moved. The currents for Ngatangiia Reef passage, Station 1, were generally larger than the Muri current meter, Station 2.

Kirk (1980) measured currents in the Harbour using a dye tracer. The tracer was deployed immediately north of the gravel delta at Avana Stream and current velocities were determined at half hourly intervals throughout a complete tidal cycle by timing the movement of the dye patch over a measured interval. The results indicate that maximum currents reached 80 cm/s with material larger than medium sand moving in excess of 30% of the time (Fig. 5.10).

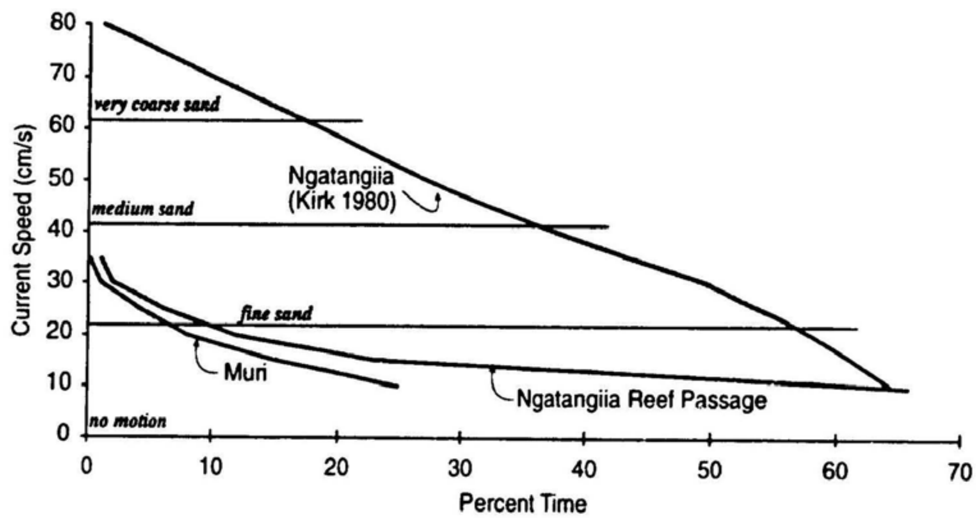

Figure 5.10 Plot of the percent of time the current speed exceeded a specific value. Values for threshold of sediment motion of various grain-sizes are superimposed on the plot.

Approximate current speeds were also measured by Scoffin et al. (1985) using a dye tracer. They reported velocities of between 10 cm/s and 50 cm/s in 50 cm of water in the main channel, and between 20 cm/s and 95 cm/s just south of the large fish trap between Oneroa and the mainland. Scoffin et al. (1985) also measured currents of 40 cm/s to 110 cm/s in the gap between Motu Tapu and Oneroa.

5.4.3 Sediment Transport Rate

The method for determining transport rate is based on the work of Bagnold (1963) modified by Inman et al. (1966) and expressed by the equation:

$$\frac{\rho_s - \rho}{\rho_s} gj = K\rho u_*^3 \qquad (5.7)$$

where j is the mass discharge of sediment (g $cm^{-1}s^{-1}$) and K is a proportionality coefficient. Using field measurements, Kachel and Sternberg (1971), relate the value of K to grain size and to the excess boundary shear stress. In effect any shear stress over and above that required to initiate movement is applied to the rate of transport. Also of note is that the rate of transport is proportional to the cube of the friction velocity. The value for K can be determined by the following equations from Dyer (1986):

$$\begin{aligned} K &= 0.005 \exp(0.7\left(\tfrac{\tau-\tau_c}{\tau_c}\right)) \text{ for D} < 250\mu\text{m} \\ K &= 0.005 \exp(\left(\tfrac{\text{D}}{140}-1.5\right)\left(\tfrac{\tau-\tau_c}{\tau_c}\right)) \text{ for D} > 300\mu\text{m} \end{aligned} \qquad (5.8).$$

To determine the rate of transport of sediment in Ngatangiia Harbour and Muri Lagoon under unidirectional currents, the above equations are applied to the velocities recorded on the current meters of Station 1 and Station 4. This is done by first determining if the recorded velocity exceeded the threshold for grain movement. If threshold was exceeded then the value for j is calculated for each recorded velocity and an average of all velocities is taken. If threshold was not exceeded the value of j is zero. This calculation is made for all grain sizes and the values totalled. A summary of the results is presented in Table 5.5.

Table 5.5 Summary of predicted transport rates across the passage at Ngatangiia and the channel at Station 4 based on recorded current velocities.

GRAIN SIZE(mm)	**0.03**	**0.06**	**0.09**	**0.13**
Ngatangiia				
g/cm/s	2.50E-06	1.55E-06	9.05E-07	1.36E-07
kg/m/s	2.50E-07	1.55E-07	9.05E-08	1.36E-08
kg/passage/s	1.25E-05	7.75E-06	4.52E-06	6.81E-07
kg/passage/year	394.31	244.66	142.74	21.49
TOTAL ANNUAL DISCHARGE		**803 kg**	**0.46 m^3**	
Muri				
g/cm/s	3.41E-06	1.34E-06	4.06E-07	1.25E-07
kg/m/s	3.41E-07	1.34E-07	4.06E-08	1.25E-08
kg/passage/s	3.41E-05	1.34E-05	4.06E-06	1.25E-06
kg/passage/year	1077.15	425.54	128.32	39.72
TOTAL ANNUAL DISCHARGE		**1671 kg**	**0.97 m^3**	

The above results indicate that average transport rates at Station 1, Ngatangiia Reef Passage are predicted to be in the order of 800 kg/yr through the passage. If the average density of the sediment is taken at 2480 kg/m^3 and porosity of approximately 45% (Komar, 1976b), then the amount of sediment transported is equal to a volume of 0.46 m^3. Rates at Station 4, Muri Lagoon are predicted to be over twice that of the Ngatangiia Passage. In contrast, the same method is applied to the data of Kirk (1980) and in this case an estimated 12, 800,000 kg or 7486 m^3 of sediment is expected to be transported. The extreme difference in rate of transport is obviously related to current speed and points to the difficulty of obtaining meaningful estimates. The variation in current speed at each locality is caused by minor changes in the geometry of the channels (Scoffin et al., 1985).

Holden (1992) describes the relationship of deep water wave height to the unidirectional current velocity at Station 1, Ngatangiia Reef Passage by Equation 4.19. Using this relationship it should be possible to estimate sediment transport through the passage at Ngatangiia given values for deep water wave height. Table 5.6 summarizes the results of such calculations.

Table 5.6 Summary of calculations relating deep water wave height to unidirectional current velocities and discharge per day at Station 4, Ngatangiia Reef Passage.

Height (m)	Current (cm/s)	Discharge (kg)	Discharge (m^3)
3.00	25	0.16	0.00
4.00	39	3.18	0.00
5.00	54	37.01	0.01
6.00	68	614.30	0.36
7.00	83	19186.03	11.22

From Table 5.6 it can be seen that over 11 m^3 of material per day can be removed through the passage if the significant wave heights average 7 m. As discussed earlier, if there are waves present in the channel such that the maximum horizontal velocity exceeds the critical value for the initiation of sediment movement then much of the excess bottom stress will go into the movement of the sediment and the rate will increase accordingly.

5.5 Interpretation

The Muri Lagoon - Ngatangiia Harbour system must be considered in terms of a continuous system with numerous hydrodynamic regimes superimposed on the available sediment. Figure 5.11 presents grain-size distribution histograms from samples along a path from the lagoon near the edge of the outer reef flat towards Muri Beach (77 - 70), in the channel between Motu Tapu and the mainland (31), and a transect out Ngatangiia Harbour (12 - 7). The figure also shows mean grain size for each sample as a superimposed thick line.

At the beginning of the transect, the area is within 200 m of the outer reef flat, close to the sediment source. Waves, transformed by crossing the reef flat, are the dominant forcing mechanism. The sediments are unimodal and negatively skewed (sample 77). In a shoreward direction the mode remains similar but there is an increase in coarser sediment (samples 76 - 74). Through this part of the transect , a weak unidirectional current (3 cm/s) is superimposed on the oscillatory current produced by the waves. The next sample taken some 60 m towards the shore shows a different distribution with sediment around 1.41 mm becoming the dominant mode. The mean has shifted towards the coarsest fraction but is still finer than the mode. The distribution is now positively skewed. This point corresponds with the 1 m isobath. The waves may be imparting a greater amount of energy to the seabed than in deeper water as shown by the calculations of expected threshold grain size (Table 5.3). Indeed this shift may represent the point where the oscillatory currents are strong enough to put 0.3 to 0.6 mm sediments into motion.

This area also coincides with a significant increase in unidirectional currents as observed by the drogue studies. The drogues up to this point were moving at about 3 cm/s towards the shore. As they reached a point west of Koromiri the direction changed to a more northerly flow and speed increased to about 7 cm/s.

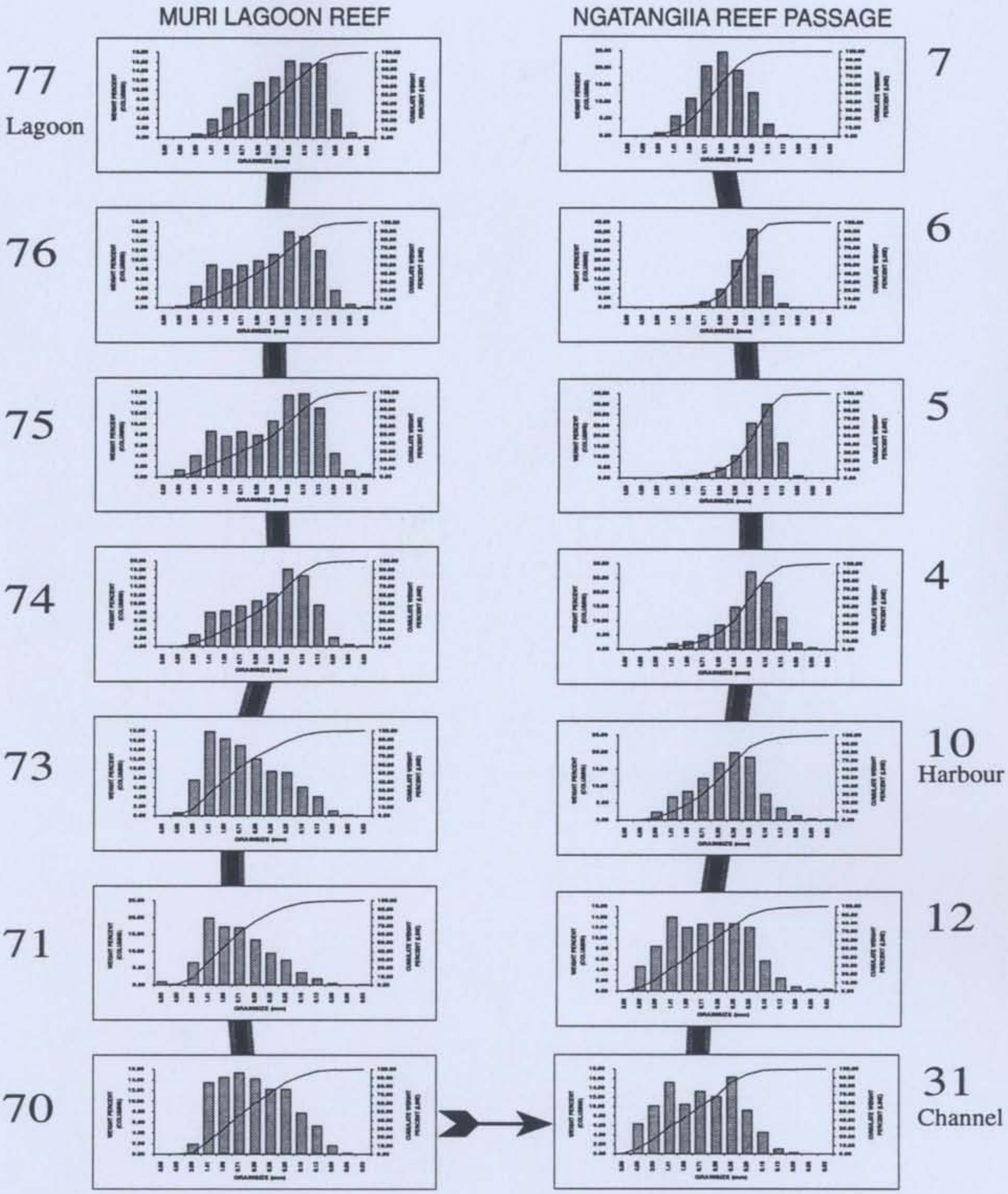

Figure 5.11 Grain-size distribution plots of a transect of samples from the seaward edge of the lagoon, through the channel, harbour and into the reef passage. The thick line superimposed on the plots indicates mean grain size.

Further evidence for this change in flow direction lies in the characteristic striated patterns on the lagoon bed and the sediment deposits in the lee of the large *Porites* boulders or microatolls present throughout the Lagoon (Scoffin, 1985; Lewis, 1978) (Plate 5.9). It is likely that the shift in sediment distribution at this point is the result of the combination of the unidirectional and oscillatory currents causing a significantly increased threshold grain-size.

Sample 70 represents a location still in the lagoon but in reduced depths where a more complex hydrodynamic condition exists. Here longshore currents may have an influence along with the effect of short period wind driven waves generated within the lagoon. Observations from this area indicate that the net current direction is to the north and is probably of similar velocity to that measured at the Muri current meter.

In the lagoon transect it is apparent that towards the shore, the sediment gets coarser and there is an increase in the unidirectional currents. This may be explained by water "piling up" as a result of the elevated levels due to wave "set-up" As the flow becomes more constricted the velocity is expected to increase. Samples 31 and 12 represent samples from the channel. Channel sediments may represent three hydrodynamic regions. The very coarse fraction, >1 mm, probably represents a lag deposit formed following extreme current speeds during a storm. The bimodal population in the sand size fraction may be due to tidal influences. The coarser peak at 0.71 mm, may have developed in response to ebb tide superimposed on superelevated water causing higher lagoon currents. The peak at 0.35 may result from a flooding tide.

The flow becomes less restricted in the harbour as the channel widens. It is possible that the current speed is reduced to the point where only sediments around 0.18 mm are being moved under average conditions (Samples 4 and 5). The coarse tail results from tide and lagoon set-up acting at the same time in the same direction. Samples 6 and 7 are likely influenced by more restricted flow conditions and by waves coming through the channel passage.

5.6 Summary

1) Seven physiographic and sedimentary units have been defined. These are the outer, inner and altered reef flats, lagoon bed sand, strandline stand, river gravel and *Porites* boulders.

2) Most of the sand sized particles consist of calcareous red algae with lesser amounts of mollusc, echinoderm, and coral fragments. Terrestrial material averages less than 5% in the lagoon and about 15% in the harbour.

3) Sediments from the harbour, channel, and lagoon have differing grain-size distributions. The grain size distribution of lagoon samples is depth dependent.

4) Sediment stability in the lagoon is influenced primarily by waves and to a lesser extent by unidirectional currents. During average conditions the majority of lagoon sediment is predicted to be in motion over 10% of the time. Sediment stability in the channel and harbour is primarily a function of unidirectional currents. Recorded current velocities indicate that sediment at Stations 1 and 4 rarely moves during average conditions.

5) Recorded current velocities indicate that sediment is transported into the harbour at a rate over twice as fast as is removed through the reef passage.

CHAPTER 6 DISCUSSION

There are two questions which warrant further discussion. What were the controlling processes that shaped the surficial geology and to what extent are those processes active today?

The surficial geology of Muri Lagoon and Ngatangiia Harbour is consistent with that of areas whose sedimentary deposits are considered storm dominated and which have undergone subsequent modification during non-storm conditions (Scoffin et al., 1993). These features include reef islands (motus) composed of coral rubble, evidence for shoreline retreat, tongues of shingle and boulder tracts.

Following a storm in 1972 on Funafuti, Tuvalu, a rubble ridge 19 km long, 37 m wide and 4 m high was created on the reef flat (Maragos et al., 1973). Baines et al. (1974), in a study of the ridge, attributed motu shape to reef front morphology. They suggest that the reef islands were observed where there is a broad reef platform (inner and outer reef flat) with a convex seaward rim and a well developed spur and groove topography below which the reef drops steeply to a sloping terrace 7-8 m deep. This is consistent with the physiography of the study area.

Scoffin et al. (1993) pointed out that erosional effects on reef islands result in former shorelines retreating lagoonward. The evidence for shoreline retreat exists in Muri Lagoon with the remnant beachrock seaward of Koromiri. Following a large storm, coral rubble motus undergo a leeward migration until they are impeded by earlier ridges, stabilized by the growth of rooted vegetation or become lithified. The latter two are observed in the study area. Cementation is attributed to microflora that are associated with coral debris that became anaerobic a few centimetres below the surface (Morita, 1976).

Also consistent with storm dominated deposits are tongues of shingle pointing lagoonward. In the study area these are best developed east of Koromiri. Scoffin et al. (1993) describe the existence of regularly spaced wedged lobes extending from the reef rim towards the centre of the lagoon on Lady Musgrave Island, Great Barrier Reef.

Boulder tracts are also common on reef platforms of the Great Barrier Reef (Scoffin et al., 1993). *Porites* boulder fields documented in Muri Lagoon were likely formed as boulder tracks deposited during a storm event and subsequently colonized by *Porites.*

It is likely the extreme storm conditions that controlled the gross physiographic characteristics we see today in Ngatangiia Harbour and Muri Lagoon have not been present for a significant period of time and certainly not within the timeframe addressed in this study (~50 years). Scoffin et al. (1993) suggest that cemented storm ridges and beachrock are most likely to be found in areas where extreme events occur infrequently. The ability to map the same *Porites* microatoll on photographs from 1954 and 1990 would suggest a depositional setting through this period that was dominated by less than extreme storm conditions.

Storm conditions such as Cyclone Peni or Sally can however have a dramatic effect on the more mobile sediments in the harbour and lagoon. The results of the bathymetric analyses suggest that there was erosion in the lagoon and deposition in the harbour with relatively little net erosion apparent in the channel. The only bathymetric data prior to 1981 was the 1948 survey of the harbour. In a comparison of the harbour cross sections, a relatively even blanket of sediment was deposited between 1948 and 1981. Accumulation rates for the period 1981 to 1990 show an appreciable increase in sedimentation. Current meter and sediment grainsize analysis predict that strong currents in the lagoon are possible during cyclones, with velocities more than adequate to transport sediments. An adequate supply of sediment is available which could, under the influence of a cyclone, be removed from the lagoon, transported through the channel area and deposited in the harbour. In the period 1984 to 1991 the lagoon lost 80,904 m^3 of sediment. The channel gained 4,570 m^3 in a similar time frame. In the period 1981 to 1990 the harbour gained 57,167 m^3 of sediment. More than enough material was eroded from the lagoon to account for the infilling of the harbour. The excess material (approx. 19,166 m^3) may have passed through the system and out into the deep ocean or may have been removed by dredging in the inner harbour. Cyclone Peni hit the east side of Rarotonga in February of 1990 with waves of 7.6 m which would likely have generated currents strong enough to move through the channel and harbour.

The dynamic stability of the lagoon environment can also be influenced by anthropogenic forcing. Coastal protection devices such as seawalls and artificial reshaping of coastal zones by land reclamation schemes have an impact on stability. For example, during dredging operations, when material was being removed from the Avana Stream Delta, a causeway was built to allow an excavator to gain access to the centre of passage. This causeway diverted the flow of the channel onto the landward beach of Motu Tapu causing considerable erosion (D. Dorell per. comm., 1990). The dredging by excavator also provided material for transport into the harbour.

Kirk (1980) and Carter and Steer (1984) suggested that erosion in the catchment of the Avana Stream resulted in accelerated sedimentation in the harbour by the deposition of volcanic sediment. Upon inspection of the Avana Stream catchment, there is little evidence of modern of soil erosion (J Allinson per. comm., 1990). An analysis of sediment in the harbour shows less than 20% volcanic clasts on average. The volume of material brought into the system by the Avana Stream is small in comparison to the volume of material available from the lagoon.

In the modern, non-storm, depositional environment, waves are the dominant mechanism controlling lagoon circulation with tides being of secondary influence. This is evidenced by a positive correlation between the current meter data and the wave rider data. This suggests that wave transmission over the reef is important when trying to relate the effects of deep-water waves on sediment transport in the lagoon.

Waves play two roles in lagoon and harbour sediment hydrodynamics. Firstly, they transport sediments by the establishment of oscillatory currents. These oscillatory currents largely influence sediment transport in the lagoon. Secondly, the set-up caused by waves overtopping the reef and forcing water into the lagoon faster than it can flow out of the reef passage creates unidirectional currents. These unidirectional currents dominate sediment transport in the harbour, channel and inner lagoon.

Studies from the Great Barrier Reef and the Caribbean suggest that factors influencing the ability of waves to deliver water over the reef and into the lagoon include wave period, wave height, wave direction, water depth at the reef crest, reef morphology and reef organisms (Gerritsen, 1981; Young, 1989, Lugo-Fernández et al., 1994). There is widespread agreement that most (>85%) of wave energy is dissipated by breaking on the reef crest. In a study in Puerto Rico, Lugo-Fernández et al. (1994) concluded that wave period was the dominant influence in energy transmission across the reef. They point out that local waves (period 4s; height 0.65 m) attenuate less during transmission than do trade-wind waves (period 6 s; height 1.2m). This corresponds with the results of this study where periods of less than 9 s influence wave height in the lagoon. Sediment transport in the lagoon area is likely dominated by waves with shorter periods, such as those produced locally by high winds.

Unidirectional currents correlate positively with a measure of the amount of water carried forward by each wave which is given by the wave height/period relationship of H^2/T. Large deep-ocean swell will have the greatest impact at the northwest end of the lagoon, through the channel and at the reef passage where the unidirectional currents caused by set-up are greatest.

The current meter data show that under non-storm conditions, twice as much material is being transported to the harbour as is moving out of the harbour. This provides at least a partial explanation for sediment accretion in the harbour. While storm events such as Cyclone Sally have the ability to move sediment out of the harbour, it will likely take an extreme event to re-establish harbour depths to pre-1948 levels.

CHAPTER 7 CONCLUSIONS

A series of investigations of Ngatangiia Harbour and Muri Lagoon dating back to 1948 has provided the data set for this study. The objectives were to describe changes in the bathymetry of the area, the physical oceanographic conditions which normally control the sediment deposition and the sediments. The results provide a scientific basis with which to compare data from other areas.

In terms of historical bathymetric analysis it is concluded that:

1. Ngatangiia Harbour has had a net accumulation of sediment from 1948 to 1990 with an estimated 78,041 m^3 of sediment being deposited since 1948. Sediments have preferentially infilled lower lying depressions in the northern portion of the harbour and at the inner entrance to the reef passage.

2. The channel area has had a net deposition of 4,571 m^3 of material between 1985 and 1990. There has been relatively little change in the bathymetry of this area.

3. Muri Lagoon has had a net loss of sediment from 1984 to 1991 with an estimated 80,904 m^3 of material being removed. In addition to the loss there has been appreciable redistribution of sediment in the form of a shore-parallel ridge just seaward of the beach.

4. The rate of net accumulation is highly variable in the harbour and in the order of 2 cm/year. The net deposition in the channel area is approximately 0.08 cm/year. The net erosion of the lagoon is approximately 0.02 cm/year.

In summary, over the past 45 years material has been removed from the lagoon, transported through the channel and deposited in the harbour. Storm events likely accelerated this process and locally redistributed sediment in the lagoon.

In terms of physical oceanography it is concluded that:

1. There is a greater than 90% reduction in deep water height as a characteristic wave moves over the reef at Muri Lagoon

2. The submerged height of the reef is a controlling factor in wave height attenuation over the reef.

3. There is a direct correlation between the characteristics of deep water waves and lagoon/harbour circulation.

4. The current flow out Ngatangiia Harbour is primarily a result of superelevated water levels caused by wave set-up.

5. Diurnal variability in current speed and direction related to tides is observable in both the lagoon and harbour.

In summary, waves overtopping the reef crest and spilling out into the lagoon are the dominant factor controlling circulation. Tidal influences are important but secondary. A positive correlation between deep water wave height/period ratio of H2/T and lagoon/harbour current speed is evident.

In terms of the sedimentary geology it is concluded that:

1) Seven physiographic and sedimentary units have been defined. These are the outer, inner and altered reef flats, lagoon bed sand, strandline sand, river gravel and *Porties* boulders.

2) Most of the sand sized particles consist of calcareous red algae with lesser amounts of mollusc, echinoderm, and coral fragments. Terrigenous material averages less than 5% in the lagoon and about 15% in the harbour.

3) Sediments from the harbour, channel, and lagoon have differing grain-size distributions. The grain-size distribution of lagoon samples is depth dependent.

4) Sediment stability in the lagoon is influenced primarily by waves and to a lesser extent by unidirectional currents. During average conditions the majority of lagoon sediment is predicted to be in motion over 10% of the time. Sediment stability in the channel and harbour is primarily a function of unidirectional currents. Recorded current velocities indicate that sediment at Stations 1 and 4 rarely moves during average conditions.

5) Recorded current velocities indicate that sediment is transported into the harbour at a rate over twice as fast as is removed through the reef passage.

In summary, the physiography and sediments of the study area reflect deposition under an extreme storm conditions with subsequent modification under normal and moderate storm conditions.

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APPENDIX I

AERIAL PHOTOGRAPHS

INDEX TO PHOTO LOCATIONS

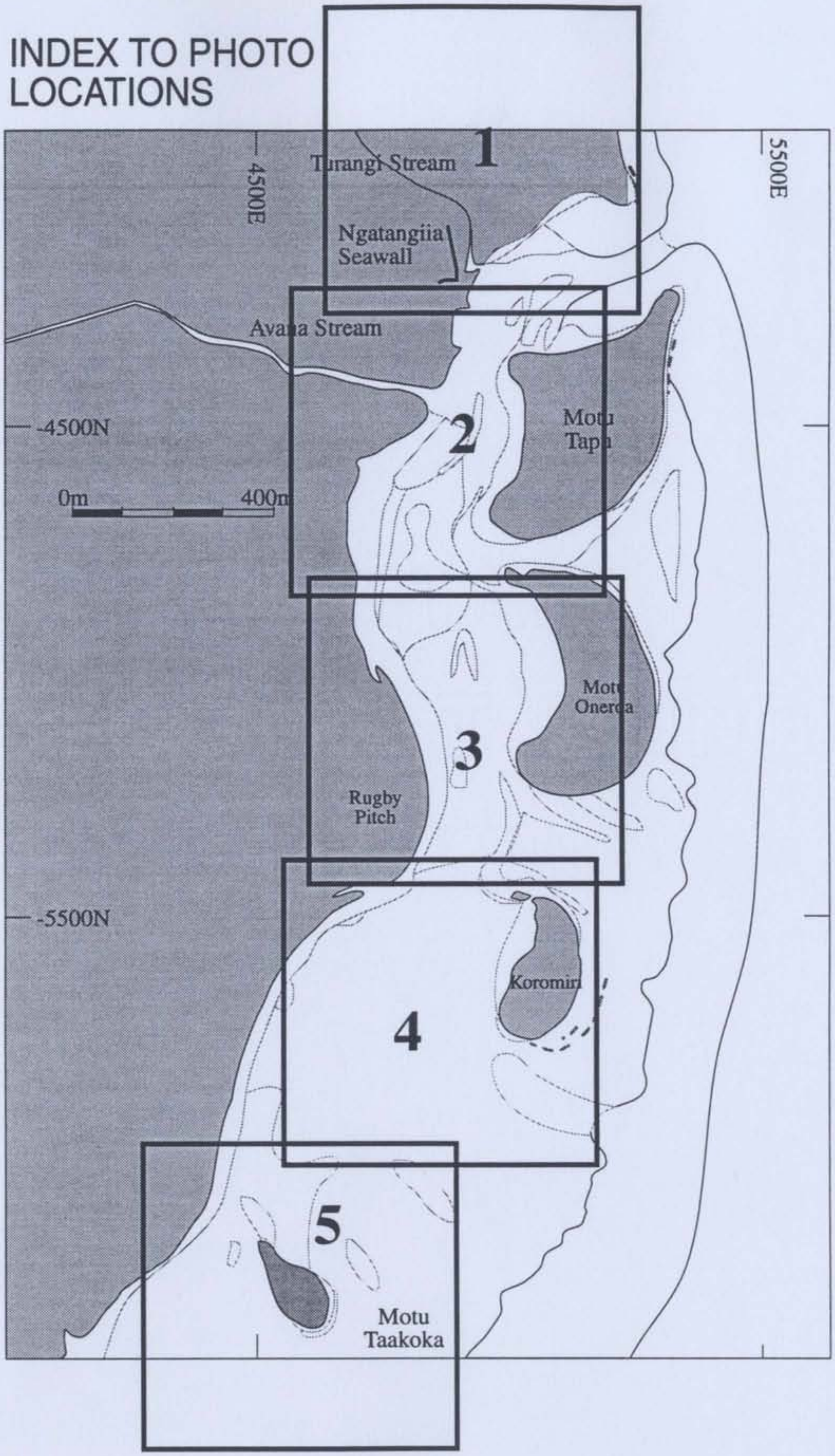


Photo 1, Run 8/88, Cook Islands Survey Department, Scale 1:3,183

Photo 2, Run 8/88, Cook Islands Survey Department, Scale 1:3,183

Photo 3, Run 8/88, Cook Islands Survey Department, Scale 1:3,183

Photo 4, Run 8/88, Cook Islands Survey Department, Scale 1:3,183

Photo 5, Run 8/88, Cook Islands Survey Department, Scale 1:3,183

APPENDIX II

RESULTS OF GRAIN-SIZE ANALYSIS

SIEVE DATABASE

PROJECT: NGATANGIIA HARBOUR AND MURI LAGOON **PROCESSED BY:** BILL COLLINS

DATE: 22/1/96 **DATA INPUT BY:** BILL COLLINS

Sample	cont	wt+cont	tot.wt. (g)	8mm	4mm	2mm	1.4mm	1mm	.71mm	.5mm	.35mm	.25mm	.18mm	.125mm	.09mm	.063mm	pan
1	56.40	249.90	193.50	54.19	21.84	34.77	33.10	26.92	17.58	3.89	0.51	0.15	0.04	0.01	0.00	0.00	0.00
2	56.40	220.00	163.60	0.00	0.00	0.05	5.07	9.57	24.90	43.74	45.11	29.83	5.30	0.27	0.00	0.00	0.00
3	56.40	293.50	237.10	136.67	26.05	25.93	15.47	12.65	11.04	5.41	2.34	1.36	0.59	0.23	0.05	0.00	0.00
4	56.40	132.20	75.80	0.00	0.09	0.54	1.59	2.08	3.88	6.60	11.39	20.77	17.75	8.63	1.90	0.53	0.14
5	56.40	157.40	101.00	0.00	0.00	0.37	0.94	1.02	2.28	4.93	10.90	26.68	35.70	17.23	1.42	0.22	0.04
6	56.40	223.90	167.50	0.00	0.00	0.20	0.84	1.55	5.07	16.08	42.15	69.92	28.07	3.74	0.32	0.00	0.00
7	56.40	155.00	98.60	0.00	0.00	0.98	5.77	11.04	20.37	24.63	19.16	12.73	3.58	0.46	0.05	0.00	0.00
9	56.40	217.70	161.30	0.00	0.00	0.52	4.05	9.91	27.69	41.59	33.01	25.14	12.84	5.47	0.59	0.15	0.11
10	56.40	150.30	93.90	0.00	0.23	2.31	6.55	8.03	11.60	16.00	18.90	17.52	7.26	3.55	1.35	0.51	0.31
11	56.40	163.20	106.80	0.00	0.00	2.94	6.65	6.82	10.32	16.68	24.42	27.30	9.40	1.64	0.37	0.16	0.15
12	56.40	240.50	184.10	33.85	7.15	12.91	21.17	18.14	19.22	19.51	19.33	18.13	8.68	3.88	1.37	0.66	0.64
13	56.40	204.10	147.70	2.74	0.11	0.23	0.15	0.33	3.75	23.23	41.72	44.53	27.38	3.84	0.00	0.00	0.01
14	56.40	200.70	144.30	31.17	40.54	22.01	15.73	13.88	8.47	4.82	2.99	2.82	1.39	0.70	0.10	0.01	0.00
15	56.40	189.40	133.00	0.00	0.07	0.73	3.80	7.81	14.36	23.63	21.95	23.92	21.17	14.68	1.47	0.01	0.00
16	56.40	233.50	177.10	2.16	0.14	0.64	2.48	6.06	15.70	20.84	22.08	40.37	43.73	22.00	1.12	0.05	0.20
17	56.40	193.50	137.10	16.74	6.26	8.67	24.46	22.42	17.53	11.02	7.65	7.87	6.67	6.61	1.17	0.14	0.06
18	56.40	200.10	143.70	0.00	0.06	0.09	0.23	0.37	1.20	4.14	13.39	52.91	54.85	15.72	0.59	0.01	0.12
19	56.40	230.20	173.80	0.00	0.24	1.45	3.51	6.26	16.24	27.68	34.09	43.23	28.64	7.31	1.69	1.25	2.11
20	56.40	192.20	135.80	81.10	6.86	5.00	2.46	2.91	4.53	7.12	8.68	8.53	4.70	2.95	0.84	0.23	0.01
21	56.40	150.20	93.80	37.88	7.09	3.40	3.80	4.16	7.54	9.28	7.99	6.56	3.96	2.15	0.26	0.06	0.00
22	56.40	239.30	182.90	17.92	4.96	4.55	10.20	13.78	23.16	28.48	23.97	22.31	19.34	12.69	1.21	0.02	0.00
23	56.40	193.60	137.20	86.49	5.93	4.15	10.12	9.05	7.68	5.93	3.91	2.70	1.02	0.48	0.07	0.00	0.00
24	56.40	224.40	168.00	135.58	14.04	4.14	2.55	1.72	1.86	1.89	1.92	2.01	1.30	0.81	0.32	0.14	0.01
25	19.66	113.32	93.66	46.22	13.29	5.26	5.32	2.88	3.72	2.91	4.49	3.70	3.21	1.22	0.90	0.33	0.20
26	19.66	125.40	105.74	44.36	11.86	7.29	8.66	6.01	6.82	4.29	6.54	3.80	3.51	1.23	0.31	0.19	0.14
27	19.66	173.80	154.14	69.42	20.18	10.08	11.86	7.14	9.07	5.92	9.12	4.99	4.09	1.44	0.60	0.41	0.33
28	19.66	117.20	97.54	38.80	8.70	8.05	10.10	5.21	5.44	3.77	5.46	3.96	4.19	2.16	0.63	0.35	0.29
29	19.66	94.19	74.53	1.64	0.21	2.38	5.22	5.05	9.83	9.27	15.96	10.81	9.59	2.86	0.69	0.17	0.07
30	19.66	139.13	119.47	5.00	2.60	5.02	11.46	12.46	27.88	24.60	23.39	5.30	0.67	0.02	0.01	0.06	0.06
31	19.66	166.66	147.00	17.65	8.13	13.14	19.52	13.61	17.06	15.60	20.97	11.98	5.97	1.43	0.49	0.15	0.10
32	19.66	175.95	156.29	11.25	15.89	33.97	38.25	20.36	16.79	9.83	6.17	2.17	0.93	0.36	0.20	0.12	0.10
37	19.68	119.89	100.21	0.00	0.80	4.29	12.74	5.52	5.92	4.18	8.66	11.28	32.13	8.37	4.68	0.26	0.08
38	19.68	137.92	118.24	19.47	6.01	21.88	38.04	17.88	12.64	4.86	3.68	1.85	1.29	0.62	0.48	0.22	0.20
39	19.68	135.95	116.27	1.88	0.62	1.03	5.51	6.17	13.71	18.08	25.02	19.34	13.50	7.86	2.21	0.35	0.02
40	19.68	113.41	93.73	1.89	1.22	3.19	7.27	5.99	8.58	9.89	17.23	17.16	14.95	4.79	1.29	0.14	0.07
62	56.40	230.10	173.70	0.00	0.00	1.44	14.46	22.11	25.88	26.24	22.56	20.50	12.72	14.53	9.43	2.86	0.69
63	56.40	123.20	66.80	0.00	0.00	0.84	4.58	6.17	8.61	9.69	8.96	9.21	6.73	6.48	3.67	1.23	0.56
64	19.68	156.86	137.18	7.29	2.75	18.55	23.11	18.22	21.97	15.04	15.05	7.68	4.20	1.41	0.73	0.22	0.19
65	19.68	126.97	107.29	0.59	0.06	2.82	8.10	7.05	9.18	8.12	13.91	14.45	22.78	14.38	4.56	0.58	0.16

SIEVE DATABASE

PROJECT: NGATANGIIA HARBOUR AND MURI LAGOON PROCESSED BY: BILL COLLINS

DATE: 22/1/96 DATA INPUT BY: BILL COLLINS

Sample	cont	wt+cont	tot.wt. (g)	8mm	4mm	2mm	1.4mm	1mm	.71mm	.5mm	.35mm	.25mm	18mm	.125mm	.09mm	063mm	pan
66	19.68	151.35	131.67	1.82	0.44	5.15	13.54	10.13	11.78	10.48	15.73	14.66	20.78	15.87	9.18	1.32	0.21
67	19.68	151.46	131.78	17.15	7.22	44.16	39.69	10.76	5.62	1.98	1.38	0.74	0.66	0.55	0.46	0.26	0.20
68	19.68	135.96	116.28	0.70	0.48	10.67	35.42	20.56	17.59	9.52	10.05	5.48	3.44	0.83	0.34	0.15	0.11
69	56.40	167.80	111.40	0.00	0.00	1.49	5.67	8.67	12.99	13.88	11.67	11.37	10.24	14.34	13.44	5.29	1.84
70	56.40	148.30	91.90	0.00	0.00	1.80	12.48	13.42	14.22	13.10	11.32	11.35	7.22	4.96	1.55	0.34	0.16
71	56.40	148.50	92.10	1.00	0.19	6.17	18.45	16.06	15.75	12.43	8.74	6.90	3.57	1.80	0.54	0.20	0.27
72	56.40	167.90	111.50	0.55	2.98	14.19	26.11	17.41	15.73	12.36	8.39	6.02	3.59	2.86	0.95	0.37	0.39
73	56.40	185.10	128.70	0.00	0.92	9.67	22.88	20.95	19.12	15.48	12.12	11.77	7.94	5.23	1.40	0.28	0.16
74	56.40	157.40	101.00	0.00	0.17	2.90	8.21	8.55	9.59	10.89	12.56	18.34	16.75	9.85	2.25	0.52	0.32
75	56.40	110.70	54.30	4.82	0.67	2.02	4.32	3.80	4.23	3.92	5.28	7.69	7.83	6.46	2.21	0.64	0.28
76	56.40	132.50	76.10	0.00	0.24	3.41	6.87	6.10	6.82	7.54	8.54	12.17	11.45	9.20	2.85	0.61	0.24
77	56.40	135.20	78.80	0.00	0.00	0.62	3.05	4.97	7.21	9.13	10.02	12.88	12.41	12.43	4.79	0.93	0.16
78	56.40	159.80	103.40	17.83	13.03	14.44	10.40	8.08	8.79	9.40	8.28	6.80	3.53	1.88	0.74	0.45	0.95

STATISTICS COMPILATION

PROJECT: NGATANGIIA HARBOUR AND MURI LAGOON | **PROCESSED BY:**

DATE: 22/1/96 | **DATA INPUT BY:**

NUMB	GRAVEL	SAND	MUD	MEAN	MEAN	SORTING	SORTING	SKEWNESS	SKEWNESS	KURTOSIS	KURTOSIS	ERROR
1	57	43	0	2.62	2.40	1.38	1.29	0.13	0.16	0.77	1.02	0.26
2	0	100	0	0.42	0.44	0.72	0.68	-0.58	-0.07	0.79	1.03	0.15
3	79	21	0	4.13	4.01	1.37	1.35	2.89	-0.34	1.04	1.03	0.29
4	1	99	0	0.24	0.27	0.93	0.91	-0.16	-0.08	1.06	1.04	0.12
5	0	100	0	0.23	0.22	0.66	0.72	-0.03	-0.04	0.98	1.06	0.72
6	0	100	0	0.31	0.29	0.62	0.58	-0.17	-0.03	1.02	1.05	0.26
7	1	99	0	0.52	0.51	0.73	0.78	0.03	-0.04	0.90	1.03	0.17
9	0	100	0	0.39	0.41	0.91	0.82	-0.20	0.05	1.69	1.03	0.14
10	3	97	0	0.42	0.42	1.05	1.04	0.38	-0.01	1.05	1.03	0.23
11	3	97	0	0.42	0.41	1.06	0.94	-0.62	-0.19	1.43	1.03	0.05
12	29	70	0	1.11	1.00	1.97	1.84	-4.06	-4.06	0.83	1.02	0.29
13	2	98	0	0.31	0.31	0.62	0.87	0.28	-0.40	0.80	1.16	0.22
14	65	35	0	2.74	2.36	1.46	1.41	2.64	-0.87	0.66	1.03	0.23
15	1	99	0	0.31	0.33	1.04	0.96	-0.21	-0.06	0.99	1.02	0.45
16	2	98	0	0.29	0.29	1.04	1.04	-0.67	-0.29	1.06	1.07	0.26
17	23	77	0	1.13	0.98	1.80	1.65	-1.38	-1.38	1.17	1.03	0.12
18	0	100	0	0.20	0.22	0.63	0.53	-0.55	-0.01	0.99	1.08	0.01
19	1	98	1	0.32	0.32	0.93	0.95	-1.00	0.02	0.88	1.05	0.06
20	68	32	0	2.77	2.76	2.05	2.11	8.80	-2.66	0.62	1.02	0.09
21	51	49	0	1.89	1.77	2.08	2.10	3.56	-4.09	0.58	1.01	0.35
22	15	35	0	0.56	0.59	1.64	1.67	-1.39	-1.39	1.29	1.03	0.17
23	70	30	0	3.54	3.62	1.64	1.65	5.26	-0.74	0.71	1.03	0.24
24	91	9	0	7.58	5.71	0.84	1.23	0.33	-0.34	2.93	1.11	0.17
25	69	31	0	3.14	2.76	1.95	1.95	8.94	-2.43	0.93	1.03	0.01
26	60	39	0	2.63	2.33	1.91	1.90	6.32	-2.44	0.74	1.02	0.70
27	64	35	0	3.09	2.57	1.86	1.87	6.27	-2.13	0.76	1.02	0.36
28	57	42	0	2.35	2.08	2.00	1.99	4.44	-4.16	0.76	1.02	0.44
29	6	94	0	0.46	0.45	1.11	1.22	-0.45	-1.03	0.95	1.04	1.06
30	11	89	0	0.66	0.72	1.10	1.12	-0.93	-0.93	1.10	1.05	0.90
31	27	73	0	1.10	0.96	1.82	1.62	-1.25	-1.25	0.89	1.02	0.82
32	39	61	0	1.59	1.44	1.33	1.18	-0.51	0.18	0.84	1.04	0.03
37	5	95	0	0.32	0.34	1.38	1.36	-2.65	-0.41	0.69	1.02	1.31
38	37	63	0	1.96	1.55	1.51	1.34	-2.12	-0.08	1.05	1.04	8.57
39	3	97	0	0.39	0.39	1.09	1.14	-0.29	-0.59	1.20	1.05	1.16
40	7	93	0	0.43	0.42	1.32	1.30	-1.36	-1.06	0.93	1.04	0.07
62	1	99	0	0.36	0.40	1.33	1.22	0.44	0.29	0.76	1.02	0.16
63	1	98	1	0.36	0.36	1.19	1.23	0.36	0.10	0.97	1.02	0.19
64	21	79	0	0.88	0.88	1.48	1.32	-1.05	-1.05	1.06	1.03	0.44
65	3	97	0	0.34	0.33	1.24	1.26	-0.72	-0.30	0.96	1.03	0.52

STATISTICS COMPILATION

PROJECT: NGATANGIIA HARBOUR AND MURI LAGOON

DATE: 22/1/96

PROCESSED BY:

DATA INPUT BY:

NUMB	GRAVEL	SAND	MUD	MEAN	MEAN	SORTING	SORTING	SKEWNESS	SKEWNESS	KURTOSIS	KURTOSIS	ERROR
66	6	94	0	0.38	0.37	1.53	1.44	-2.14	-0.49	0.74	1.0[illegible]	0.44
67	52	47	0	2.46	1.84	1.14	1.14	-0.73	-0.74	1.07	[illegible]	0.[illegible]3
68	10	90	0	0.91	0.85	1.09	1.01	0.47	0.47	1.41	1.04	0.81
69	1	97	2	0.31	0.28	1.39	1.38	0.29	0.01	0.81	1.02	0.01
70	2	98	0	0.52	0.50	1.30	1.13	0.62	0.50	0.98	1.02	0.02
71	8	92	0	0.71	0.70	1.20	1.12	0.92	3.97	1.03	1.04	0.03
72	16	84	0	0.84	0.81	1.32	1.20	0.27	0.27	1.12	1.04	0.36
73	8	92	0	0.63	0.63	1.26	1.18	0.64	2.49	1.02	1.03	0.61
74	3	97	0	0.34	0.36	1.29	1.19	-1.14	-0.15	0.98	1.02	0.10
75	14	86	1	0.44	0.46	1.76	1.83	-2.51	-3.59	0.99	1.03	0.24
76	5	95	0	0.38	0.36	1.37	1.29	-1.95	-0.18	0.87	1.02	0.08
77	1	99	0	0.29	0.29	1.18	1.13	-0.29	-0.08	0.80	1.02	0.25
78	43	56	1	1.31	1.27	1.95	1.84	-0.41	-0.41	0.69	1.02	1.15

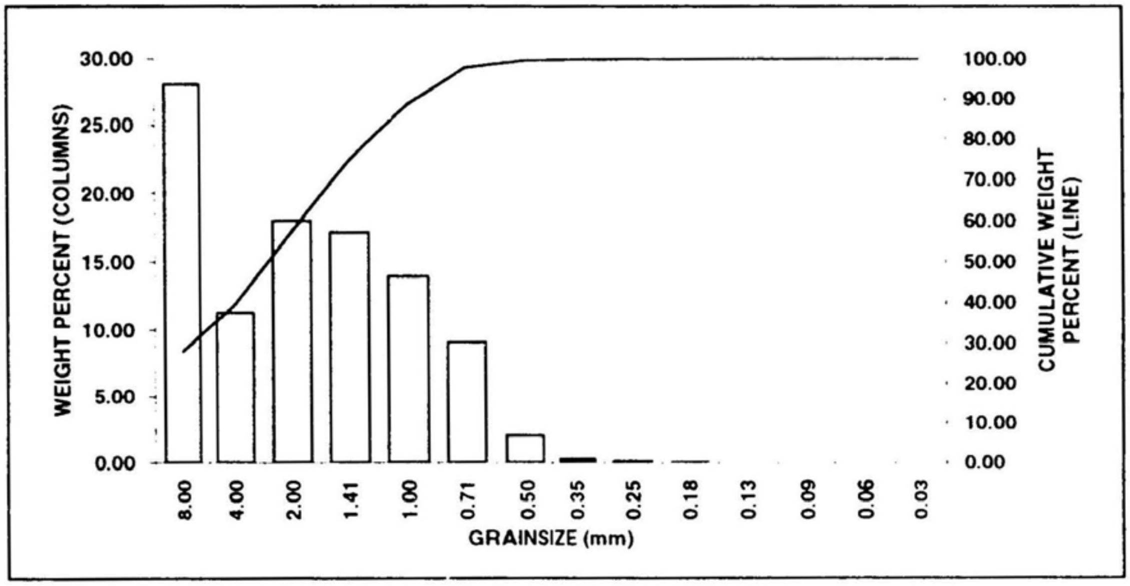
SIEVE DATA

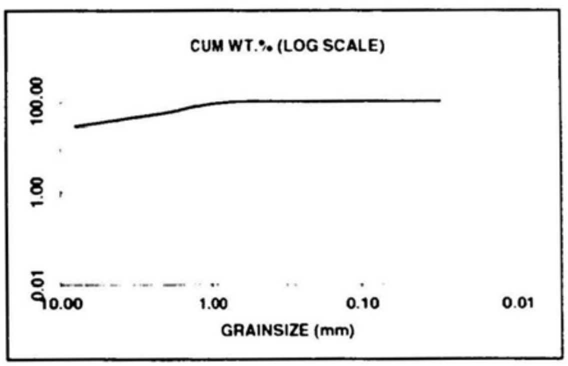
SAMPLE	1	**PROJECT**	CK.91.03
TOTAL WT.	193.50	**DATE**	1/22/96
SAMPLE LOCATION	Harbour	**SCIENTIST**	Bill Collins

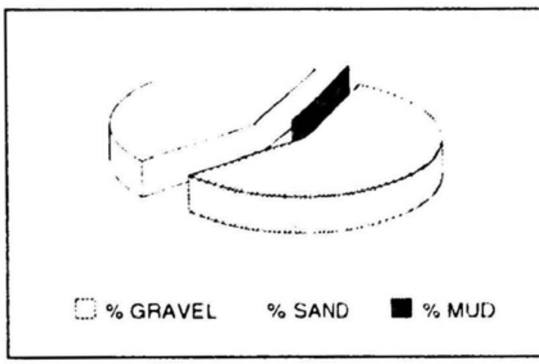
RAW DATA

MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	54.19	28.08	28.08
4.00	-2.0	21.84	11.32	39.39
2.00	-1.0	34.77	18.02	57.41
1.41	-0.5	33.10	17.15	74.56
1.00	0.0	26.92	13.95	88.51
0.71	0.5	17.58	9.11	97.62
0.50	1.0	3.89	2.02	99.63
0.35	1.5	0.51	0.26	99.90
0.25	2.0	0.15	0.08	99.97
0.18	2.5	0.04	0.02	99.99
0.13	3.0	0.01	0.01	100.00
0.09	3.5	0.00	0.00	100.00
0.06	4.0	0.00	0.00	100.00
0.03	5.0	0.00	0.00	100.00
	TOTALS	193.00	100.00	100.00

MEAN GRAINSIZE	**Granules**	
TEXTURAL CLASS	**Sandy gravel**	
SORTING	**Poor**	
SKEWNESS	**Fine**	
KURTOSIS	**Platykurtic**	
% GRAVEL	57	
% SAND	43	
% MUD	0	
GRAPHIC MEAN	2.62 mm	-1.39phi
MOMENT MEAN	2.40 mm	-1.26phi
GRAPHIC SORTING	1.38	
MOMENT SORTING	1.29	
GRAPHIC SKEWNESS	0.13	
MOMENT SKEWNESS	0.16	
GRAPHIC KURTOSIS	0.77	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.26	





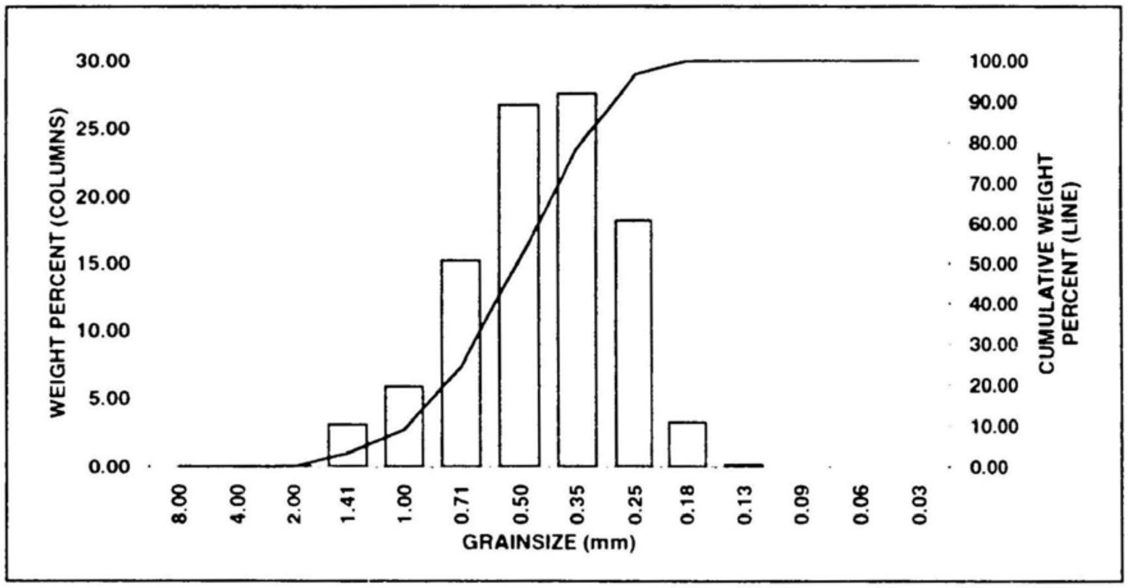


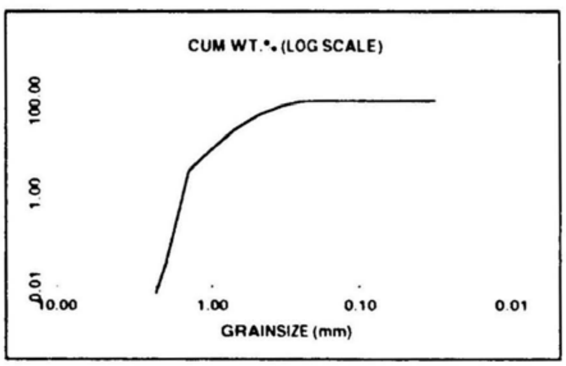
SIEVE DATA

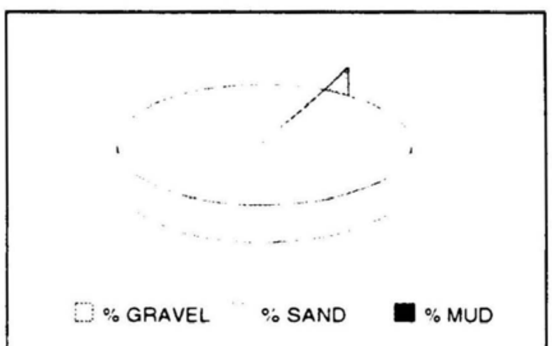
SAMPLE	2	**PROJECT**	CK 91.03
TOTAL WT.	163 60	**DATE**	1/22/96
SAMPLE LOCATION	Harbour	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8 00	-3 0	0 00	0.00	0 00
4 00	-2 0	0 00	0 00	0.00
2 00	-1 0	0 05	0 03	0 03
1 41	-0 5	5 07	3 09	3 13
1 00	0.0	9 57	5 84	8 97
0 71	0 5	24 90	15 20	24 16
0.50	1 0	43 74	26 70	50 86
0 35	1 5	45 11	27 53	78 39
0 25	2 0	29 83	18 21	96 60
0 18	2 5	5 30	3 23	99 84
0 13	3 0	0 27	0 16	100 00
0.09	3 5	0 00	0 00	100.00
0 06	4 0	0.00	0.00	100.00
0 03	5.0	0.00	0 00	100 00
	TOTALS	163 84	100.00	100 00

MEAN GRAINSIZE	**Medium sand**	
TEXTURAL CLASS	**Slightly gravelly sand**	
SORTING	**Moderate**	
SKEWNESS	**Near symmetrical**	
KURTOSIS	**Platykurtic**	
% GRAVEL	0	
% SAND	100	
% MUD	0	
GRAPHIC MEAN	0.42 mm	1.25phi
MOMENT MEAN	0.44 mm	1 19phi
GRAPHIC SORTING	0.72	
MOMENT SORTING	0.68	
GRAPHIC SKEWNESS	-0.58	
MOMENT SKEWNESS	-0.07	
GRAPHIC KURTOSIS	0.79	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.15	





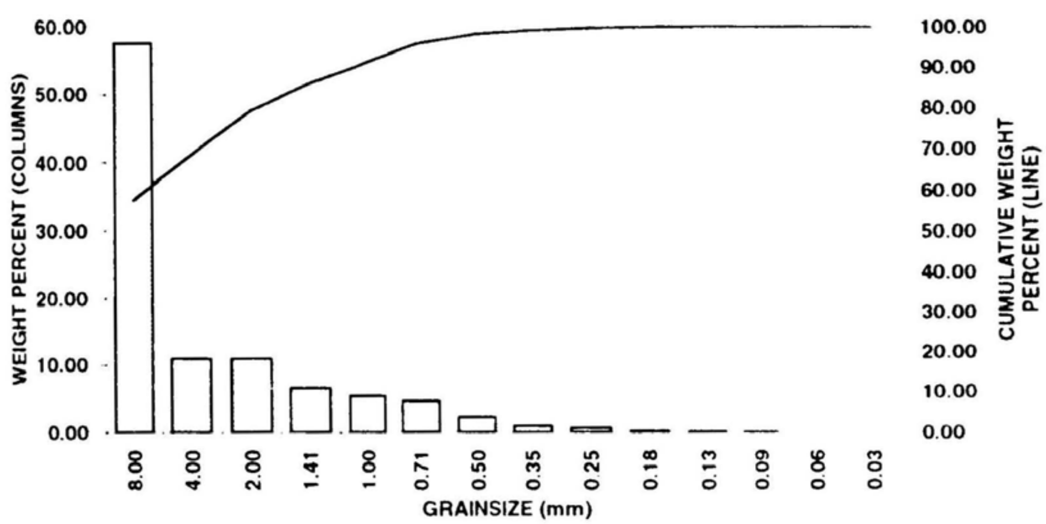


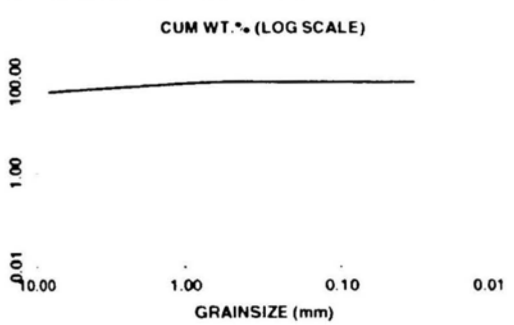
SIEVE DATA

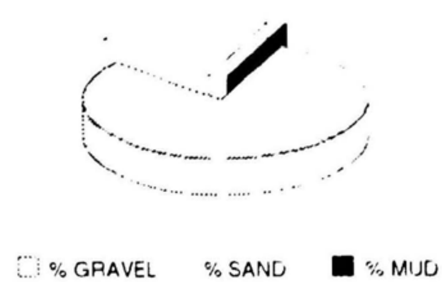
SAMPLE	3	**PROJECT**	CK 91 03
TOTAL WT.	237 10	**DATE**	1/22/96
SAMPLE LOCATION	Harbour	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	136.67	57.48	57.48
4.00	-2.0	26.05	10.96	68.43
2.00	-1.0	25.93	10.90	79.33
1.41	-0.5	15.47	6.51	85.84
1.00	0.0	12.65	5.32	91.16
0.71	0.5	11.04	4.64	95.80
0.50	1.0	5.41	2.28	98.08
0.35	1.5	2.34	0.98	99.06
0.25	2.0	1.36	0.57	99.63
0.18	2.5	0.59	0.25	99.88
0.13	3.0	0.23	0.10	99.98
0.09	3.5	0.05	0.02	100.00
0.06	4.0	0.00	0.00	100.00
0.03	5.0	0.00	0.00	100.00
	TOTALS	237.79	100.00	100.00

MEAN GRAINSIZE	**Pebbles**	
TEXTURAL CLASS	**Sandy gravel**	
SORTING	**Poor**	
SKEWNESS	**Strongly coarse**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	79	
% SAND	21	
% MUD	0	
GRAPHIC MEAN	4.13 mm	-2.04phi
MOMENT MEAN	4.01 mm	-2.00phi
GRAPHIC SORTING	1.37	
MOMENT SORTING	1.35	
GRAPHIC SKEWNESS	2.89	
MOMENT SKEWNESS	-0.34	
GRAPHIC KURTOSIS	1.04	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.29	







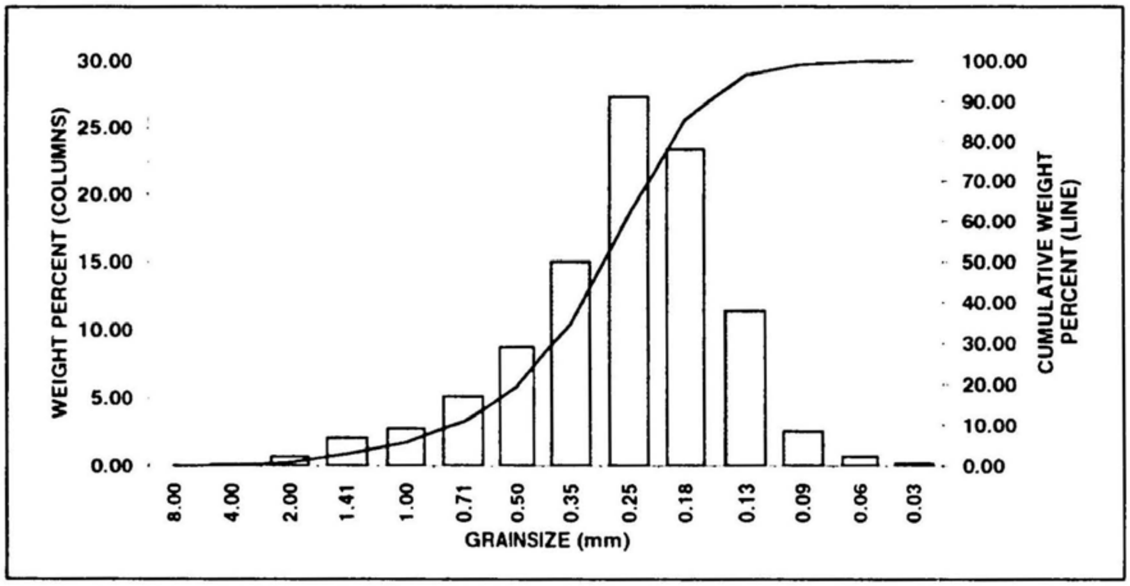
SIEVE DATA

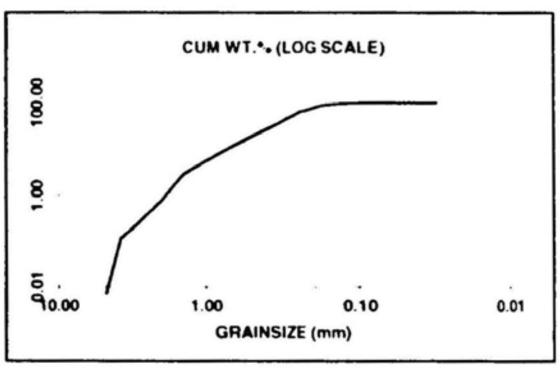
SAMPLE	4	PROJECT	CK.91.03
TOTAL WT.	75.80	DATE	1/22/96
SAMPLE LOCATION	Harbour	SCIENTIST	Bill Collins

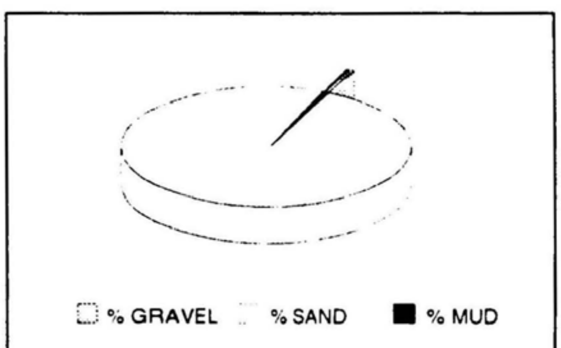
RAW DATA

MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.09	0.12	0.12
2.00	-1.0	0.54	0.71	0.83
1.41	-0.5	1.59	2.10	2.93
1.00	0.0	2.08	2.74	5.67
0.71	0.5	3.88	5.11	10.78
0.50	1.0	6.60	8.70	19.48
0.35	1.5	11.39	15.01	34.48
0.25	2.0	20.77	27.37	61.85
0.18	2.5	17.75	23.39	85.24
0.13	3.0	8.63	11.37	96.61
0.09	3.5	1.90	2.50	99.12
0.06	4.0	0.53	0.70	99.82
0.03	5.0	0.14	0.18	100.00
	TOTALS	75.89	100.00	100.00

MEAN GRAINSIZE	Fine sand	
TEXTURAL CLASS	Slightly gravelly sand	
SORTING	Moderate	
SKEWNESS	Coarse	
KURTOSIS	Mesokurtic	
% GRAVEL	1	
% SAND	99	
% MUD	0	
GRAPHIC MEAN	0.24 mm	2.04phi
MOMENT MEAN	0.27 mm	1.92phi
GRAPHIC SORTING	0.93	
MOMENT SORTING	0.91	
GRAPHIC SKEWNESS	-0.16	
MOMENT SKEWNESS	-0.08	
GRAPHIC KURTOSIS	1.06	
MOMENT KURTOSIS	1.04	
PROCESSING ERROR(%)	0.12	





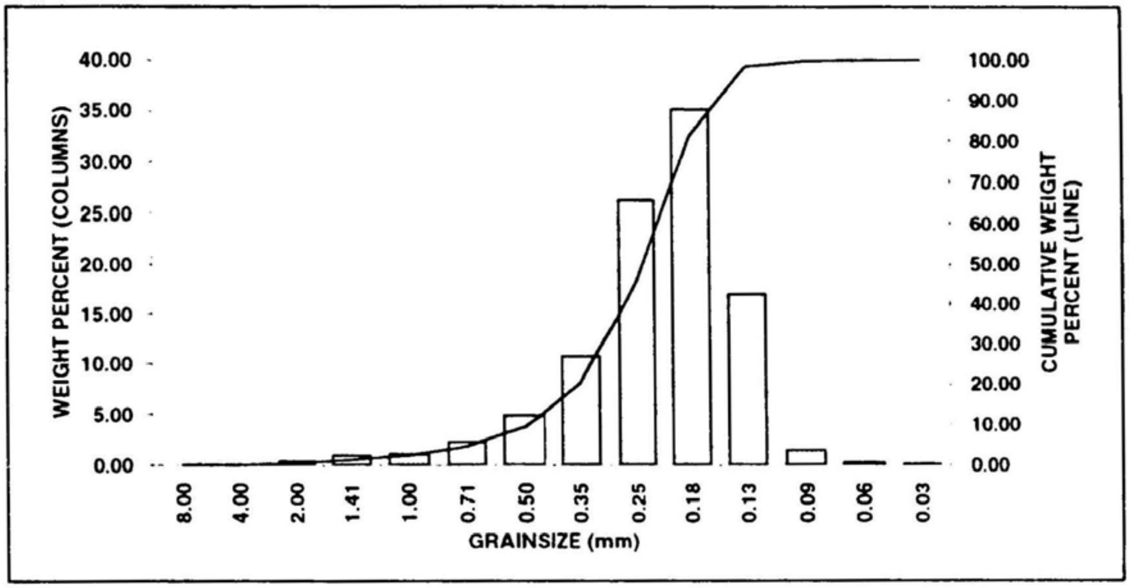


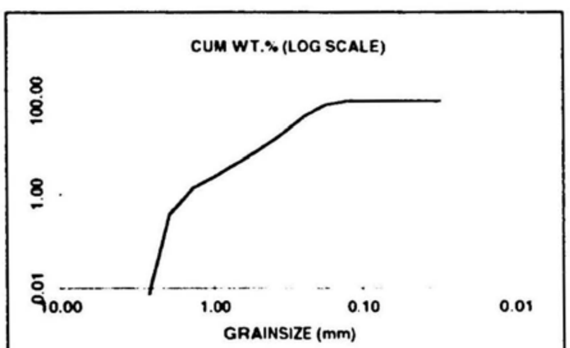
SIEVE DATA

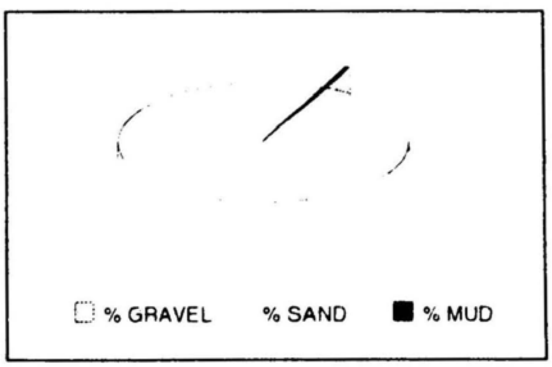
SAMPLE	5	**PROJECT**	CK 91 03
TOTAL WT.	101 00	**DATE**	1/22/96
SAMPLE LOCATION	Harbour	**SCIENTIST**	Bill Collins

RAW DATA				
MM	**PHI(Ø)**	**WT. RET.**	**WT. %**	**CUM. %**
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.00	0.00	0.00
2.00	-1.0	0.37	0.36	0.36
1.41	-0.5	0.94	0.92	1.29
1.00	0.0	1.02	1.00	2.29
0.71	0.5	2.28	2.24	4.53
0.50	1.0	4.93	4.85	9.38
0.35	1.5	10.90	10.71	20.09
0.25	2.0	26.68	26.23	46.32
0.18	2.5	35.70	35.09	81.41
0.13	3.0	17.23	16.94	98.35
0.09	3.5	1.42	1.40	99.74
0.06	4.0	0.22	0.22	99.96
0.03	5.0	0.04	0.04	100.00
	TOTALS	101.73	100.00	100.00

MEAN GRAINSIZE	**Fine sand**	
TEXTURAL CLASS	**Slightly gravelly sand**	
SORTING	**Moderately well**	
SKEWNESS	**Near symmetrical**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	0	
% SAND	100	
% MUD	0	
GRAPHIC MEAN	0.23 mm	2.13phi
MOMENT MEAN	0.22 mm	2.18phi
GRAPHIC SORTING	0.66	
MOMENT SORTING	0.72	
GRAPHIC SKEWNESS	-0.03	
MOMENT SKEWNESS	-0.04	
GRAPHIC KURTOSIS	0.98	
MOMENT KURTOSIS	1.06	
PROCESSING ERROR(%)	0.72	





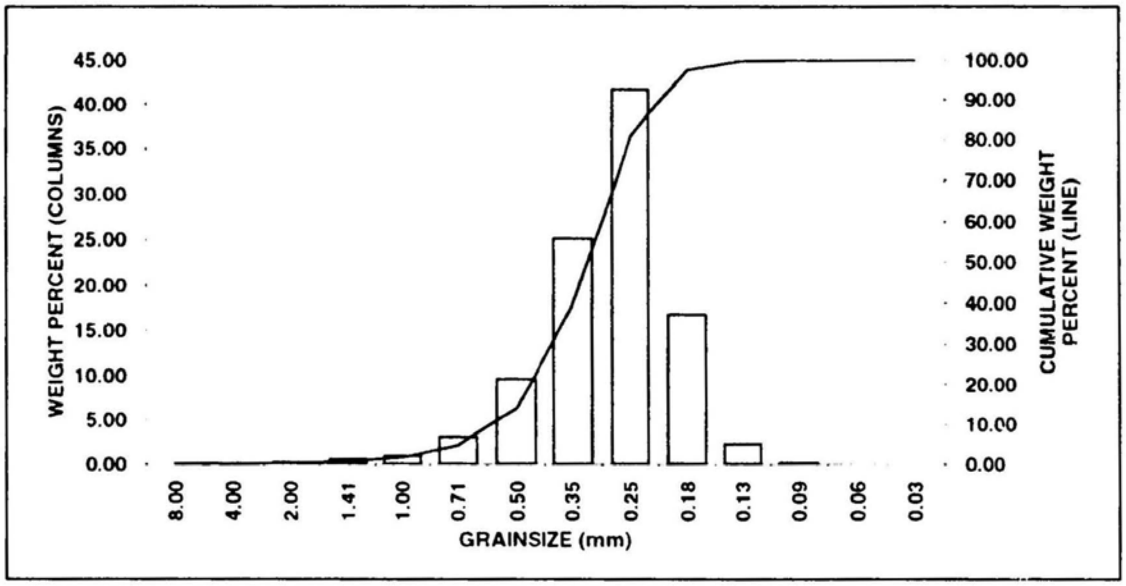


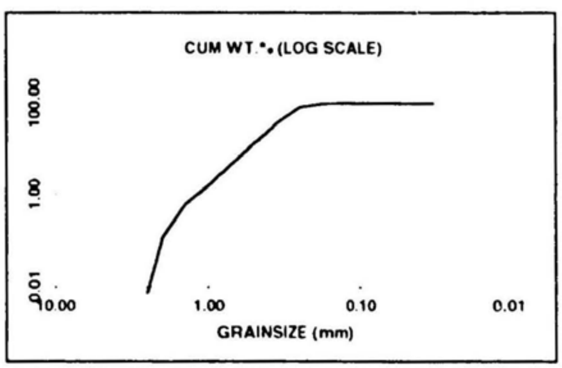
SIEVE DATA

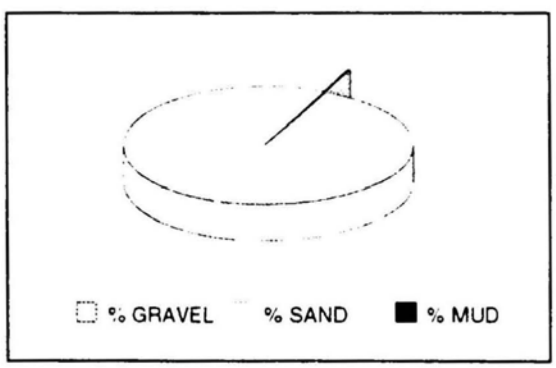
SAMPLE	**6**	**PROJECT**	CK.91.03
TOTAL WT.	167 50	**DATE**	1/22/96
SAMPLE LOCATION	Harbour	**SCIENTIST**	Bill Collins

RAW DATA				
MM	**PHI(Ø)**	**WT. RET.**	**WT. %**	**CUM. %**
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.00	0.00	0.00
2.00	-1.0	0.20	0.12	0.12
1.41	-0.5	0.84	0.50	0.62
1.00	0.0	1.55	0.92	1.54
0.71	0.5	5.07	3.02	4.56
0.50	1.0	16.08	9.57	14.14
0.35	1.5	42.15	25.10	39.23
0.25	2.0	69.92	41.63	80.87
0.18	2.5	28.07	16.71	97.58
0.13	3.0	3.74	2.23	99.81
0.09	3.5	0.32	0.19	100.00
0.06	4.0	0.00	0.00	100.00
0.03	5.0	0.00	0.00	100.00
	TOTALS	167.94	100.00	100.00

MEAN GRAINSIZE	**Medium sand**	
TEXTURAL CLASS	**Slightly gravelly sand**	
SORTING	**Moderately well**	
SKEWNESS	**Near symmetrical**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	0	
% SAND	100	
% MUD	0	
GRAPHIC MEAN	0.31 mm	1.67phi
MOMENT MEAN	0.29 mm	1.81phi
GRAPHIC SORTING	0.62	
MOMENT SORTING	0.58	
GRAPHIC SKEWNESS	-0.17	
MOMENT SKEWNESS	-0.03	
GRAPHIC KURTOSIS	1.02	
MOMENT KURTOSIS	1.05	
PROCESSING ERROR(%)	0.26	





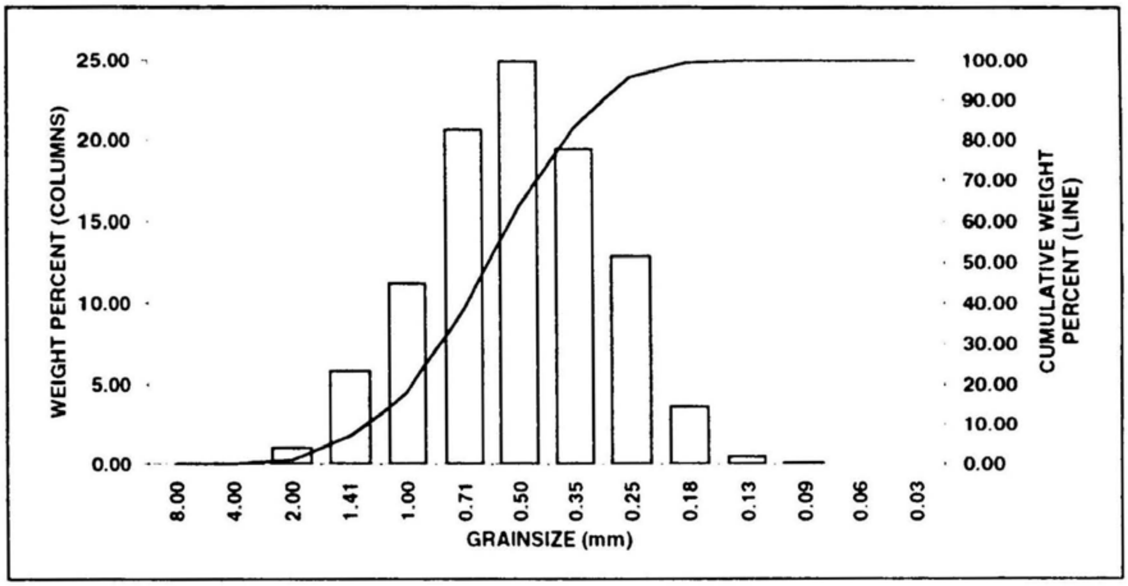


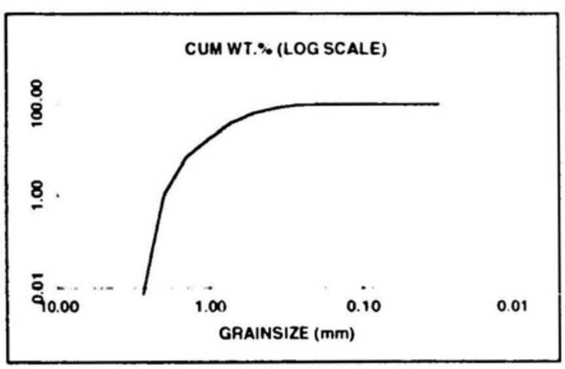
SIEVE DATA

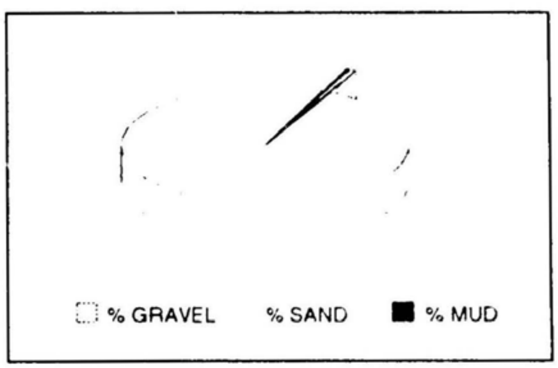
SAMPLE	7	**PROJECT**	CK.91.03
TOTAL WT.	98.60	**DATE**	1/22/96
SAMPLE LOCATION	Harbour	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.00	0.00	0.00
2.00	-1.0	0.98	0.99	0.99
1.41	-0.5	5.77	5.84	6.83
1.00	0.0	11.04	11.18	18.01
0.71	0.5	20.37	20.62	38.64
0.50	1.0	24.63	24.94	63.57
0.35	1.5	19.16	19.40	82.97
0.25	2.0	12.73	12.89	95.86
0.18	2.5	3.58	3.62	99.48
0.13	3.0	0.46	0.47	99.95
0.09	3.5	0.05	0.05	100.00
0.06	4.0	0.00	0.00	100.00
0.03	5.0	0.00	0.00	100.00
	TOTALS	98.77	100.00	100.00

MEAN GRAINSIZE	**Coarse sand**	
TEXTURAL CLASS	**Slightly gravelly sand**	
SORTING	**Moderate**	
SKEWNESS	**Near symmetrical**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	1	
% SAND	99	
% MUD	0	
GRAPHIC MEAN	0.52 mm	0.95phi
MOMENT MEAN	0.51 mm	0.97phi
GRAPHIC SORTING	0.73	
MOMENT SORTING	0.78	
GRAPHIC SKEWNESS	0.03	
MOMENT SKEWNESS	-0.04	
GRAPHIC KURTOSIS	0.90	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.17	





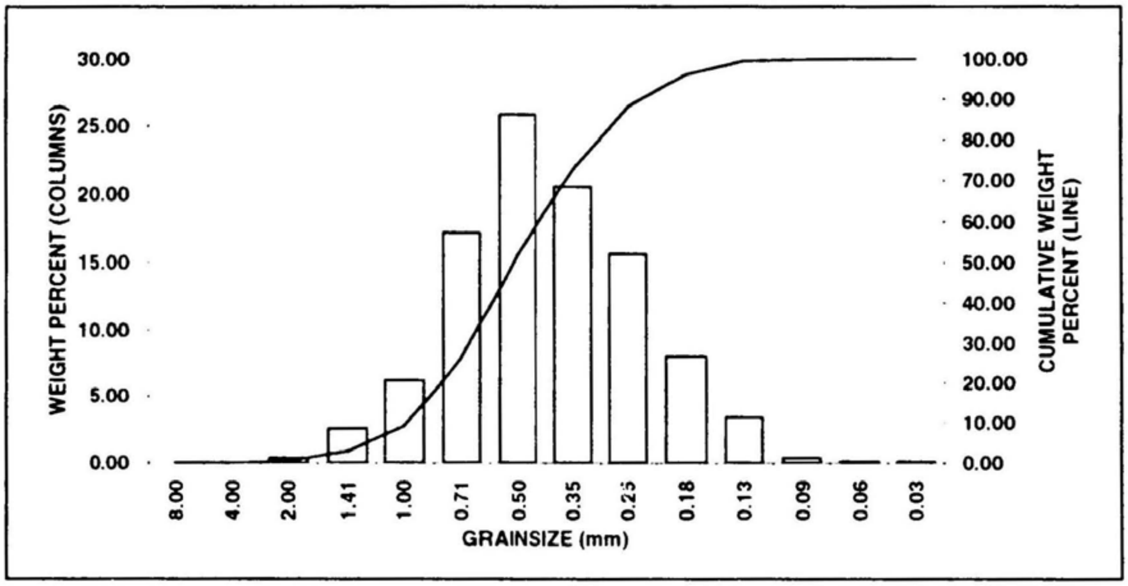


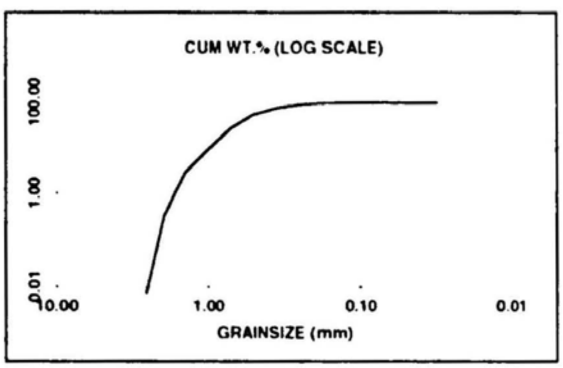
SIEVE DATA

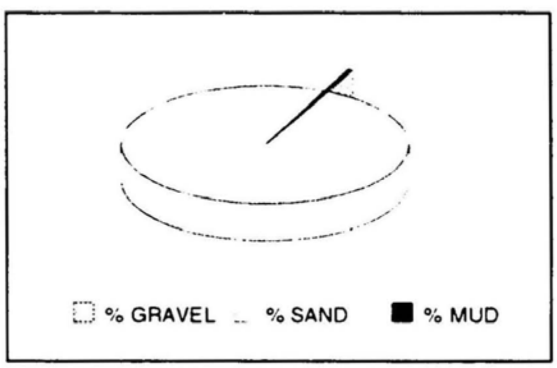
SAMPLE	9	**PROJECT**	CK.91.03
TOTAL WT.	161.30	**DATE**	1/22/96
SAMPLE LOCATION	Harbour	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.00	0.00	0.00
2.00	-1.0	0.52	0.32	0.32
1.41	-0.5	4.05	2.51	2.84
1.00	0.0	9.91	6.15	8.99
0.71	0.5	27.69	17.19	26.18
0.50	1.0	41.59	25.82	52.00
0.35	1.5	33.01	20.49	72.50
0.25	2.0	25.14	15.61	88.10
0.18	2.5	12.84	7.97	96.08
0.13	3.0	5.47	3.40	99.47
0.09	3.5	0.59	0.37	99.84
0.06	4.0	0.15	0.09	99.93
0.03	5.0	0.11	0.07	100.00
	TOTALS	161.07	100.00	100.00

MEAN GRAINSIZE	**Medium sand**	
TEXTURAL CLASS	**Slightly gravelly sand**	
SORTING	**Moderate**	
SKEWNESS	**Near symmetrical**	
KURTOSIS	**Very leptokurtic**	
% GRAVEL	0	
% SAND	100	
% MUD	0	
GRAPHIC MEAN	0.39 mm	1.36phi
MOMENT MEAN	0.41 mm	1.27phi
GRAPHIC SORTING	0.91	
MOMENT SORTING	0.82	
GRAPHIC SKEWNESS	-0.20	
MOMENT SKEWNESS	0.05	
GRAPHIC KURTOSIS	1.69	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.14	





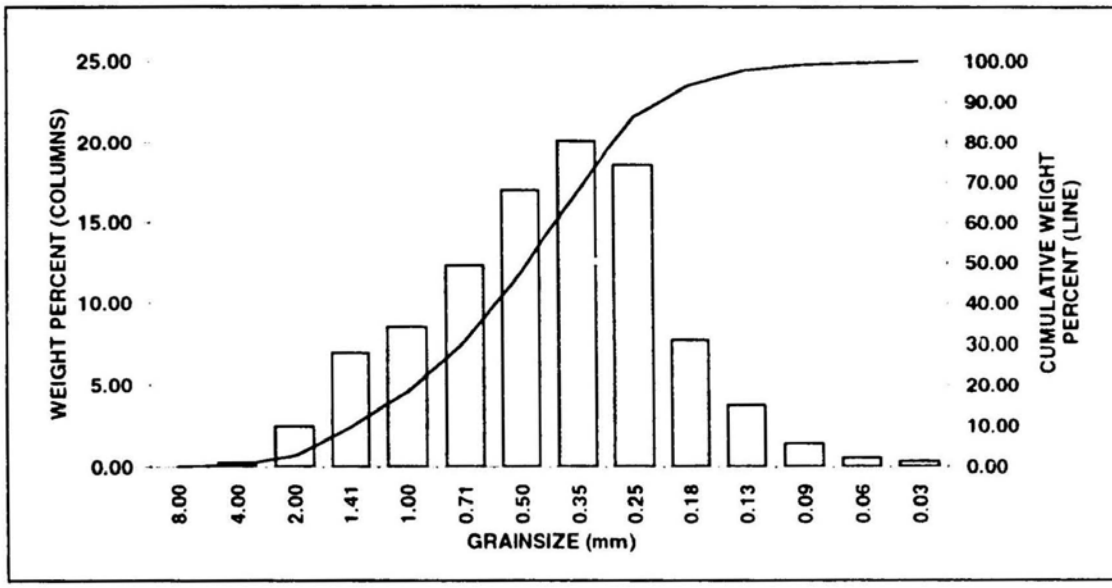


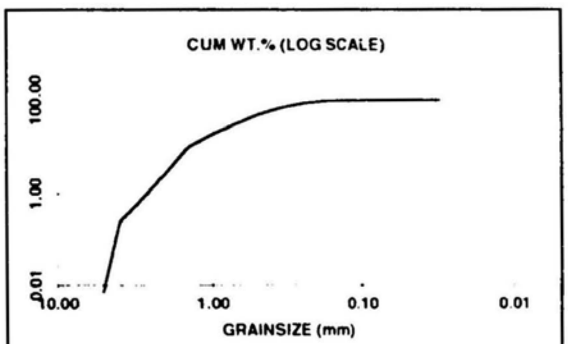
SIEVE DATA

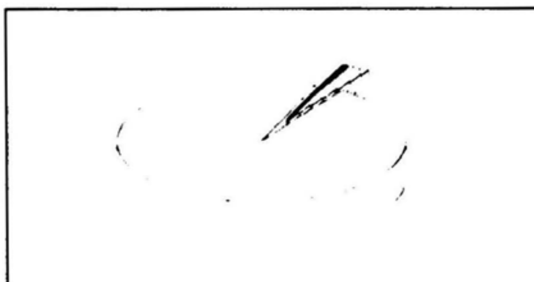
SAMPLE	10	**PROJECT**	CK 91 03
TOTAL WT.	93 90	**DATE**	1/22/96
SAMPLE LOCATION	Harbour	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.23	0.24	0.24
2.00	-1.0	2.31	2.45	2.70
1.41	-0.5	6.55	6.96	9.66
1.00	0.0	8.03	8.53	18.19
0.71	0.5	11.60	12.32	30.51
0.50	1.0	16.00	17.00	47.51
0.35	1.5	18.90	20.08	67.59
0.25	2.0	17.52	18.61	86.21
0.18	2.5	7.26	7.71	93.92
0.13	3.0	3.55	3.77	97.69
0.09	3.5	1.35	1.43	99.13
0.06	4.0	0.51	0.54	99.67
0.03	5.0	0.31	0.33	100.00
	TOTALS	94.12	100.00	100.00

MEAN GRAINSIZE	**Medium sand**	
TEXTURAL CLASS	**Slightly gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**Near symmetrical**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	3	
% SAND	97	
% MUD	0	
GRAPHIC MEAN	0.42 mm	1.25phi
MOMENT MEAN	0 42 mm	1.24phi
GRAPHIC SORTING	1.05	
MOMENT SORTING	1.04	
GRAPHIC SKEWNESS	0.38	
MOMENT SKEWNESS	-0 01	
GRAPHIC KURTOSIS	1.05	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.23	





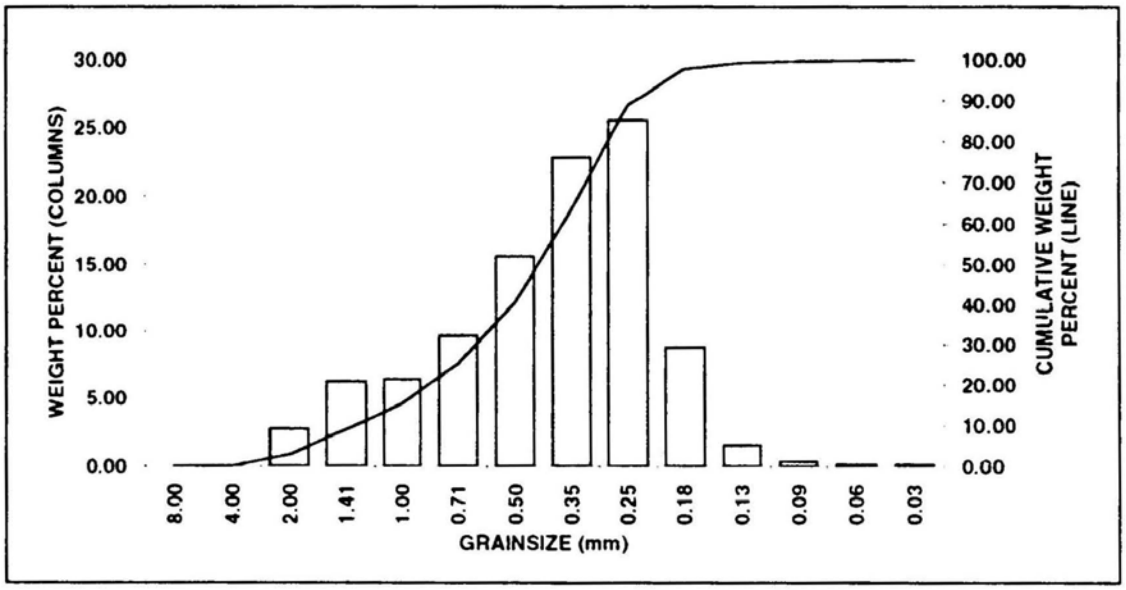


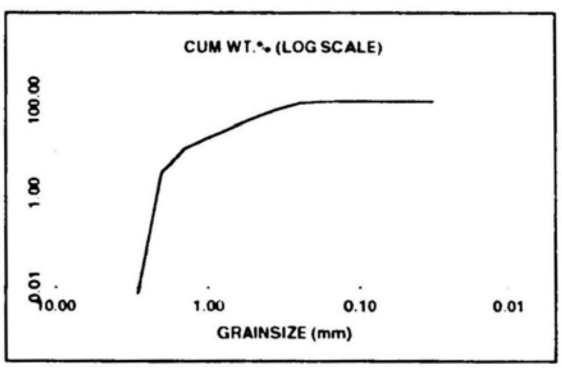
SIEVE DATA

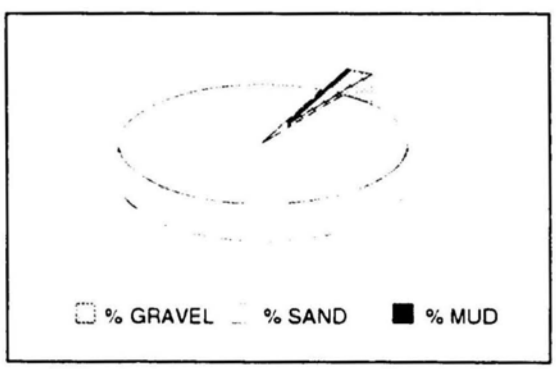
SAMPLE	11	**PROJECT**	CK 91.03
TOTAL WT.	106.80	**DATE**	1/22/96
SAMPLE LOCATION	Harbour	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.00	0.00	0.00
2.00	-1.0	2.94	2.75	2.75
1.41	-0.5	6.65	6.22	8.98
1.00	0.0	6.82	6.38	15.36
0.71	0.5	10.32	9.66	25.02
0.50	1.0	16.68	15.61	40.63
0.35	1.5	24.42	22.85	63.48
0.25	2.0	27.30	25.55	89.03
0.18	2.5	9.40	8.80	97.83
0.13	3.0	1.64	1.53	99.36
0.09	3.5	0.37	0.35	99.71
0.06	4.0	0.16	0.15	99.86
0.03	5.0	0.15	0.14	100.00
	TOTALS	106.85	100.00	100.00

MEAN GRAINSIZE	**Medium sand**	
TEXTURAL CLASS	**Slightly gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**Coarse**	
KURTOSIS	**Leptokurtic**	
% GRAVEL	3	
% SAND	97	
% MUD	0	
GRAPHIC MEAN	0.42 mm	1.26phi
MOMENT MEAN	0.41 mm	1.29phi
GRAPHIC SORTING	1.06	
MOMENT SORTING	0.94	
GRAPHIC SKEWNESS	-0.62	
MOMENT SKEWNESS	-0.19	
GRAPHIC KURTOSIS	1.43	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.05	







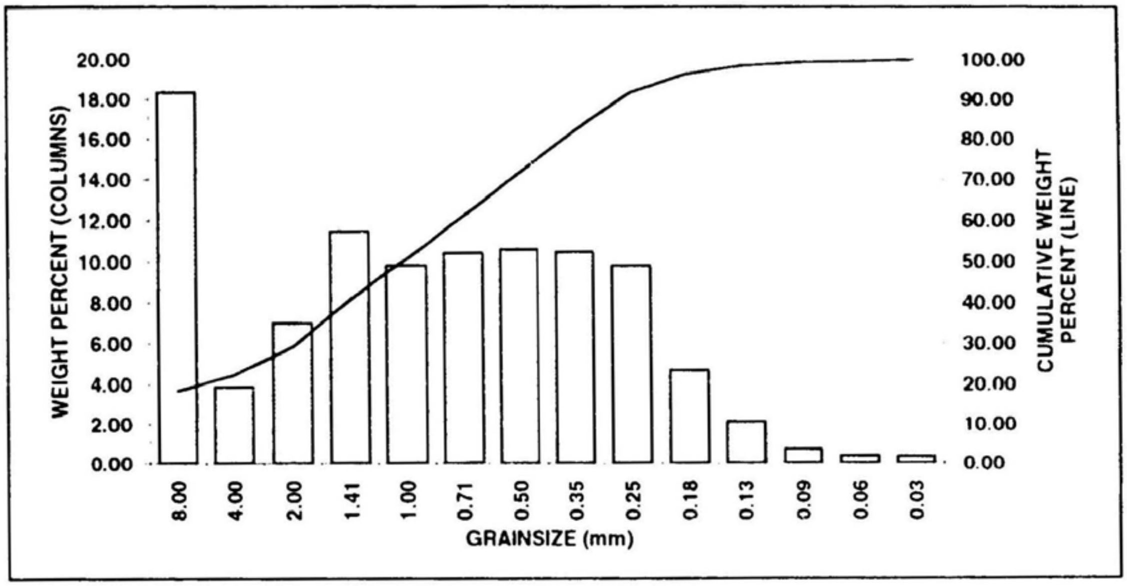
SIEVE DATA

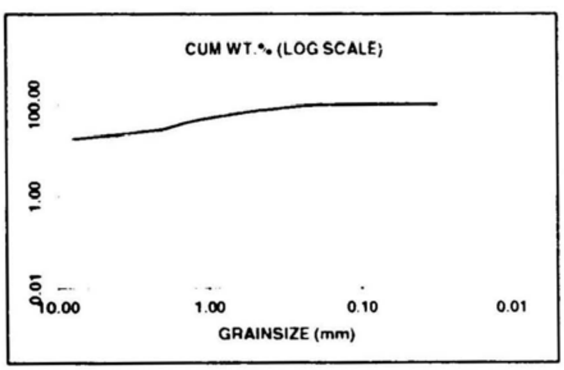
SAMPLE	12	PROJECT	CK 91 03
TOTAL WT.	184 10	DATE	1/22/96
SAMPLE LOCATION	Harbour	SCIENTIST	Bill Collins

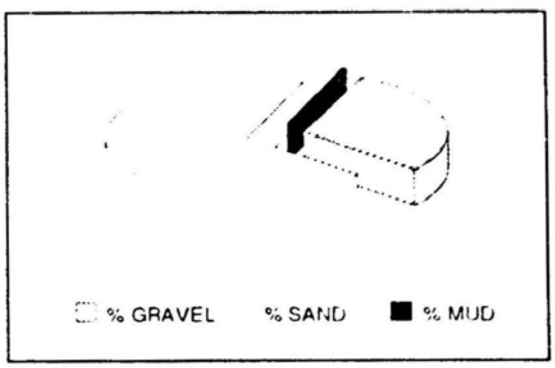
RAW DATA

MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	33.85	18.33	18.33
4.00	-2.0	7.15	3.87	22.21
2.00	-1.0	12.91	6.99	29.20
1.41	-0.5	21.17	11.47	40.66
1.00	0.0	18.14	9.82	50.49
0.71	0.5	19.22	10.41	60.90
0.50	1.0	19.51	10.57	71.46
0.35	1.5	19.33	10.47	81.93
0.25	2.0	18.13	9.82	91.75
0.18	2.5	8.68	4.70	96.45
0.13	3.0	3.88	2.10	98.55
0.09	3.5	1.37	0.74	99.30
0.06	4.0	0.66	0.36	99.65
0.03	5.0	0.64	0.35	100.00
	TOTALS	184.64	100.00	100.00

MEAN GRAINSIZE	Very coarse sand	
TEXTURAL CLASS	Gravelly sand	
SORTING	Poor	
SKEWNESS	#N/A	
KURTOSIS	Platykurtic	
% GRAVEL	29	
% SAND	70	
% MUD	0	
GRAPHIC MEAN	1.11 mm	-0.16phi
MOMENT MEAN	1.00 mm	-0.01phi
GRAPHIC SORTING	1.97	
MOMENT SORTING	1.84	
GRAPHIC SKEWNESS	-4.06	
MOMENT SKEWNESS	-4.06	
GRAPHIC KURTOSIS	0.83	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.29	





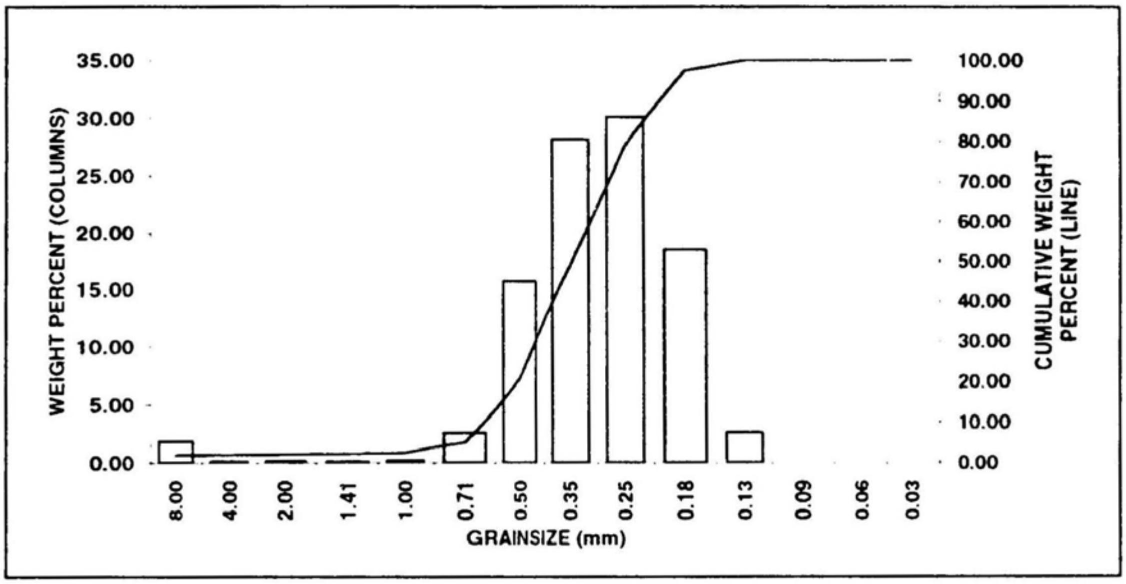


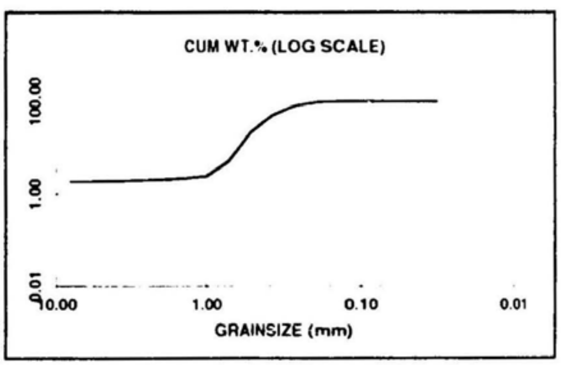
SIEVE DATA

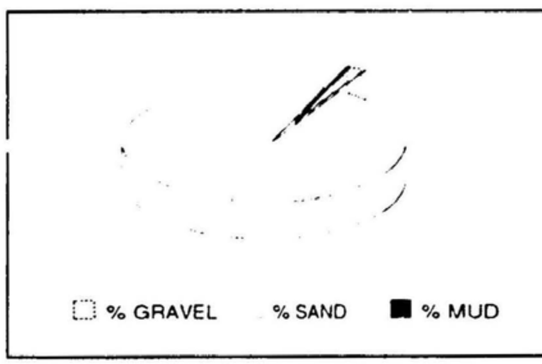
SAMPLE	13	**PROJECT**	CK 91.03
TOTAL WT.	147.70	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	2.74	1.85	1.85
4.00	-2.0	0.11	0.07	1.93
2.00	-1.0	0.23	0.16	2.08
1.41	-0.5	0.15	0.10	2.18
1.00	0.0	0.33	0.22	2.41
0.71	0.5	3.75	2.53	4.94
0.50	1.0	23.23	15.69	20.63
0.35	1.5	41.72	28.19	48.82
0.25	2.0	44.53	30.08	78.90
0.18	2.5	27.38	18.50	97.40
0.13	3.0	3.84	2.59	99.99
0.09	3.5	0.00	0.00	99.99
0.06	4.0	0.00	0.00	100.00
0.03	5.0	0.01	0.00	100.00
	TOTALS	148.02	100.00	100.00

MEAN GRAINSIZE	**Medium sand**	
TEXTURAL CLASS	**Slightly gravelly sand**	
SORTING	**Moderately well**	
SKEWNESS	**Strongly coarse**	
KURTOSIS	**Platykurtic**	
% GRAVEL	2	
% SAND	98	
% MUD	0	
GRAPHIC MEAN	0.31 mm	1.67phi
MOMENT MEAN	0.31 mm	1.68phi
GRAPHIC SORTING	0.62	
MOMENT SORTING	0.87	
GRAPHIC SKEWNESS	0.28	
MOMENT SKEWNESS	-0.40	
GRAPHIC KURTOSIS	0.80	
MOMENT KURTOSIS	1.16	
PROCESSING ERROR(%)	0.22	





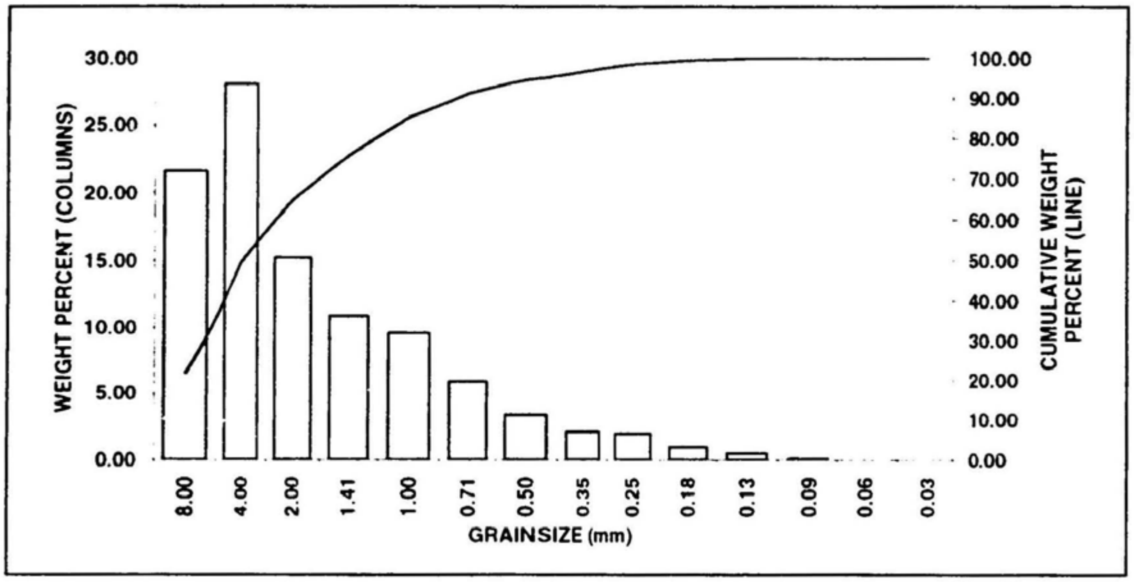


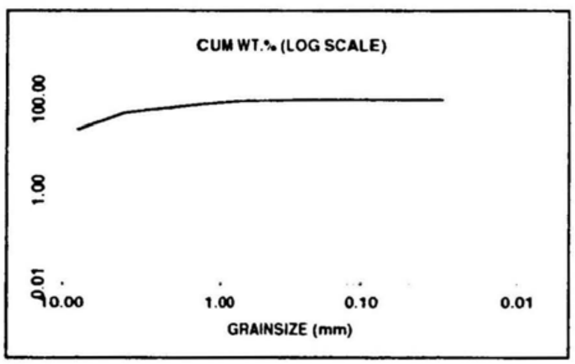
SIEVE DATA

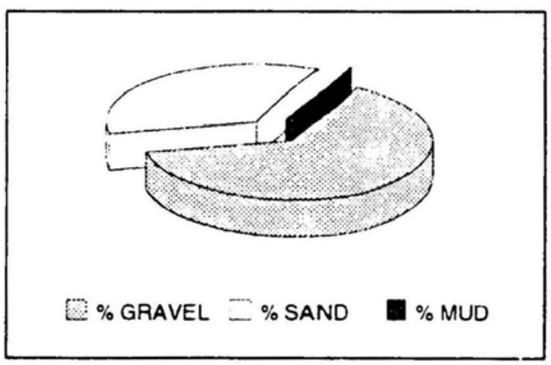
SAMPLE	**14**	PROJECT	CK.91.03
TOTAL WT.	144.30	DATE	1/22/96
SAMPLE LOCATION	Lagoon	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	31.17	21.55	21.55
4.00	-2.0	40.54	28.03	49.58
2.00	-1.0	22.01	15.22	64.80
1.41	-0.5	15.73	10.88	75.68
1.00	0.0	13.88	9.60	85.27
0.71	0.5	8.47	5.86	91.13
0.50	1.0	4.82	3.33	94.46
0.35	1.5	2.99	2.07	96.53
0.25	2.0	2.82	1.95	98.48
0.18	2.5	1.39	0.96	99.44
0.13	3.0	0.70	0.48	99.92
0.09	3.5	0.10	0.07	99.99
0.06	4.0	0.01	0.01	100.00
0.03	5.0	0.00	0.00	100.00
	TOTALS	144.63	100.00	100.00

MEAN GRAINSIZE	**Granules**	
TEXTURAL CLASS	**Sandy gravel**	
SORTING	**Poor**	
SKEWNESS	**Strongly coarse**	
KURTOSIS	**Very platykurtic**	
% GRAVEL	65	
% SAND	35	
% MUD	0	
GRAPHIC MEAN	2.74 mm	-1.45phi
MOMENT MEAN	2.36 mm	-1.24phi
GRAPHIC SORTING	1.46	
MOMENT SORTING	1.41	
GRAPHIC SKEWNESS	2.64	
MOMENT SKEWNESS	-0.87	
GRAPHIC KURTOSIS	0.66	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.23	





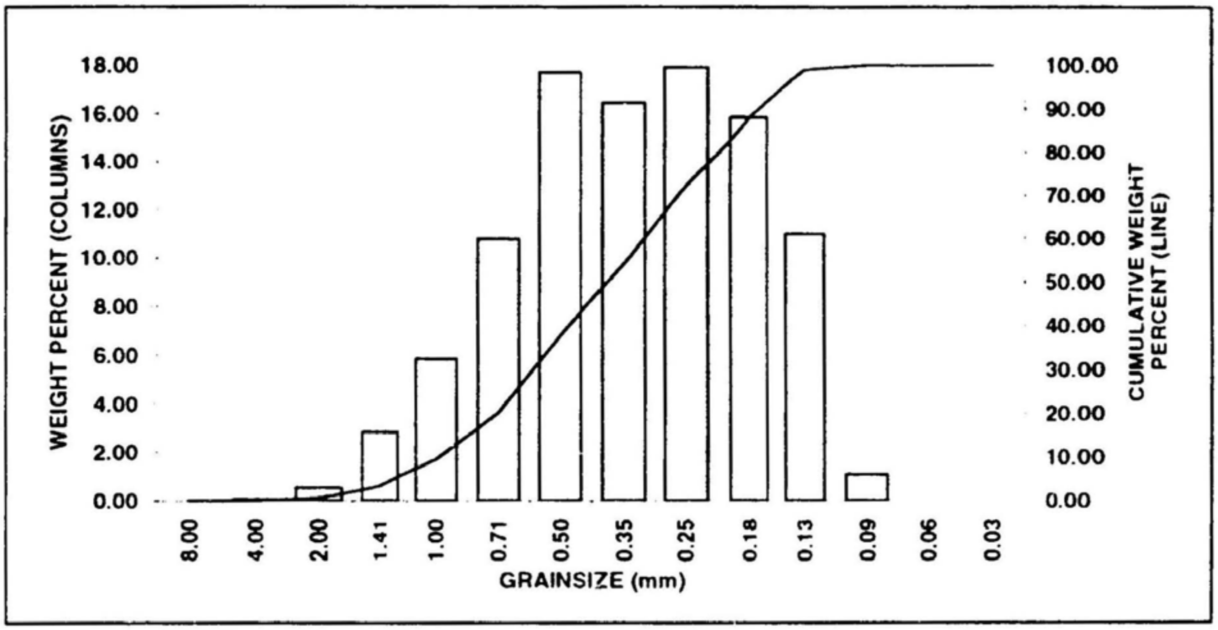


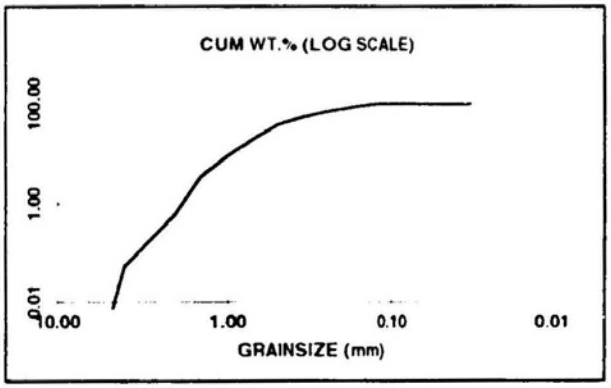
SIEVE DATA

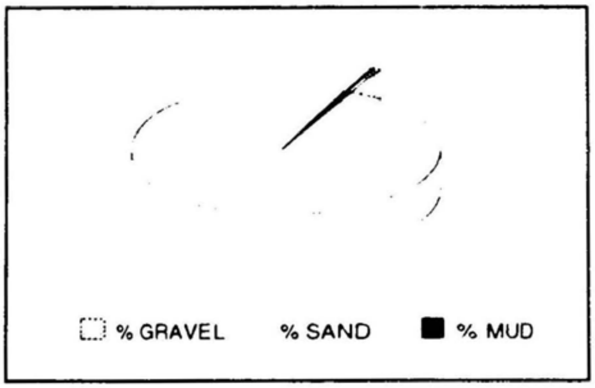
SAMPLE	15	PROJECT	CK 91 03
TOTAL WT.	133 00	DATE	1/22 96
SAMPLE LOCATION	Lagoon	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0 00
4.00	-2.0	0.07	0.05	0 05
2.00	-1.0	0.73	0.55	0 60
1.41	-0.5	3.80	2 84	3 44
1.00	0.0	7.81	5.85	9.29
0.71	0.5	14.36	10.75	20.04
0.50	1.0	23.63	17.69	37.73
0.35	1.5	21.95	16.43	54.16
0.25	2.0	23.92	17.90	72.06
0.18	2.5	21.17	15.85	87.91
0.13	3.0	14.68	10.99	98.89
0.09	3.5	1.47	1.10	99.99
0.06	4.0	0.01	0.00	100.00
0.03	5.0	0 00	0.00	100.00
	TOTALS	133.60	100.00	100 00

MEAN GRAINSIZE	Medium sand	
TEXTURAL CLASS	Slightly gravelly sand	
SORTING	Poor	
SKEWNESS	Near symmetrical	
KURTOSIS	Mesokurtic	
% GRAVEL	1	
% SAND	99	
% MUD	0	
GRAPHIC MEAN	0.31 mm	1 71phi
MOMENT MEAN	0 33 mm	1 58phi
GRAPHIC SORTING	1.04	
MOMENT SORTING	0.96	
GRAPHIC SKEWNESS	-0.21	
MOMENT SKEWNESS	-0.06	
GRAPHIC KURTOSIS	0.99	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0 45	





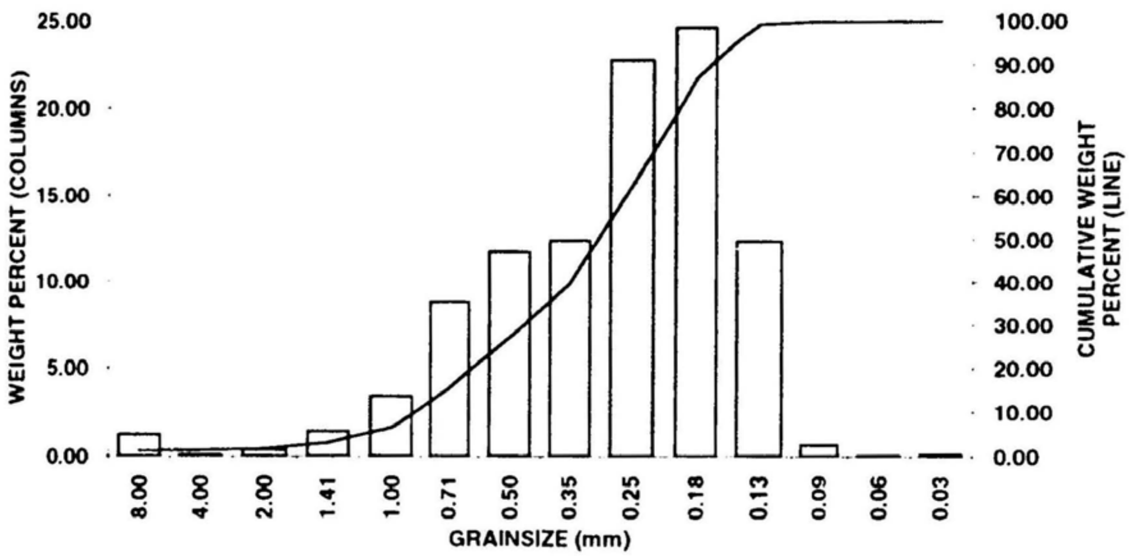


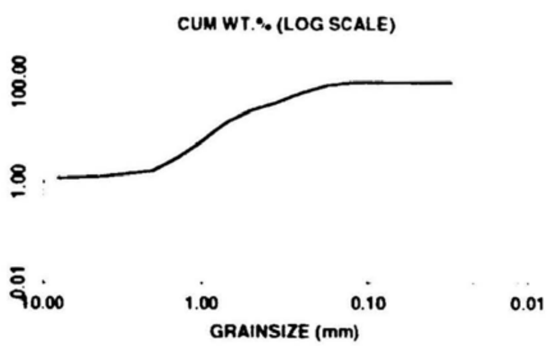
SIEVE DATA

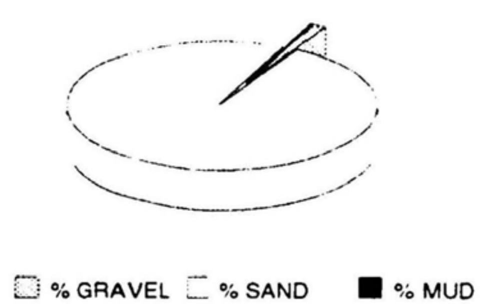
SAMPLE	16	PROJECT	CK.91.03
TOTAL WT.	177 10	DATE	1/22/96
SAMPLE LOCATION	Channel	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	2.16	1.22	1.22
4.00	-2.0	0.14	0.08	1.30
2.00	-1.0	0.64	0.36	1.66
1.41	-0.5	2.48	1.40	3.05
1.00	0.0	6.06	3.41	6.47
0.71	0.5	15.70	8.84	15.31
0.50	1.0	20.84	11.74	27.04
0.35	1.5	22.08	12.43	39.48
0.25	2.0	40.37	22.73	62.21
0.18	2.5	43.73	24.63	86.84
0.13	3.0	22.00	12.39	99.23
0.09	3.5	1.12	0.63	99.86
0.06	4.0	0.05	0.03	99.89
0.03	5.0	0.20	0.11	100.00
	TOTALS	177.57	100.00	100.00

MEAN GRAINSIZE	Medium sand	
TEXTURAL CLASS	Slightly gravelly sand	
SORTING	Poor	
SKEWNESS	Coarse	
KURTOSIS	Mesokurtic	
% GRAVEL	2	
% SAND	98	
% MUD	0	
GRAPHIC MEAN	0.29 mm	1.80phi
MOMENT MEAN	0.29 mm	1.77phi
GRAPHIC SORTING	1.04	
MOMENT SORTING	1.04	
GRAPHIC SKEWNESS	-0.67	
MOMENT SKEWNESS	-0.29	
GRAPHIC KURTOSIS	1.06	
MOMENT KURTOSIS	1.07	
PROCESSING ERROR(%)	0.26	





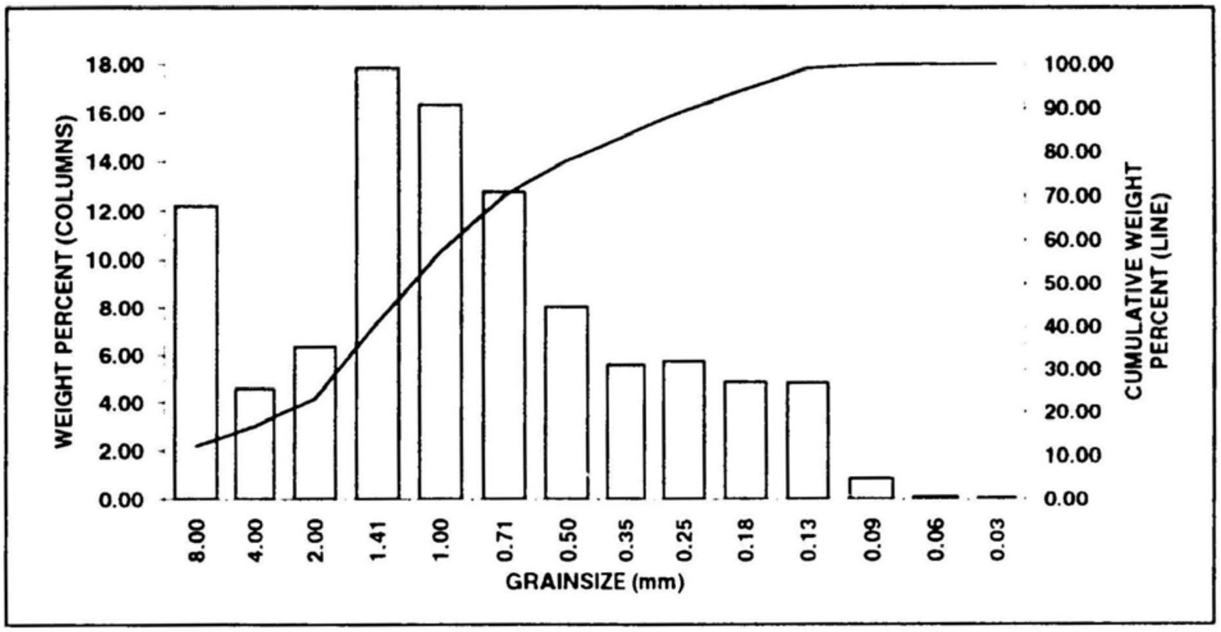


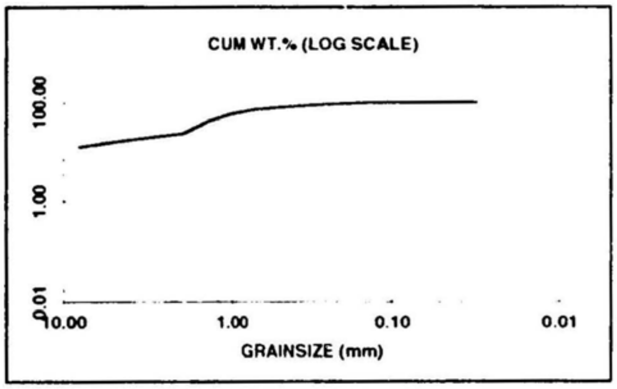
SIEVE DATA

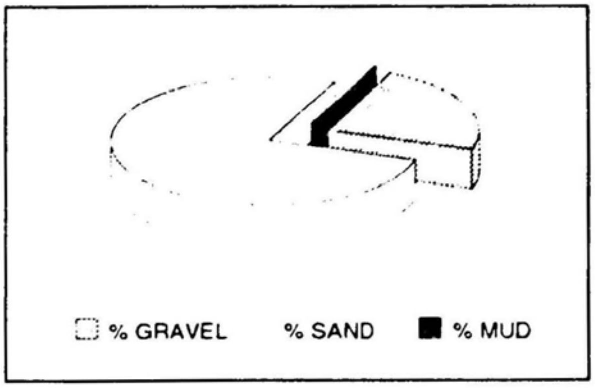
SAMPLE	**17**	**PROJECT**	CK 91 03
TOTAL WT.	137.10	**DATE**	1/22/96
SAMPLE LOCATION	Channel	**SCIENTIST**	Bill Collins

RAW DATA				
MM	**PHI(Ø)**	**WT. RET.**	**WT. %**	**CUM. %**
8.00	-3.0	16.74	12.20	12.20
4.00	-2.0	6.26	4.56	16.76
2.00	-1.0	8.67	6.32	23.07
1.41	-0.5	24.46	17.82	40.89
1.00	0.0	22.42	16.33	57.23
0.71	0.5	17.53	12.77	70.00
0.50	1.0	11.02	8.03	78.03
0.35	1.5	7.65	5.57	83.60
0.25	2.0	7.87	5.73	89.33
0.18	2.5	6.67	4.86	94.19
0.13	3.0	6.61	4.82	99.01
0.09	3.5	1.17	0.85	99.86
0.06	4.0	0.14	0.10	99.96
0.03	5.0	0.05	0.04	100.00
	TOTALS	137.26	100.00	100.00

MEAN GRAINSIZE	**Very coarse sand**	
TEXTURAL CLASS	**Gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**#N/A**	
KURTOSIS	**Leptokurtic**	
% GRAVEL	23	
% SAND	77	
% MUD	0	
GRAPHIC MEAN	1.13 mm	-0.18phi
MOMENT MEAN	0.98 mm	0.03phi
GRAPHIC SORTING	1.80	
MOMENT SORTING	1.65	
GRAPHIC SKEWNESS	-1.38	
MOMENT SKEWNESS	-1.38	
GRAPHIC KURTOSIS	1.17	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.12	





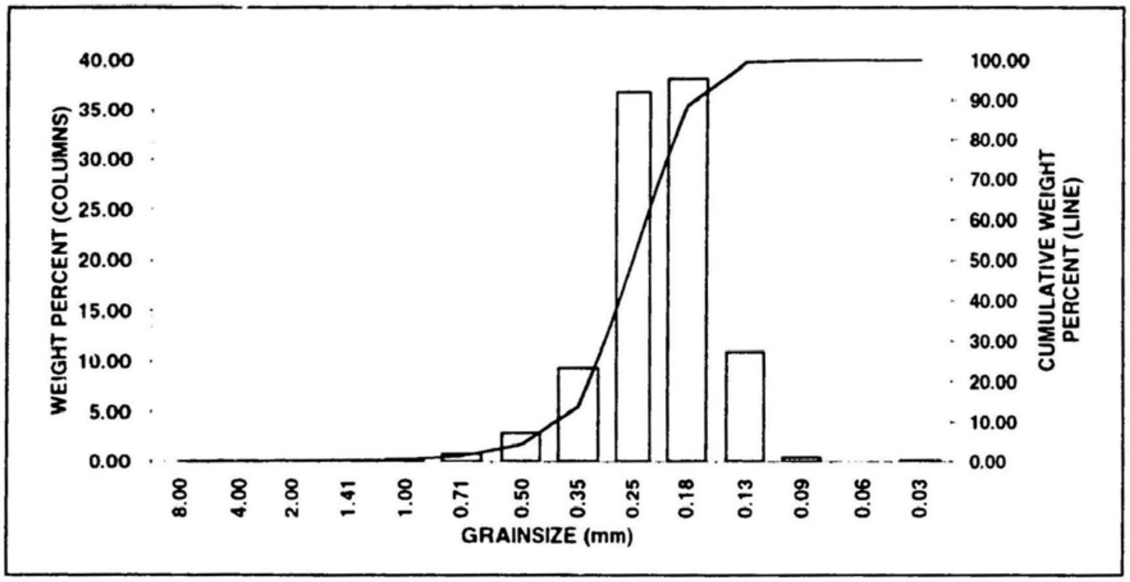


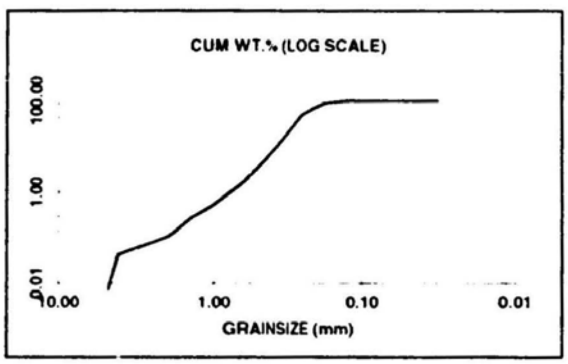
SIEVE DATA

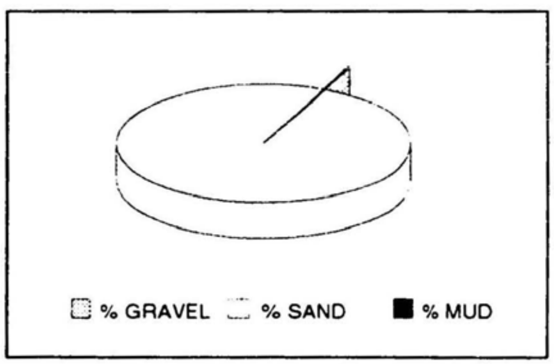
SAMPLE	18	PROJECT	CK.91.03
TOTAL WT.	143.70	DATE	1/22/96
SAMPLE LOCATION	Channel	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.06	0.04	0.04
2.00	-1.0	0.09	0.06	0.10
1.41	-0.5	0.23	0.16	0.26
1.00	0.0	0.37	0.26	0.52
0.71	0.5	1.20	0.84	1.36
0.50	1.0	4.14	2.86	4.24
0.35	1.5	13.39	9.32	13.56
0.25	2.0	52.91	36.82	50.38
0.18	2.5	54.85	38.18	88.56
0.13	3.0	15.72	10.94	99.50
0.09	3.5	0.59	0.41	99.91
0.06	4.0	0.01	0.01	99.92
0.03	5.0	0.12	0.08	100.00
	TOTALS	143.68	100.00	100.00

MEAN GRAINSIZE	Fine sand	
TEXTURAL CLASS	Slightly gravelly sand	
SORTING	Moderately well	
SKEWNESS	Near symmetrical	
KURTOSIS	Mesokurtic	
% GRAVEL	0	
% SAND	100	
% MUD	0	
GRAPHIC MEAN	0.20 mm	2.31phi
MOMENT MEAN	0.22 mm	2.21phi
GRAPHIC SORTING	0.63	
MOMENT SORTING	0.53	
GRAPHIC SKEWNESS	-0.55	
MOMENT SKEWNESS	-0.01	
GRAPHIC KURTOSIS	0.99	
MOMENT KURTOSIS	1.08	
PROCESSING ERROR(%)	0.01	





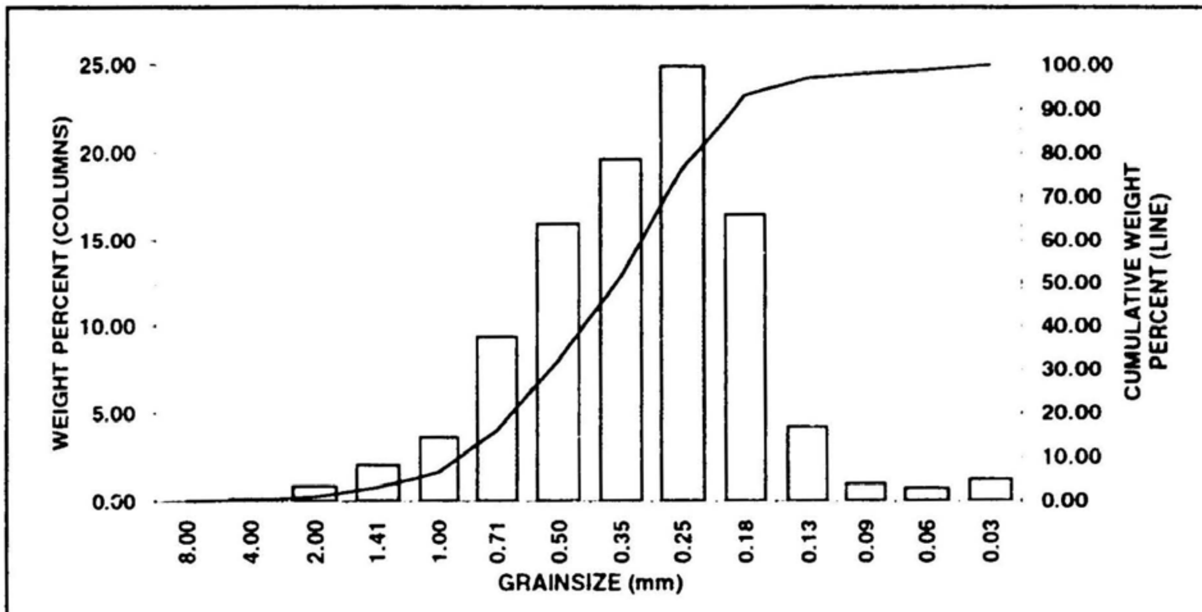


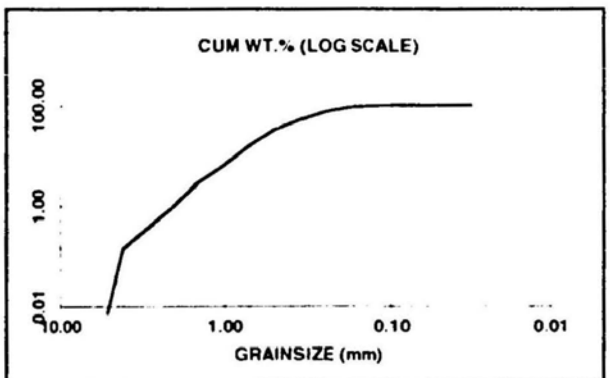
SIEVE DATA

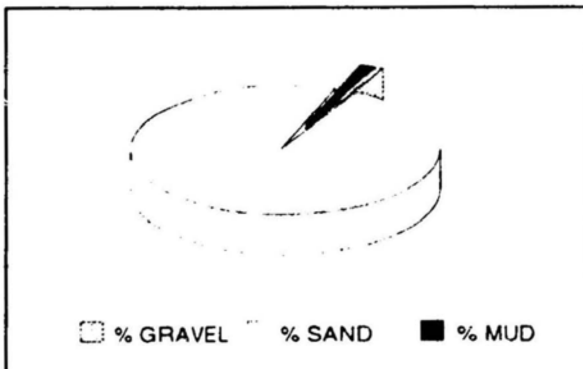
SAMPLE	19	PROJECT	CK.91.03
TOTAL WT.	173.80	DATE	1/22/96
SAMPLE LOCATION	Lagoon	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.24	0.14	0.14
2.00	-1.0	1.45	0.83	0.97
1.41	-0.5	3.51	2.02	2.99
1.00	0.0	6.26	3.60	6.60
0.71	0.5	16.24	9.35	15.95
0.50	1.0	27.68	15.94	31.88
0.35	1.5	34.09	19.63	51.51
0.25	2.0	43.23	24.89	76.40
0.18	2.5	28.64	16.49	92.88
0.13	3.0	7.31	4.21	97.09
0.09	3.5	1.69	0.97	98.07
0.06	4.0	1.25	0.72	98.79
0.03	5.0	2.11	1.21	100.00
	TOTALS	173.70	100.00	100.00

MEAN GRAINSIZE	Medium sand	
TEXTURAL CLASS	Slightly gravelly sand	
SORTING	Moderate	
SKEWNESS	Near symmetrical	
KURTOSIS	Platykurtic	
% GRAVEL	1	
% SAND	98	
% MUD	1	
GRAPHIC MEAN	0.32 mm	1.63phi
MOMENT MEAN	0.32 mm	1.64phi
GRAPHIC SORTING	0.93	
MOMENT SORTING	0.95	
GRAPHIC SKEWNESS	-1.00	
MOMENT SKEWNESS	0.02	
GRAPHIC KURTOSIS	0.88	
MOMENT KURTOSIS	1.05	
PROCESSING ERROR(%)	0.06	





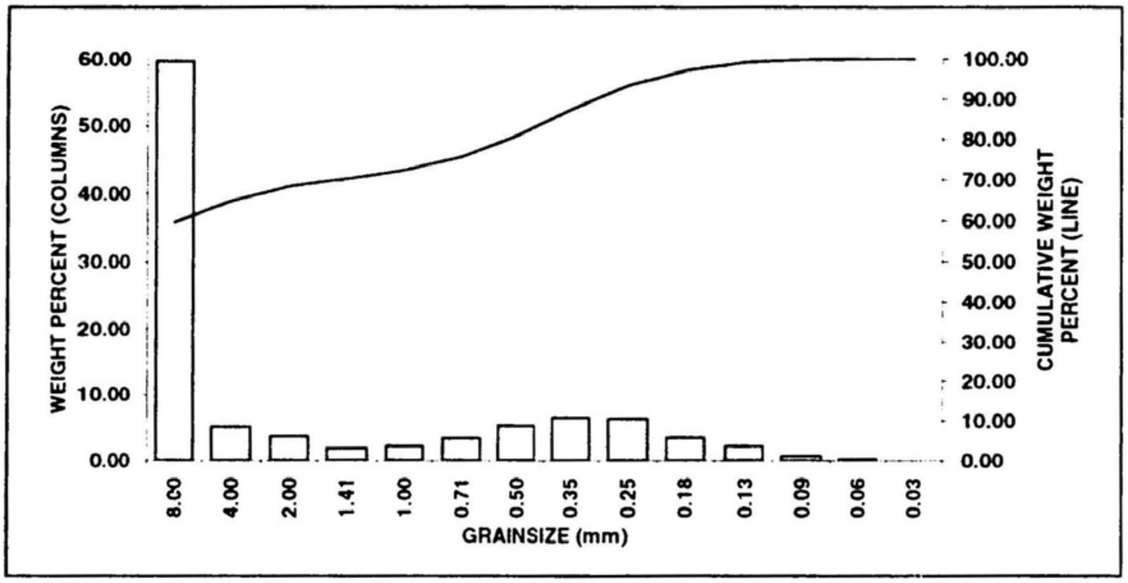


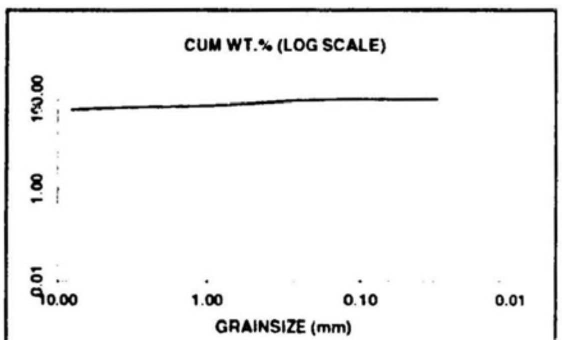
SIEVE DATA

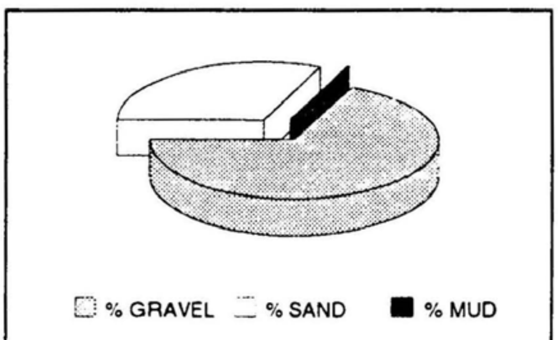
SAMPLE	20	PROJECT	CK.91.03
TOTAL WT.	135.80	DATE	1/22/96
SAMPLE LOCATION	Channel	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	81.10	59.67	59.67
4.00	-2.0	6.86	5.05	64.71
2.00	-1.0	5.00	3.68	68.39
1.41	-0.5	2.46	1.81	70.20
1.00	0.0	2.91	2.14	72.34
0.71	0.5	4.53	3.33	75.68
0.50	1.0	7.12	5.24	80.92
0.35	1.5	8.68	6.39	87.30
0.25	2.0	8.53	6.28	93.58
0.18	2.5	4.70	3.46	97.04
0.13	3.0	2.95	2.17	99.21
0.09	3.5	0.84	0.62	99.82
0.06	4.0	0.23	0.17	99.99
0.03	5.0	0.01	0.01	100.00
	TOTALS	135.92	100.00	100.00

MEAN GRAINSIZE	Granules	
TEXTURAL CLASS	Sandy gravel	
SORTING	Very poor	
SKEWNESS	#N/A	
KURTOSIS	Very platykurtic	
% GRAVEL	68	
% SAND	32	
% MUD	0	
GRAPHIC MEAN	2.77 mm	-1.47phi
MOMENT MEAN	2.76 mm	-1.47phi
GRAPHIC SORTING	2.05	
MOMENT SORTING	2.11	
GRAPHIC SKEWNESS	8.80	
MOMENT SKEWNESS	-2.66	
GRAPHIC KURTOSIS	0.62	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.09	





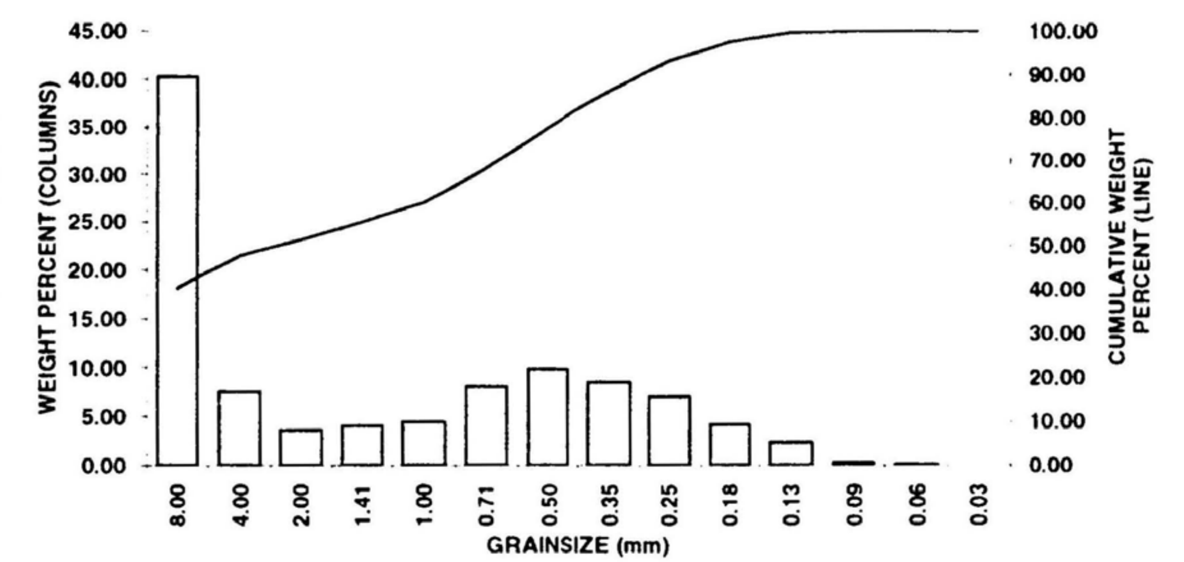


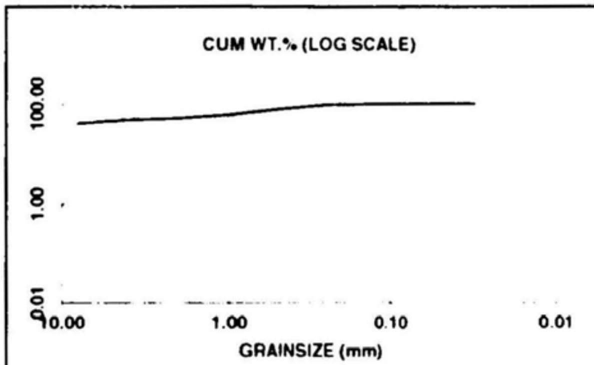
SIEVE DATA

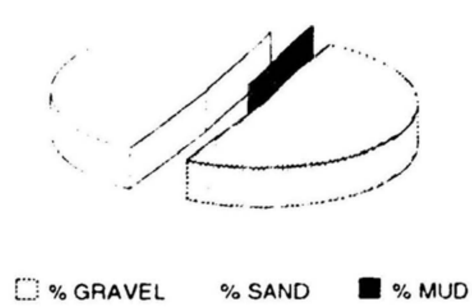
SAMPLE	21	**PROJECT**	CK 91 03
TOTAL WT.	93.80	**DATE**	1/22/96
SAMPLE LOCATION	Channel	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	37.88	40.24	40.24
4.00	-2.0	7.09	7.53	47.77
2.00	-1.0	3.40	3.61	51.39
1.41	-0.5	3.80	4.04	55.42
1.00	0.0	4.16	4.42	59.84
0.71	0.5	7.54	8.01	67.85
0.50	1.0	9.28	9.86	77.71
0.35	1.5	7.99	8.49	86.20
0.25	2.0	6.56	6.97	93.17
0.18	2.5	3.96	4.21	97.38
0.13	3.0	2.15	2.28	99.66
0.09	3.5	0.26	0.28	99.94
0.06	4.0	0.06	0.06	100.00
0.03	5.0	0.00	0.00	100.00
	TOTALS	94.13	100.00	100.00

MEAN GRAINSIZE	**Very coarse sand**	
TEXTURAL CLASS	**Sandy gravel**	
SORTING	**Very poor**	
SKEWNESS	**#N/A**	
KURTOSIS	**Very platykurtic**	
% GRAVEL	51	
% SAND	49	
% MUD	0	
GRAPHIC MEAN	1.89 mm	-0.92phi
MOMENT MEAN	1.77 mm	-0.82phi
GRAPHIC SORTING	2.08	
MOMENT SORTING	2.10	
GRAPHIC SKEWNESS	3.56	
MOMENT SKEWNESS	-4.09	
GRAPHIC KURTOSIS	0.58	
MOMENT KURTOSIS	1.01	
PROCESSING ERROR(%)	0.35	





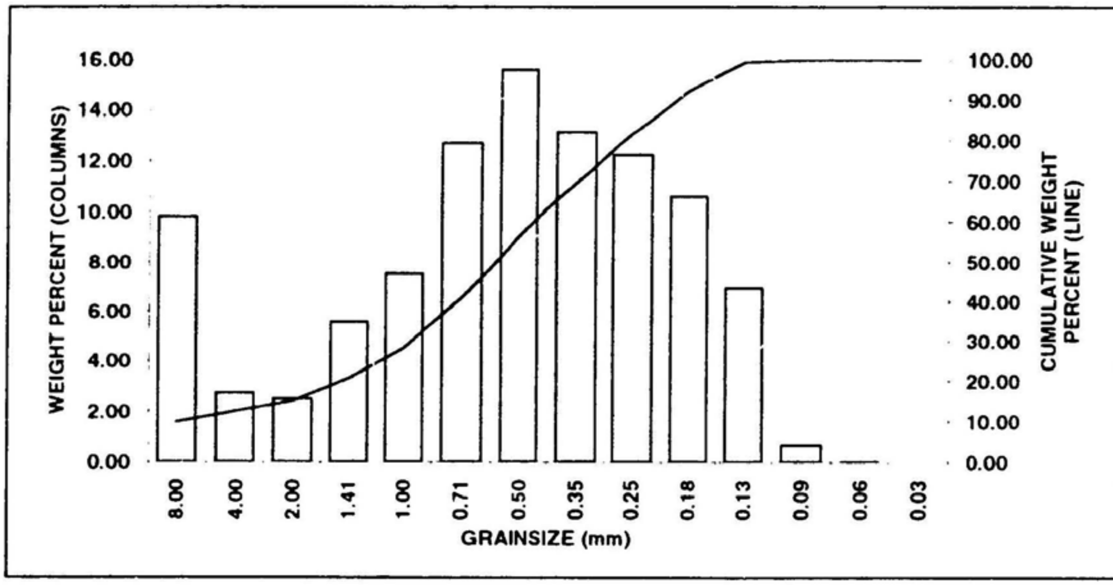


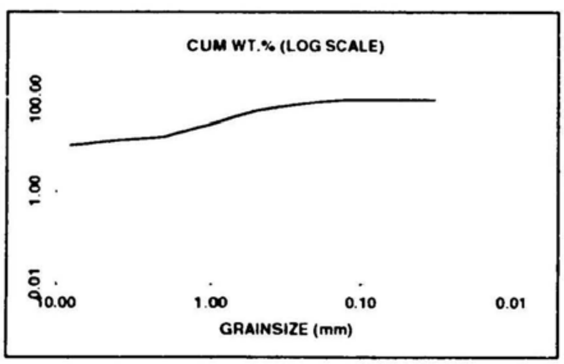
SIEVE DATA

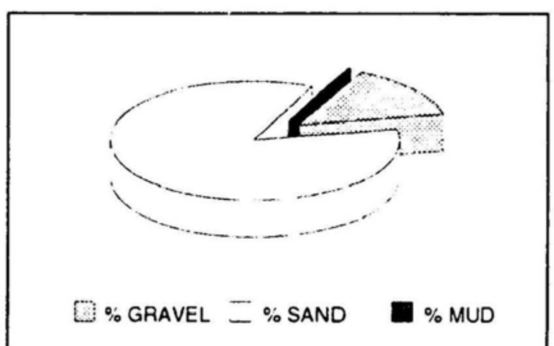
SAMPLE	22	**PROJECT**	CK 91 03
TOTAL WT.	182 90	**DATE**	1/22/96
SAMPLE LOCATION	Channel	**SCIENTIST**	Bill Collins

RAW DATA				
MM	**PHI(Ø)**	**WT. RET.**	**WT. %**	**CUM. %**
8.00	-3.0	17.92	9.81	9.81
4.00	-2.0	4.96	2.72	12.53
2.00	-1.0	4.55	2.49	15.02
1.41	-0.5	10.20	5.59	20.61
1.00	0.0	13.78	7.55	28.16
0.71	0.5	23.16	12.68	40.84
0.50	1.0	28.48	15.60	56.44
0.35	1.5	23.97	13.13	69.57
0.25	2.0	22.31	12.22	81.78
0.18	2.5	19.34	10.59	92.38
0.13	3.0	12.69	6.95	99.33
0.09	3.5	1.21	0.66	99.99
0.06	4.0	0.02	0.01	100.00
0.03	5.0	0.00	0.00	100.00
	TOTALS	182.59	100.00	100.00

MEAN GRAINSIZE	**Coarse sand**	
TEXTURAL CLASS	**Gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**#N/A**	
KURTOSIS	**Leptokurtic**	
% GRAVEL	15	
% SAND	85	
% MUD	0	
GRAPHIC MEAN	0.56 mm	0.82phi
MOMENT MEAN	0.59 mm	0.76phi
GRAPHIC SORTING	1.64	
MOMENT SORTING	1.67	
GRAPHIC SKEWNESS	-1.39	
MOMENT SKEWNESS	-1.39	
GRAPHIC KURTOSIS	1.29	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.17	





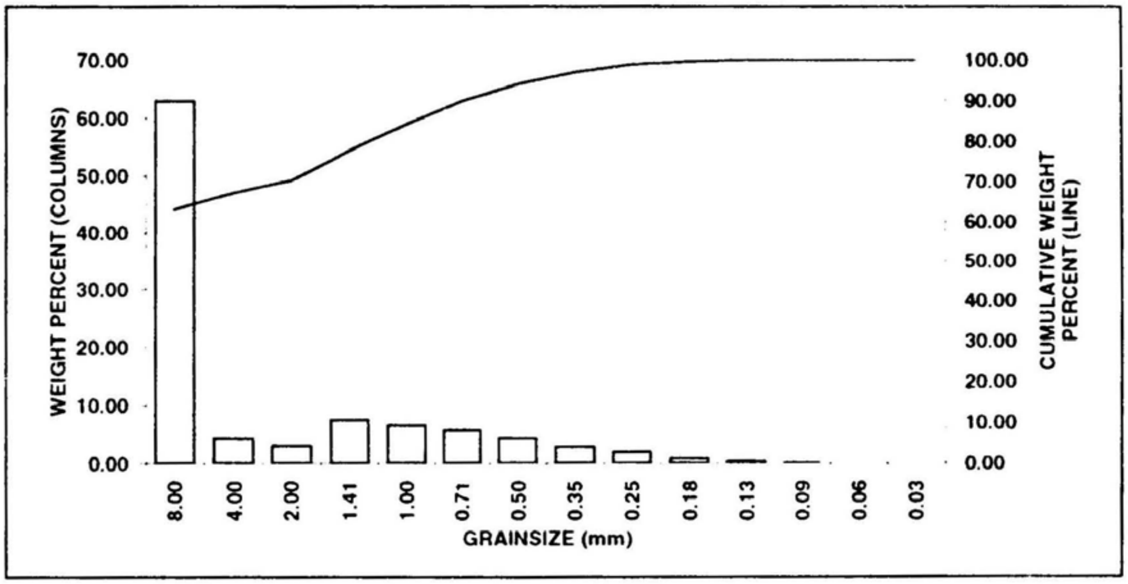


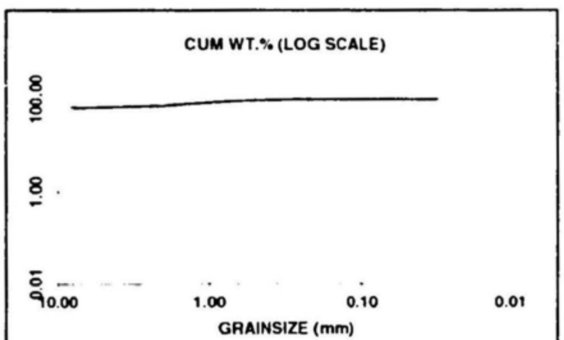
SIEVE DATA

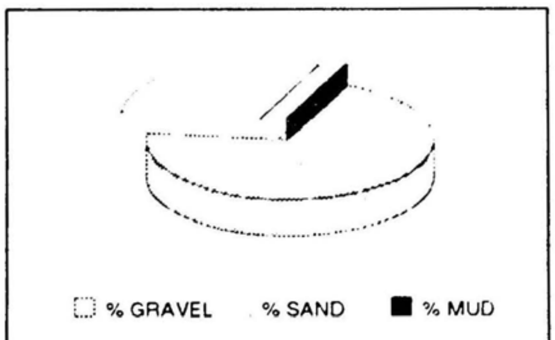
SAMPLE	**23**	**PROJECT**	CK 91.03
TOTAL WT.	137.20	**DATE**	1/22/96
SAMPLE LOCATION	Channel	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	86.49	62.89	62.89
4.00	-2.0	5.93	4.31	67.20
2.00	-1.0	4.15	3.02	70.22
1.41	-0.5	10.12	7.36	77.58
1.00	0.0	9.05	6.58	84.16
0.71	0.5	7.68	5.58	89.74
0.50	1.0	5.93	4.31	94.05
0.35	1.5	3.91	2.84	96.90
0.25	2.0	2.70	1.96	98.86
0.18	2.5	1.02	0.74	99.60
0.13	3.0	0.48	0.35	99.95
0.09	3.5	0.07	0.05	100.00
0.06	4.0	0.00	0.00	100.00
0.03	5.0	0.00	0.00	100.00
	TOTALS	137.53	100.00	100.00

MEAN GRAINSIZE	**Granules**	
TEXTURAL CLASS	**Sandy gravel**	
SORTING	**Poor**	
SKEWNESS	**Strongly coarse**	
KURTOSIS	**Platykurtic**	
% GRAVEL	70	
% SAND	30	
% MUD	0	
GRAPHIC MEAN	3.54 mm	-1.82phi
MOMENT MEAN	3.62 mm	-1.86phi
GRAPHIC SORTING	1.64	
MOMENT SORTING	1.65	
GRAPHIC SKEWNESS	5.26	
MOMENT SKEWNESS	-0.74	
GRAPHIC KURTOSIS	0.71	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.24	







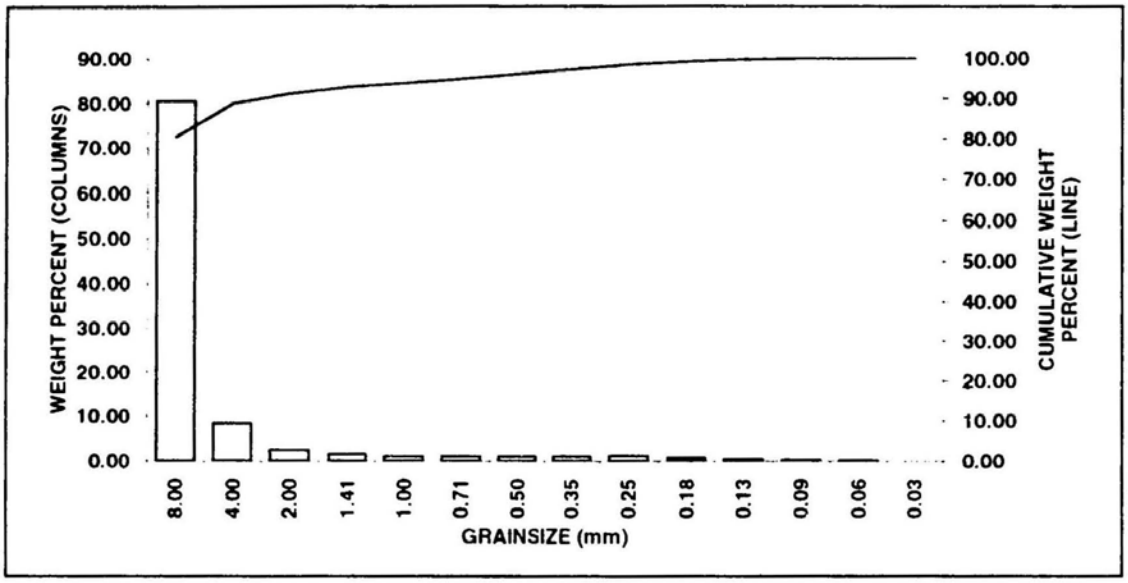
SIEVE DATA

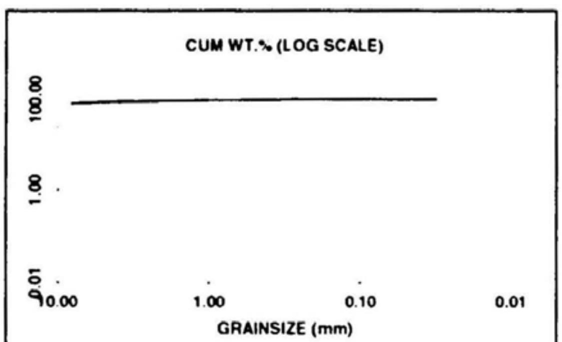
SAMPLE	**24**	**PROJECT**	CK.91.03
TOTAL WT.	168.00	**DATE**	1/22/96
SAMPLE LOCATION	Channel	**SCIENTIST**	Bill Collins

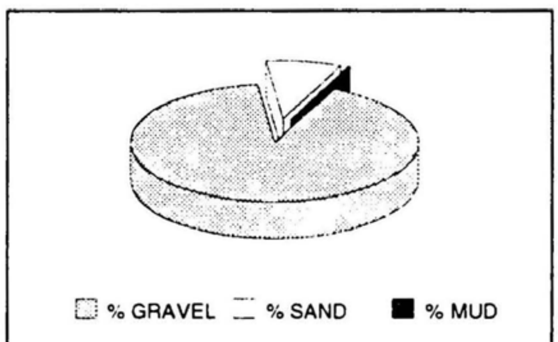
RAW DATA

MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	135.58	80.56	80.56
4.00	-2.0	14.04	8.34	88.91
2.00	-1.0	4.14	2.46	91.37
1.41	-0.5	2.55	1.52	92.88
1.00	0.0	1.72	1.02	93.90
0.71	0.5	1.86	1.11	95.01
0.50	1.0	1.89	1.12	96.13
0.35	1.5	1.92	1.14	97.27
0.25	2.0	2.01	1.19	98.47
0.18	2.5	1.30	0.77	99.24
0.13	3.0	0.81	0.48	99.72
0.09	3.5	0.32	0.19	99.91
0.06	4.0	0.14	0.08	99.99
0.03	5.0	0.01	0.01	100.00
	TOTALS	168.29	100.00	100.00

MEAN GRAINSIZE	**Pebbles**	
TEXTURAL CLASS	**Gravel**	
SORTING	**Moderate**	
SKEWNESS	**Strongly coarse**	
KURTOSIS	**Very leptokurtic**	
% GRAVEL	91	
% SAND	9	
% MUD	0	
GRAPHIC MEAN	7.58 mm	-2.92phi
MOMENT MEAN	5.71 mm	-2.51phi
GRAPHIC SORTING	0.84	
MOMENT SORTING	1.23	
GRAPHIC SKEWNESS	0.33	
MOMENT SKEWNESS	-0.34	
GRAPHIC KURTOSIS	2.93	
MOMENT KURTOSIS	1.11	
PROCESSING ERROR(%)	0.17	





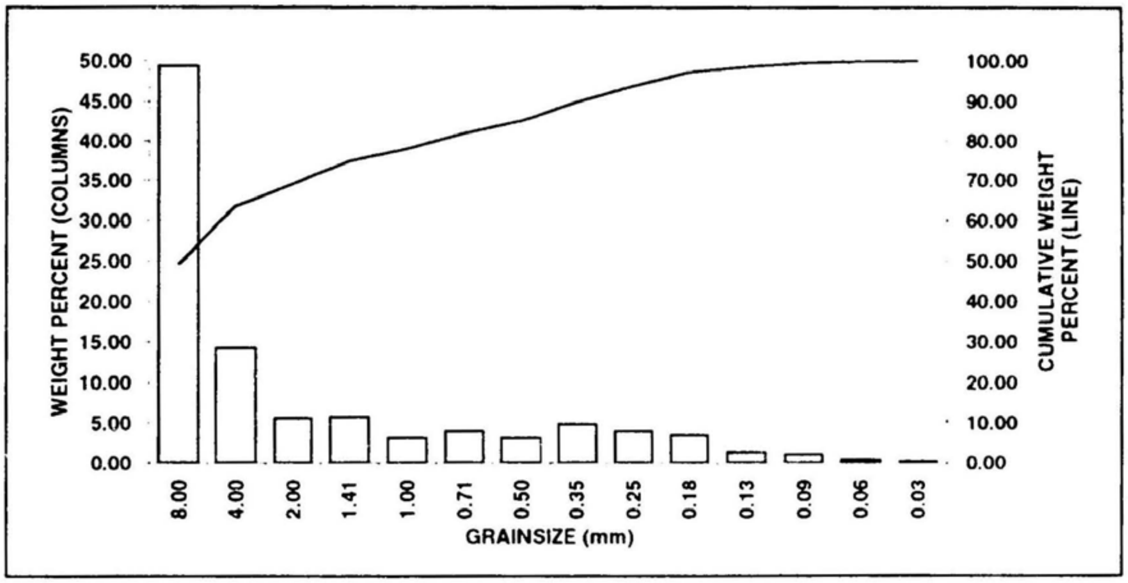


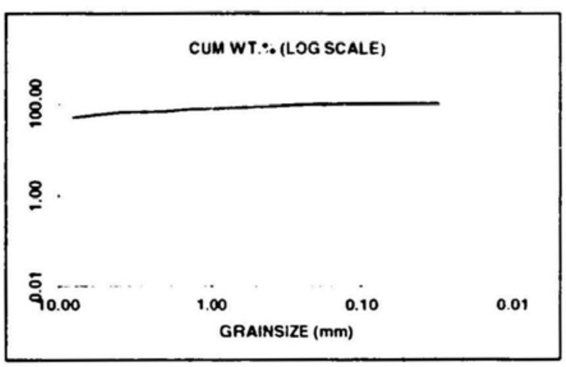
SIEVE DATA

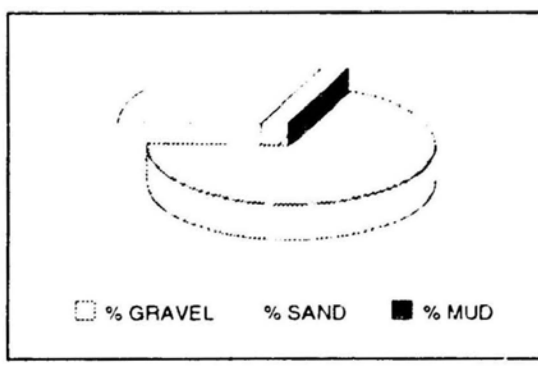
SAMPLE	**25**	**PROJECT**	CK 91 03
TOTAL WT.	93 66	**DATE**	1/22/96
SAMPLE LOCATION	Channel	**SCIENTIST**	Bill Collins

RAW DATA				
MM	**PHI(O)**	**WT. RET.**	**WT. %**	**CUM. %**
8.00	-3.0	46.22	49.35	49.35
4.00	-2.0	13.29	14.19	63.55
2.00	-1.0	5.26	5.62	69.16
1.41	-0.5	5.32	5.68	74.84
1.00	0.0	2.88	3.08	77.92
0.71	0.5	3.72	3.97	81.89
0.50	1.0	2.91	3.11	85.00
0.35	1.5	4.49	4.79	89.79
0.25	2.0	3.70	3.95	93.74
0.18	2.5	3.21	3.43	97.17
0.13	3.0	1.22	1.30	98.47
0.09	3.5	0.90	0.96	99.43
0.06	4.0	0.33	0.35	99.79
0.03	5.0	0.20	0.21	100.00
	TOTALS	93.65	100.00	100.00

MEAN GRAINSIZE	**Granules**	
TEXTURAL CLASS	**Sandy gravel**	
SORTING	**Poor**	
SKEWNESS	**#N/A**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	69	
% SAND	31	
% MUD	0	
GRAPHIC MEAN	3 14 mm	-1 65phi
MOMENT MEAN	2 76 mm	-1 46phi
GRAPHIC SORTING	1.95	
MOMENT SORTING	1.95	
GRAPHIC SKEWNESS	8.94	
MOMENT SKEWNESS	-2 43	
GRAPHIC KURTOSIS	0 93	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.01	







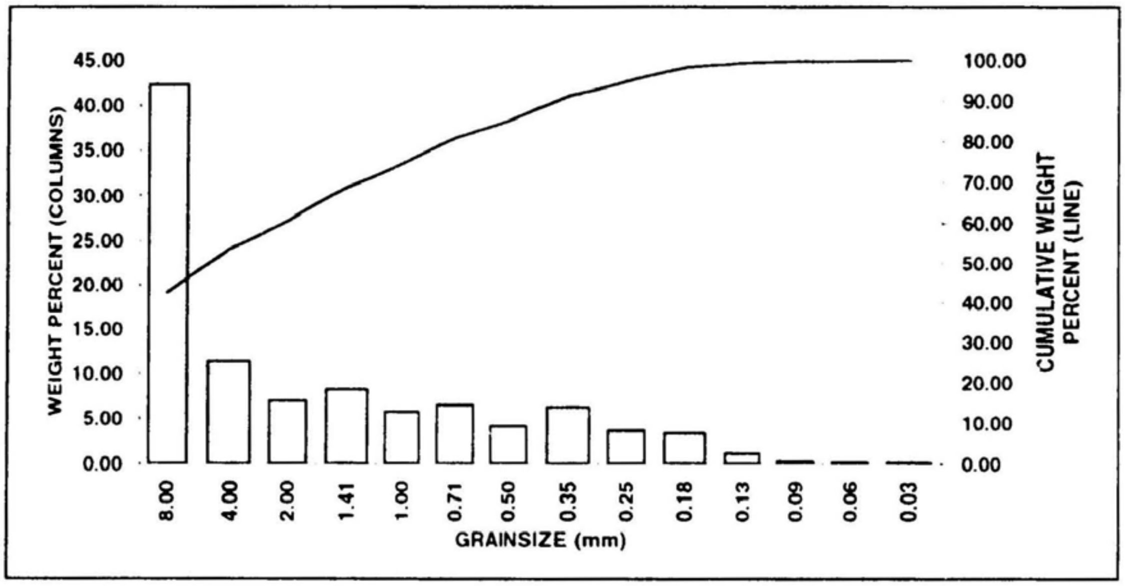
SIEVE DATA

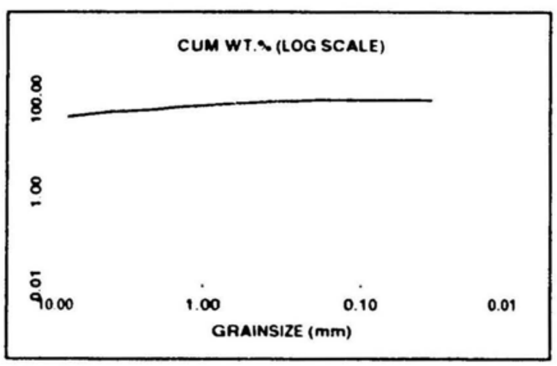
SAMPLE	26	**PROJECT**	CK 91.03
TOTAL WT.	105.74	**DATE**	1/22/96
SAMPLE LOCATION	Channel	**SCIENTIST**	Bill Collins

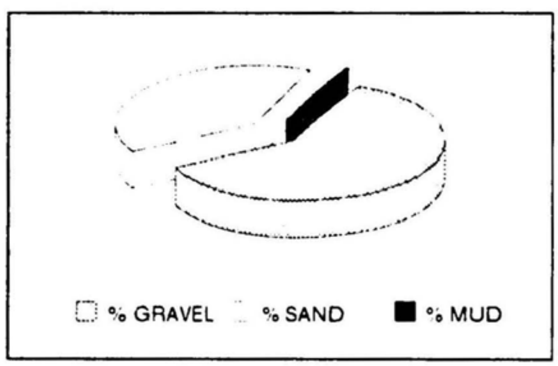
RAW DATA

MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	44.36	42.24	42.24
4.00	-2.0	11.86	11.29	53.54
2.00	-1.0	7.29	6.94	60.48
1.41	-0.5	8.66	8.25	68.73
1.00	0.0	6.01	5.72	74.45
0.71	0.5	6.82	6.49	80.94
0.50	1.0	4.29	4.09	85.03
0.35	1.5	6.54	6.23	91.26
0.25	2.0	3.80	3.62	94.88
0.18	2.5	3.51	3.34	98.22
0.13	3.0	1.23	1.17	99.39
0.09	3.5	0.31	0.30	99.69
0.06	4.0	0.19	0.18	99.87
0.03	5.0	0.14	0.13	100.00
	TOTALS	105.01	100.00	100.00

MEAN GRAINSIZE	**Granules**	
TEXTURAL CLASS	**Sandy gravel**	
SORTING	**Poor**	
SKEWNESS	**#N/A**	
KURTOSIS	**Platykurtic**	
% GRAVEL	60	
% SAND	39	
% MUD	0	
GRAPHIC MEAN	2.63 mm	-1.40phi
MOMENT MEAN	2.33 mm	-1.22phi
GRAPHIC SORTING	1.91	
MOMENT SORTING	1.90	
GRAPHIC SKEWNESS	6.32	
MOMENT SKEWNESS	-2.44	
GRAPHIC KURTOSIS	0.74	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.70	





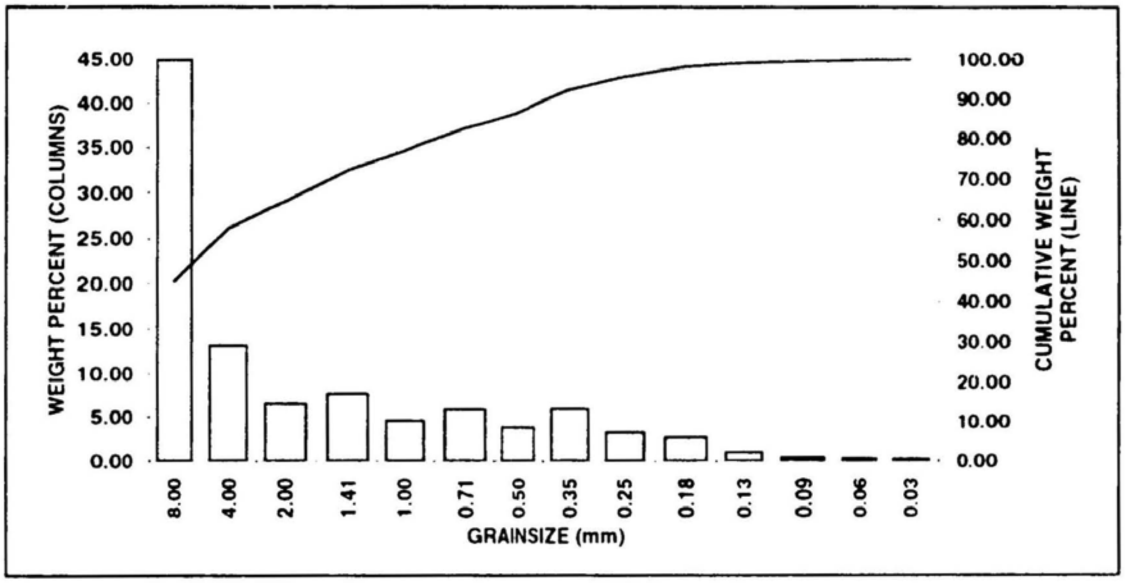


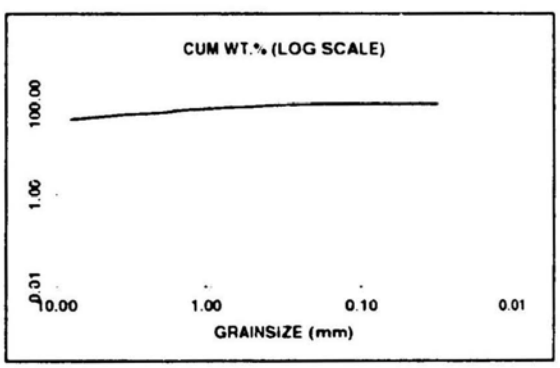
SIEVE DATA

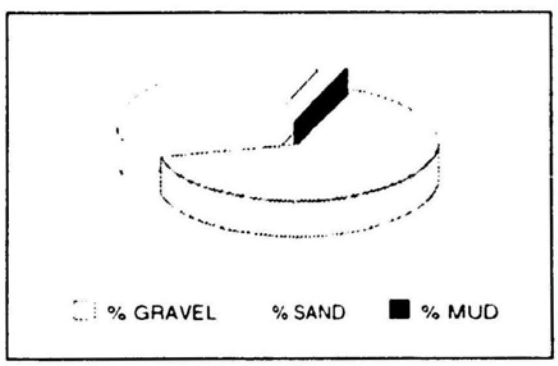
SAMPLE	27	**PROJECT**	CK 91 03
TOTAL WT.	154 14	**DATE**	1/22/96
SAMPLE LOCATION	Channel	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(O)	WT. RET.	WT. %	CUM. %
8.00	-3.0	69.42	44.87	44.87
4.00	-2.0	20.18	13.04	57.92
2.00	-1.0	10.08	6.52	64.43
1.41	-0.5	11.86	7.67	72.10
1.00	0.0	7.14	4.62	76.72
0.71	0.5	9.07	5.86	82.58
0.50	1.0	5.92	3.83	86.41
0.35	1.5	9.12	5.90	92.30
0.25	2.0	4.99	3.23	95.53
0.18	2.5	4.09	2.64	98.17
0.13	3.0	1.49	0.96	99.13
0.09	3.5	0.60	0.39	99.52
0.06	4.0	0.41	0.27	99.79
0.03	5.0	0.33	0.21	100.00
	TOTALS	154.70	100.00	100.00

MEAN GRAINSIZE	**Granules**	
TEXTURAL CLASS	**Sandy gravel**	
SORTING	**Poor**	
SKEWNESS	**#N/A**	
KURTOSIS	**Platykurtic**	
% GRAVEL	64	
% SAND	35	
% MUD	0	
GRAPHIC MEAN	3.09 mm	-1.63phi
MOMENT MEAN	2.57 mm	-1.36phi
GRAPHIC SORTING	1.86	
MOMENT SORTING	1.87	
GRAPHIC SKEWNESS	6.27	
MOMENT SKEWNESS	-2.13	
GRAPHIC KURTOSIS	0.76	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.36	





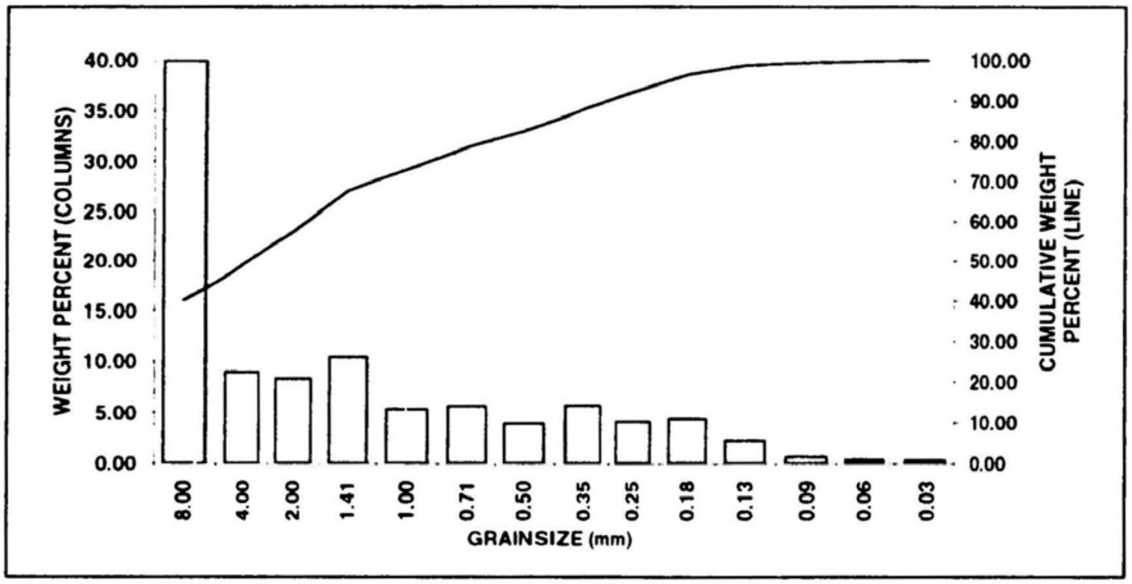


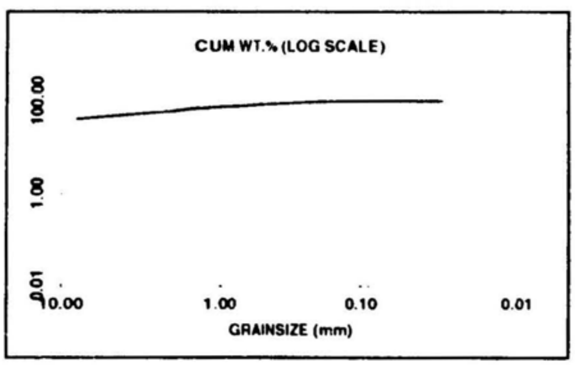
SIEVE DATA

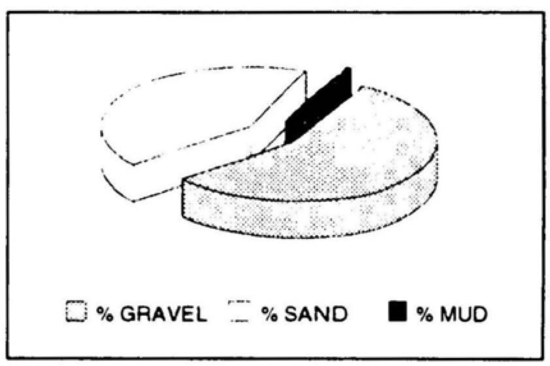
SAMPLE	28	PROJECT	CK.91.03
TOTAL WT.	97.54	DATE	1/22/96
SAMPLE LOCATION	Channel	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	38.80	39.95	39.95
4.00	-2.0	8.70	8.96	48.91
2.00	-1.0	8.05	8.29	57.20
1.41	-0.5	10.10	10.40	67.60
1.00	0.0	5.21	5.37	72.97
0.71	0.5	5.44	5.60	78.57
0.50	1.0	3.77	3.88	82.45
0.35	1.5	5.46	5.62	88.08
0.25	2.0	3.96	4.08	92.15
0.18	2.5	4.19	4.31	96.47
0.13	3.0	2.16	2.22	98.69
0.09	3.5	0.63	0.65	99.34
0.06	4.0	0.35	0.36	99.70
0.03	5.0	0.29	0.30	100.00
	TOTALS	97.11	100.00	100.00

MEAN GRAINSIZE	Granules	
TEXTURAL CLASS	Sandy gravel	
SORTING	Poor	
SKEWNESS	#N/A	
KURTOSIS	Platykurtic	
% GRAVEL	57	
% SAND	42	
% MUD	0	
GRAPHIC MEAN	2.35 mm	-1.23phi
MOMENT MEAN	2.08 mm	-1.05phi
GRAPHIC SORTING	2.00	
MOMENT SORTING	1.99	
GRAPHIC SKEWNESS	4.44	
MOMENT SKEWNESS	-4.16	
GRAPHIC KURTOSIS	0.76	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.44	





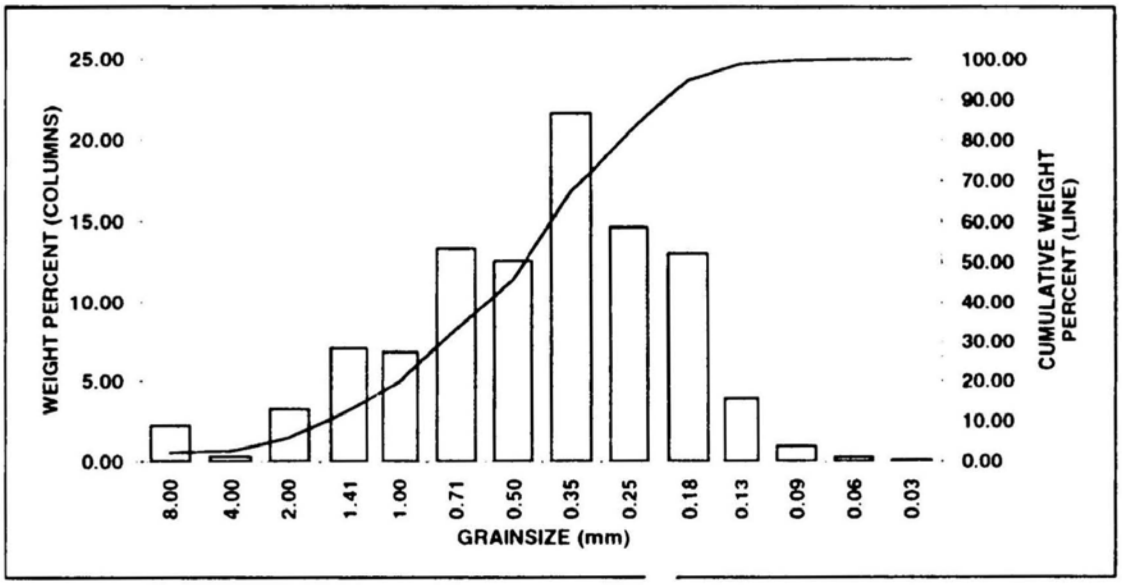


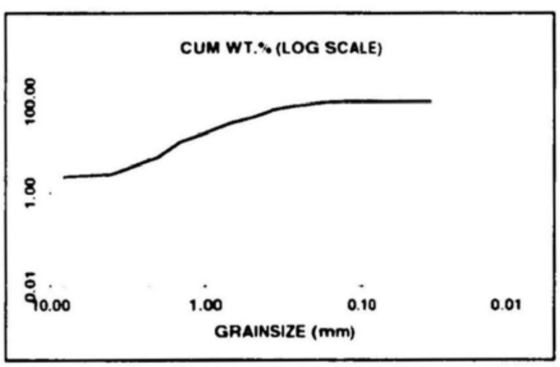
SIEVE DATA

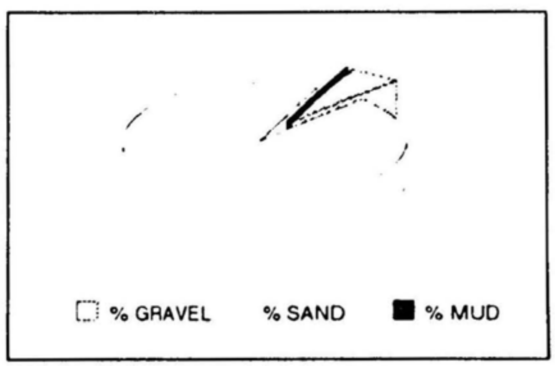
SAMPLE	29	PROJECT	CK 91 03
TOTAL WT.	74.53	DATE	1/22/96
SAMPLE LOCATION	Channel	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	1.64	2.22	2.22
4.00	-2.0	0.21	0.28	2.51
2.00	-1.0	2.38	3.23	5.74
1.41	-0.5	5.22	7.08	12.81
1.00	0.0	5.05	6.85	19.66
0.71	0.5	9.83	13.33	32.99
0.50	1.0	9.27	12.57	45.56
0.35	1.5	15.96	21.64	67.20
0.25	2.0	10.81	14.66	81.86
0.18	2.5	9.59	13.00	94.86
0.13	3.0	2.86	3.88	98.74
0.09	3.5	0.69	0.94	99.67
0.06	4.0	0.17	0.23	99.91
0.03	5.0	0.07	0.09	100.00
	TOTALS	73.75	100.00	100.00

MEAN GRAINSIZE	Medium sand	
TEXTURAL CLASS	Gravelly sand	
SORTING	Poor	
SKEWNESS	#N/A	
KURTOSIS	Mesokurtic	
% GRAVEL	6	
% SAND	94	
% MUD	0	
GRAPHIC MEAN	0.46 mm	1.11phi
MOMENT MEAN	0.45 mm	1.16phi
GRAPHIC SORTING	1.11	
MOMENT SORTING	1.22	
GRAPHIC SKEWNESS	-0.45	
MOMENT SKEWNESS	-1.03	
GRAPHIC KURTOSIS	0.95	
MOMENT KURTOSIS	1.04	
PROCESSING ERROR(%)	1.06	





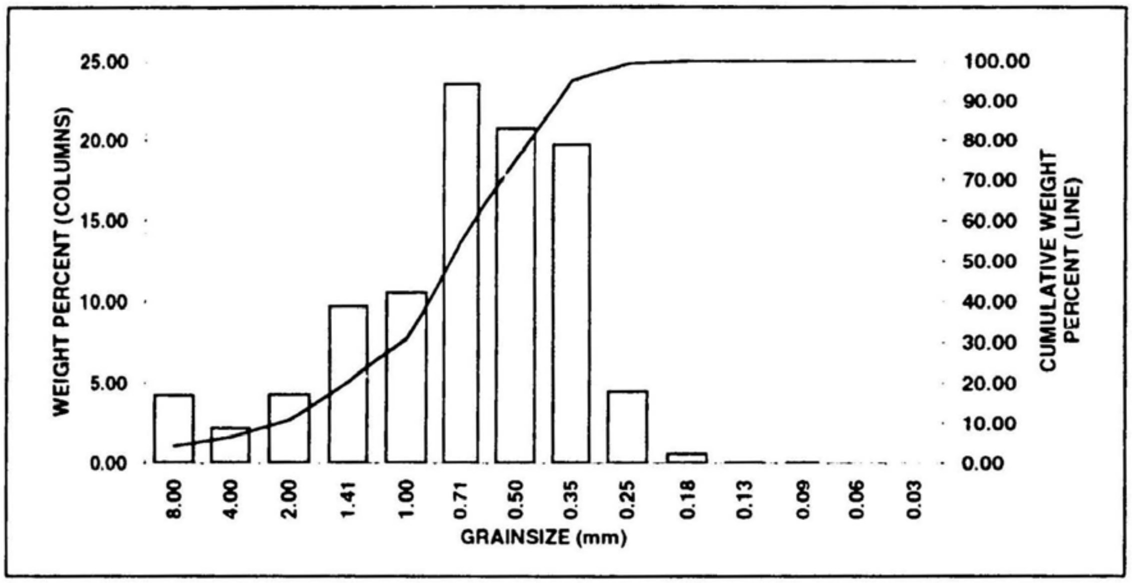


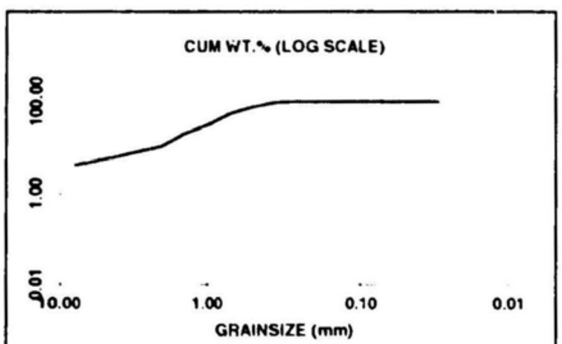
SIEVE DATA

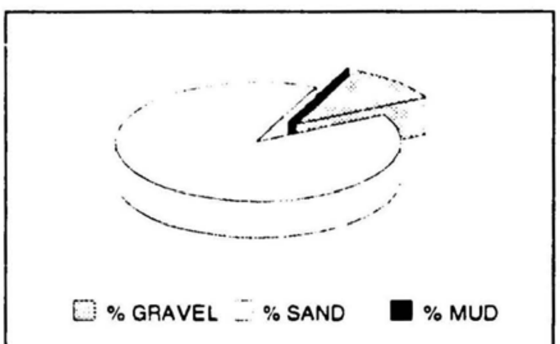
SAMPLE	30	PROJECT	CK.91.03
TOTAL WT.	119 47	DATE	1/22/96
SAMPLE LOCATION	Channel	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	5.00	4.22	4.22
4.00	-2.0	2.60	2.20	6.42
2.00	-1.0	5.02	4.24	10.66
1.41	-0.5	11.46	9.68	20.34
1.00	0.0	12.46	10.52	30.86
0.71	0.5	27.88	23.55	54.40
0.50	1.0	24.60	20.78	75.18
0.35	1.5	23.39	19.75	94.93
0.25	2.0	5.30	4.48	99.41
0.18	2.5	0.67	0.57	99.97
0.13	3.0	0.02	0.02	99.99
0.09	3.5	0.01	0.01	100.00
0.06	4.0	0.00	0.00	100.00
0.03	5.0	0.00	0.00	100.00
	TOTALS	118.41	100.00	100.00

MEAN GRAINSIZE	Coarse sand	
TEXTURAL CLASS	Gravelly sand	
SORTING	Poor	
SKEWNESS	Strongly coarse	
KURTOSIS	Mesokurtic	
% GRAVEL	11	
% SAND	89	
% MUD	0	
GRAPHIC MEAN	0.66 mm	0.60phi
MOMENT MEAN	0.72 mm	0.46phi
GRAPHIC SORTING	1.10	
MOMENT SORTING	1.12	
GRAPHIC SKEWNESS	-0.93	
MOMENT SKEWNESS	-0.93	
GRAPHIC KURTOSIS	1.10	
MOMENT KURTOSIS	1.05	
PROCESSING ERROR(%)	0.90	







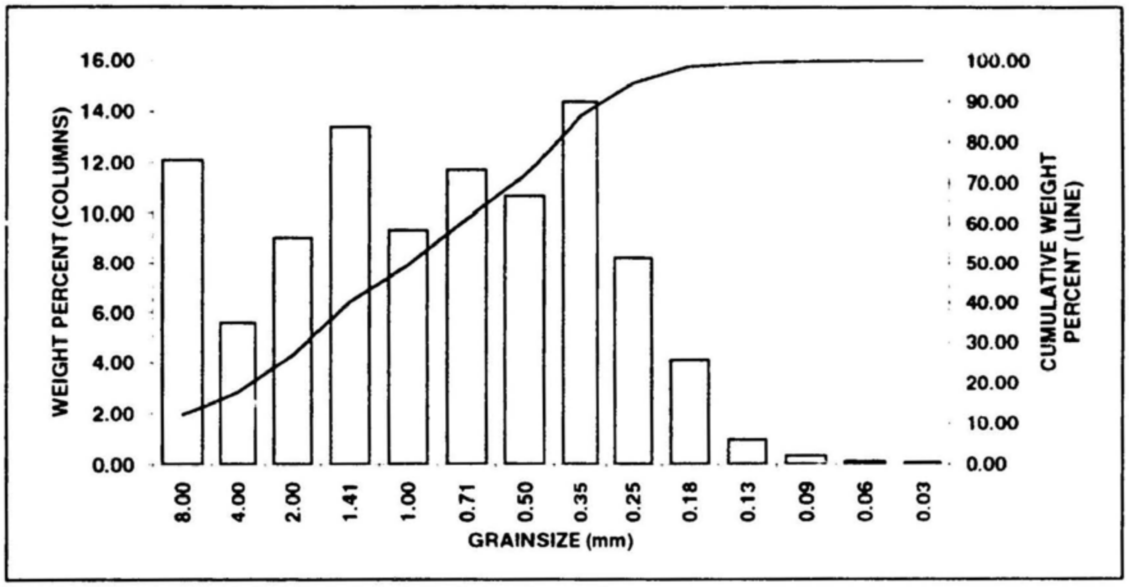
SIEVE DATA

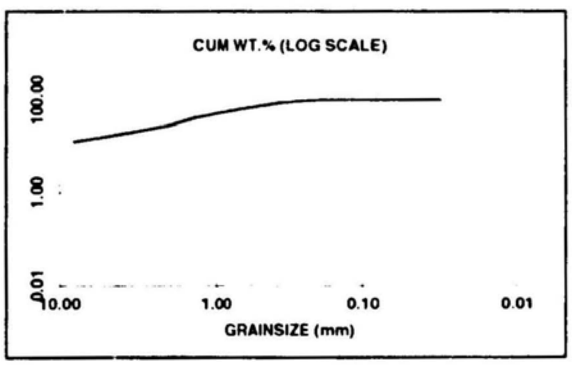
SAMPLE	31	**PROJECT**	CK.91.03
TOTAL WT.	147.00	**DATE**	1/22/96
SAMPLE LOCATION	Channel	**SCIENTIST**	Bill Collins

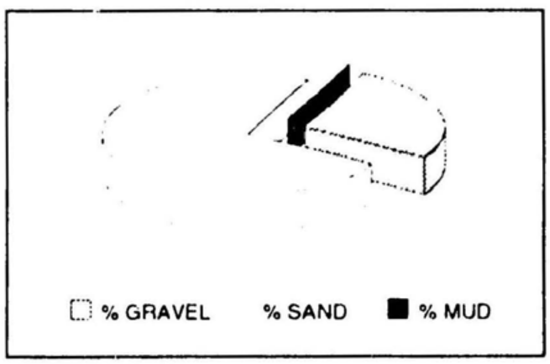
RAW DATA

MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	17.65	12.11	12.11
4.00	-2.0	8.13	5.58	17.68
2.00	-1.0	13.14	9.01	26.69
1.41	-0.5	19.52	13.39	40.08
1.00	0.0	13.61	9.33	49.42
0.71	0.5	17.06	11.70	61.12
0.50	1.0	15.60	10.70	71.82
0.35	1.5	20.97	14.38	86.20
0.25	2.0	11.98	8.22	94.42
0.18	2.5	5.97	4.09	98.51
0.13	3.0	1.43	0.98	99.49
0.09	3.5	0.49	0.34	99.83
0.06	4.0	0.15	0.10	99.93
0.03	5.0	0.10	0.07	100.00
	TOTALS	145.80	100.00	100.00

MEAN GRAINSIZE	**Very coarse sand**	
TEXTURAL CLASS	**Gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**#N/A**	
KURTOSIS	**Platykurtic**	
% GRAVEL	27	
% SAND	73	
% MUD	0	
GRAPHIC MEAN	1.10 mm	-0.13phi
MOMENT MEAN	0.96 mm	0.06phi
GRAPHIC SORTING	1.82	
MOMENT SORTING	1.62	
GRAPHIC SKEWNESS	-1.25	
MOMENT SKEWNESS	-1.25	
GRAPHIC KURTOSIS	0.89	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.82	





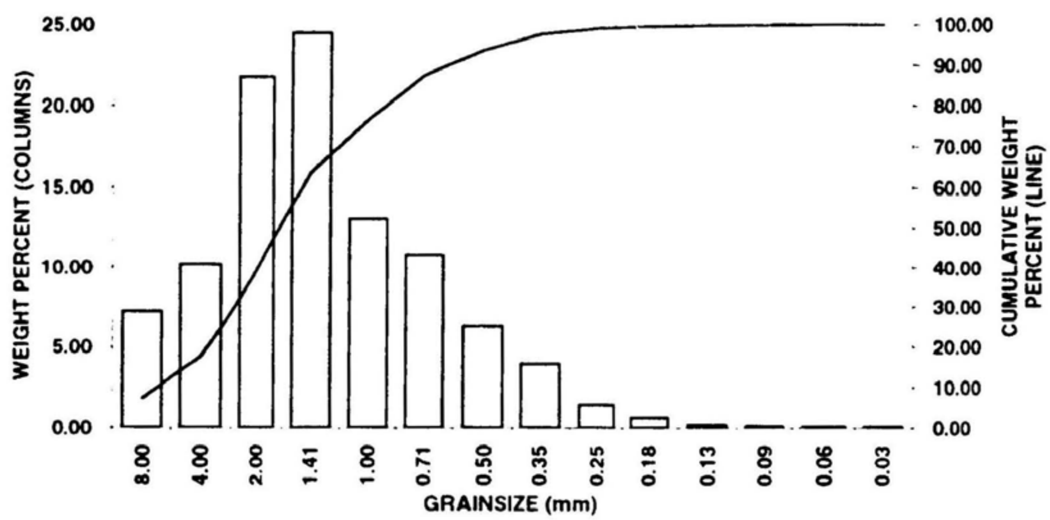


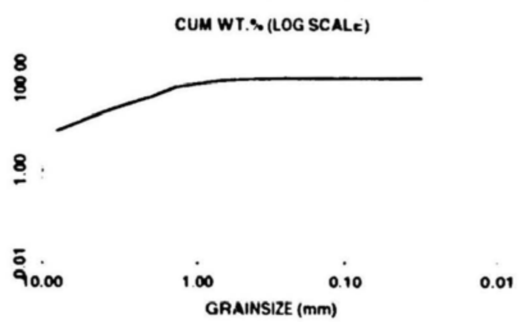
SIEVE DATA

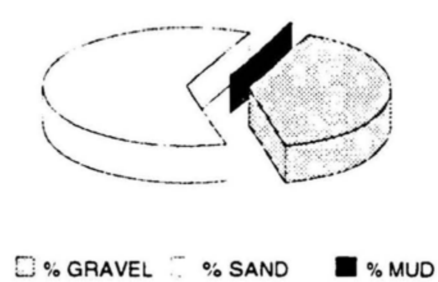
SAMPLE	**32**	**PROJECT**	CK.91.03
TOTAL WT.	156.29	**DATE**	1/22/96
SAMPLE LOCATION	Channel	**SCIENTIST**	Bill Collins

RAW DATA				
MM	**PHI(Ø)**	**WT. RET.**	**WT. %**	**CUM. %**
8.00	-3.0	11.25	7.20	7.20
4.00	-2.0	15.89	10.16	17.36
2.00	-1.0	33.97	21.73	39.09
1.41	-0.5	38.25	24.47	63.56
1.00	0.0	20.36	13.02	76.58
0.71	0.5	16.79	10.74	87.32
0.50	1.0	9.83	6.29	93.61
0.35	1.5	6.17	3.95	97.56
0.25	2.0	2.17	1.39	98.94
0.18	2.5	0.93	0.59	99.54
0.13	3.0	0.30	0.19	99.73
0.09	3.5	0.20	0.13	99.86
0.06	4.0	0.12	0.08	99.94
0.03	5.0	0.10	0.06	100.00
	TOTALS	156.33	100.00	100.00

MEAN GRAINSIZE	**Very coarse sand**	
TEXTURAL CLASS	**Sandy gravel**	
SORTING	**Poor**	
SKEWNESS	**Fine**	
KURTOSIS	**Platykurtic**	
% GRAVEL	39	
% SAND	61	
% MUD	0	
GRAPHIC MEAN	1.59 mm	-0.67phi
MOMENT MEAN	1.44 mm	-0.52phi
GRAPHIC SORTING	1.33	
MOMENT SORTING	1.18	
GRAPHIC SKEWNESS	-0.51	
MOMENT SKEWNESS	0.18	
GRAPHIC KURTOSIS	0.84	
MOMENT KURTOSIS	1.04	
PROCESSING ERROR(%)	0.03	





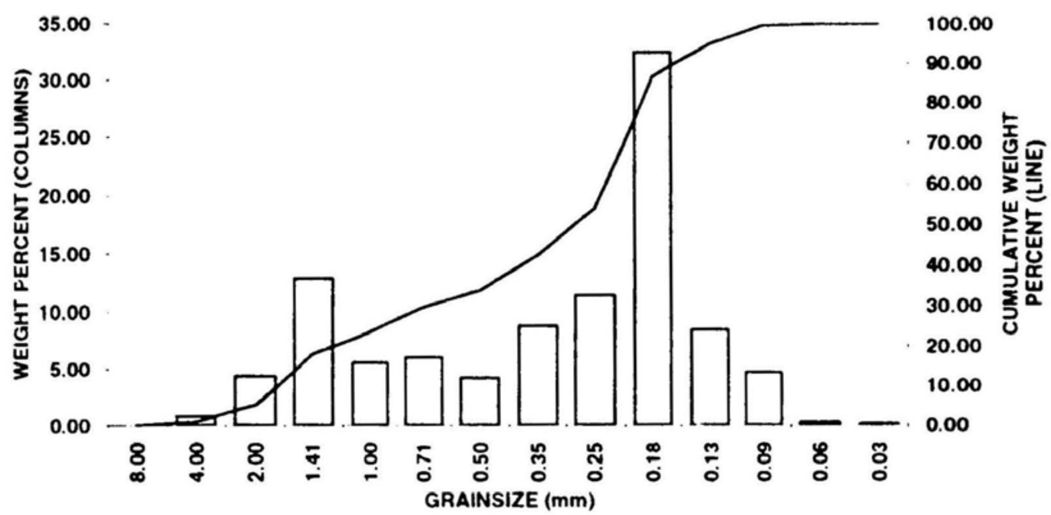


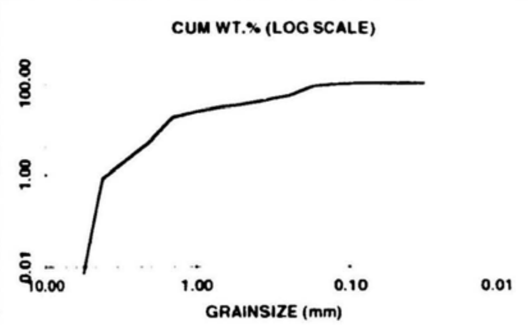
SIEVE DATA

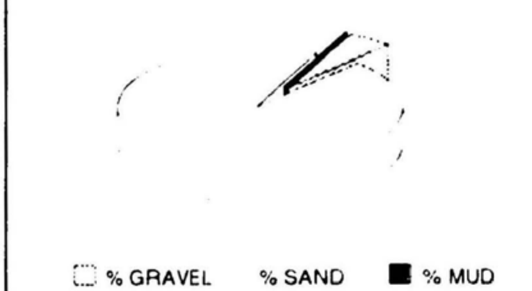
SAMPLE	37	PROJECT	CK.91.03
TOTAL WT.	100.21	DATE	1/22/96
SAMPLE LOCATION	Lagoon	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.80	0.81	0.81
2.00	-1.0	4.29	4.34	5.15
1.41	-0.5	12.74	12.88	18.03
1.00	0.0	5.52	5.58	23.61
0.71	0.5	5.92	5.99	29.59
0.50	1.0	4.18	4.23	33.82
0.35	1.5	8.66	8.76	42.57
0.25	2.0	11.28	11.40	53.98
0.18	2.5	32.13	32.48	86.46
0.13	3.0	8.37	8.46	94.92
0.09	3.5	4.68	4.73	99.66
0.06	4.0	0.26	0.26	99.92
0.03	5.0	0.08	0.08	100.00
	TOTALS	98.91	100.00	100.00

MEAN GRAINSIZE	Medium sand	
TEXTURAL CLASS	Gravelly sand	
SORTING	Poor	
SKEWNESS	Strongly coarse	
KURTOSIS	Platykurtic	
% GRAVEL	5	
% SAND	95	
% MUD	0	
GRAPHIC MEAN	0.32 mm	1.64phi
MOMENT MEAN	0.34 mm	1.55phi
GRAPHIC SORTING	1.38	
MOMENT SORTING	1.36	
GRAPHIC SKEWNESS	-2.65	
MOMENT SKEWNESS	-0.41	
GRAPHIC KURTOSIS	0.69	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	1.31	





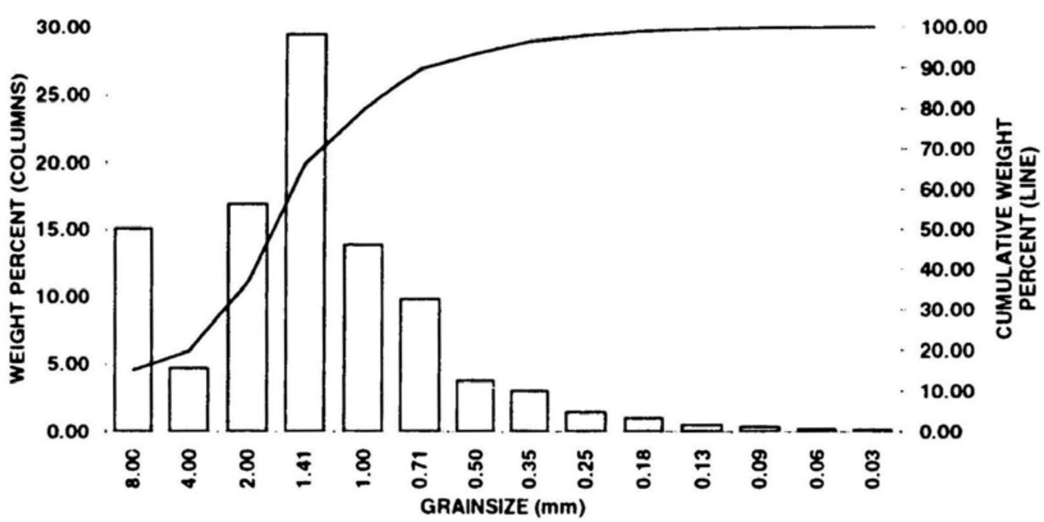


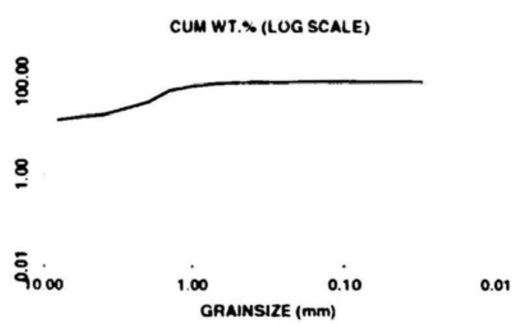
SIEVE DATA

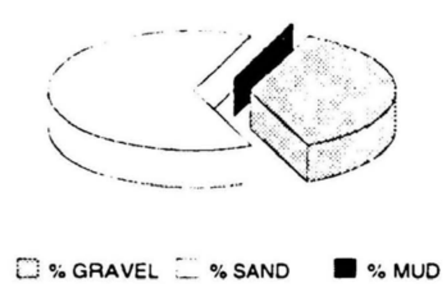
SAMPLE	**38**	**PROJECT**	CK.91.03
TOTAL WT.	118.24	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	19.47	15.06	15.06
4.00	-2.0	6.01	4.65	19.70
2.00	-1.0	21.88	16.92	36.62
1.41	-0.5	38.04	29.42	66.04
1.00	0.0	17.88	13.83	79.86
0.71	0.5	12.64	9.77	89.64
0.50	1.0	4.86	3.76	93.40
0.35	1.5	3.88	3.00	96.40
0.25	2.0	1.85	1.43	97.83
0.18	2.5	1.29	1.00	98.82
0.13	3.0	0.62	0.48	99.30
0.09	3.5	0.48	0.37	99.68
0.06	4.0	0.22	0.17	99.85
0.03	5.0	0.20	0.15	100.00
	TOTALS	129.32	100.00	100.00

MEAN GRAINSIZE	**Very coarse sand**	
TEXTURAL CLASS	**Sandy gravel**	
SORTING	**Poor**	
SKEWNESS	**Near symmetrical**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	37	
% SAND	63	
% MUD	0	
GRAPHIC MEAN	1.96 mm	-0.97phi
MOMENT MEAN	1.55 mm	-0.63phi
GRAPHIC SORTING	1.51	
MOMENT SORTING	1.34	
GRAPHIC SKEWNESS	-2.12	
MOMENT SKEWNESS	-0.08	
GRAPHIC KURTOSIS	1.05	
MOMENT KURTOSIS	1.04	
PROCESSING ERROR(%)	8.57	





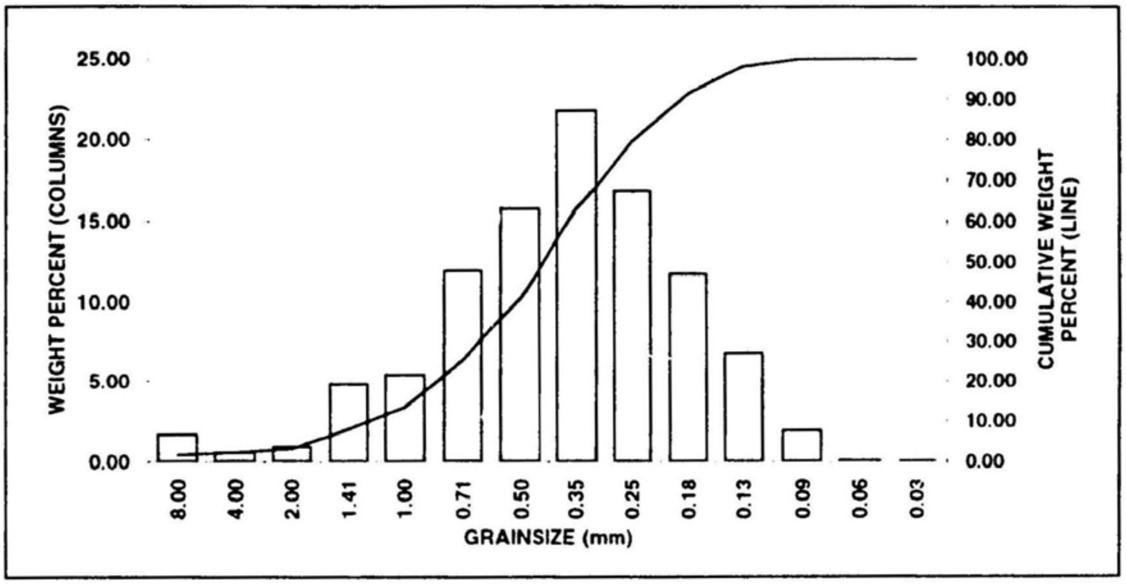


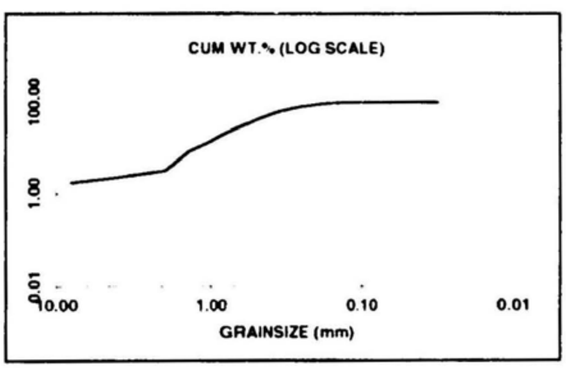
SIEVE DATA

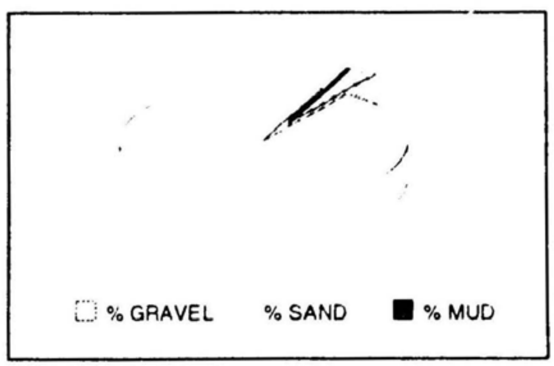
SAMPLE	39	PROJECT	CK 91 03
TOTAL WT.	116.27	DATE	1/22/96
SAMPLE LOCATION	Lagoon	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	1.88	1.64	1.64
4.00	-2.0	0.62	0.54	2.18
2.00	-1.0	1.03	0.90	3.07
1.41	-0.5	5.51	4.79	7.87
1.00	0.0	6.17	5.37	13.23
0.71	0.5	13.71	11.93	25.16
0.50	1.0	18.08	15.73	40.89
0.35	1.5	25.02	21.77	62.66
0.25	2.0	19.34	16.83	79.49
0.18	2.5	13.50	11.75	91.23
0.13	3.0	7.80	6.79	98.02
0.09	3.5	2.21	1.92	99.94
0.06	4.0	0.05	0.04	99.98
0.03	5.0	0.02	0.02	100.00
	TOTALS	114.94	100.00	100.00

MEAN GRAINSIZE	Medium sand	
TEXTURAL CLASS	Slightly gravelly sand	
SORTING	Poor	
SKEWNESS	Strongly coarse	
KURTOSIS	Leptokurtic	
% GRAVEL	3	
% SAND	97	
% MUD	0	
GRAPHIC MEAN	0.39 mm	1.34phi
MOMENT MEAN	0.39 mm	1.35phi
GRAPHIC SORTING	1.09	
MOMENT SORTING	1.14	
GRAPHIC SKEWNESS	-0.29	
MOMENT SKEWNESS	-0.59	
GRAPHIC KURTOSIS	1.20	
MOMENT KURTOSIS	1.05	
PROCESSING ERROR(%)	1.16	





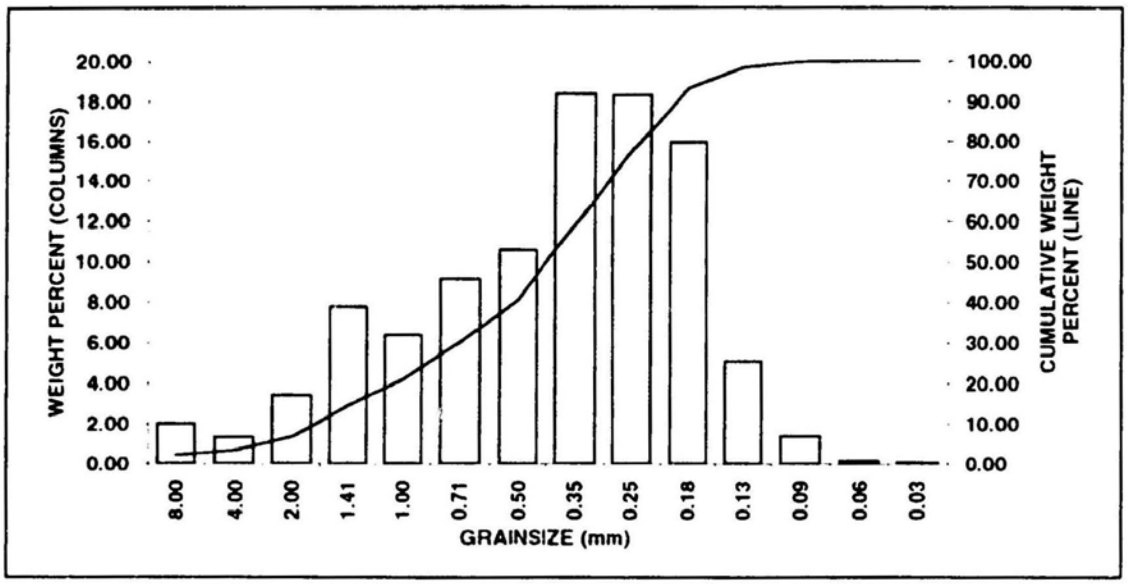


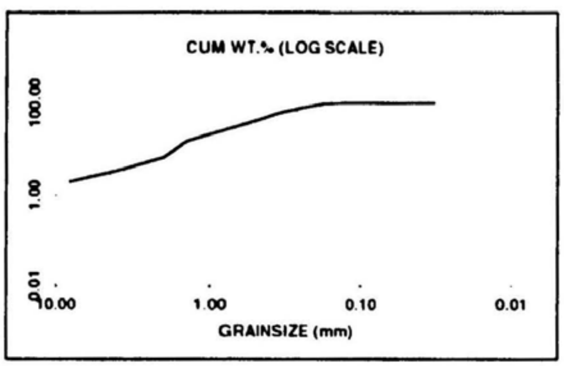
SIEVE DATA

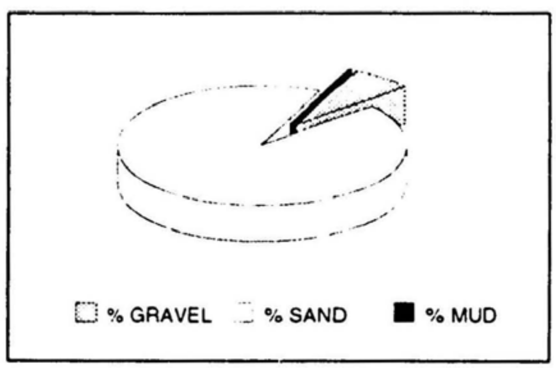
SAMPLE	**40**	**PROJECT**	CK.91.03
TOTAL WT.	93.73	**DATE**	1/22/96
SAMPLE LOCATION	Channel	**SCIENTIST**	Bill Collins

RAW DATA				
MM	**PHI(Ø)**	**WT. RET.**	**WT. %**	**CUM. %**
8.00	-3.0	1.89	2.02	2.02
4.00	-2.0	1.22	1.30	3.32
2.00	-1.0	3.19	3.41	6.73
1.41	-0.5	7.27	7.76	14.49
1.00	0.0	5.99	6.40	20.88
0.71	0.5	8.58	9.16	30.04
0.50	1.0	9.89	10.56	40.60
0.35	1.5	17.23	18.40	59.00
0.25	2.0	17.16	18.32	77.32
0.18	2.5	14.95	15.96	93.28
0.13	3.0	4.79	5.11	98.40
0.09	3.5	1.29	1.38	99.78
0.06	4.0	0.14	0.15	99.93
0.03	5.0	0.07	0.07	100.00
	TOTALS	93.66	100.00	100.00

MEAN GRAINSIZE	**Medium sand**	
TEXTURAL CLASS	**Gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**#N/A**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	7	
% SAND	93	
% MUD	0	
GRAPHIC MEAN	0.43 mm	1.22phi
MOMENT MEAN	0.42 mm	1.24phi
GRAPHIC SORTING	1.32	
MOMENT SORTING	1.30	
GRAPHIC SKEWNESS	-1.36	
MOMENT SKEWNESS	-1.06	
GRAPHIC KURTOSIS	0.93	
MOMENT KURTOSIS	1.04	
PROCESSING ERROR(%)	0.07	





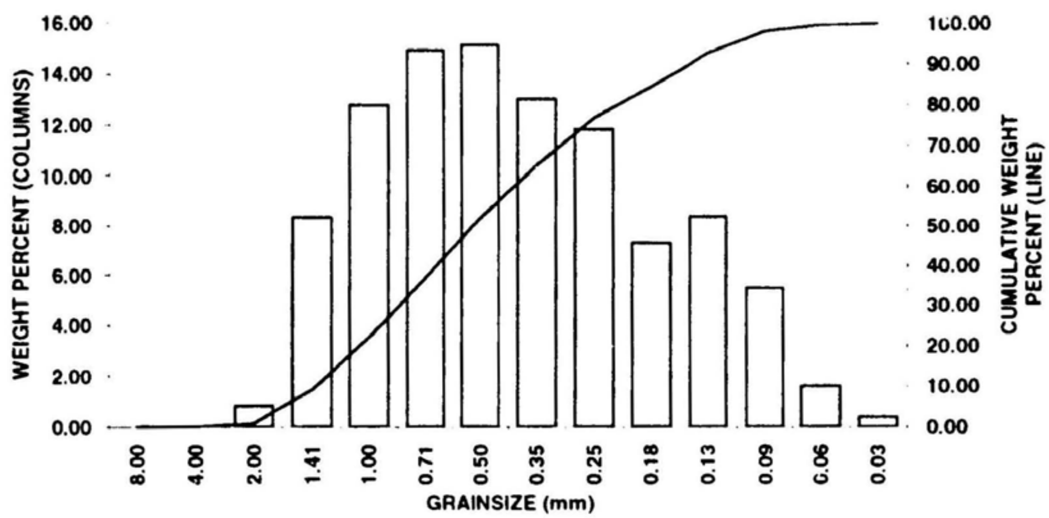


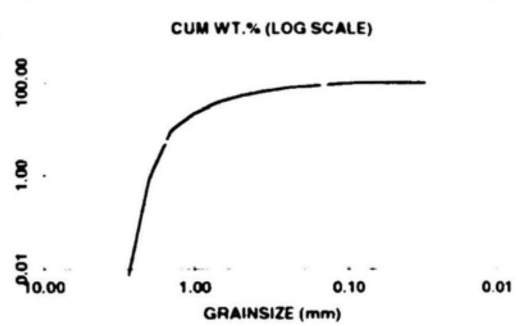
SIEVE DATA

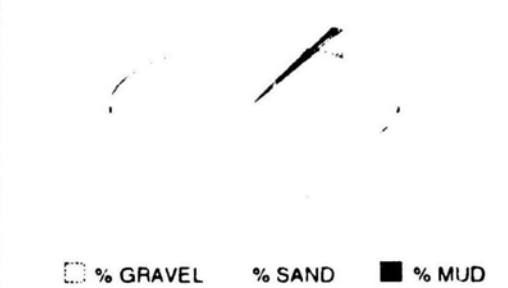
SAMPLE	62	PROJECT	CK.91.03
TOTAL WT.	173.70	DATE	1/22/96
SAMPLE LOCATION	Lagoon	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.00	0.00	0.00
2.00	-1.0	1.44	0.83	0.83
1.41	-0.5	14.46	8.34	9.17
1.00	0.0	22.11	12.75	21.92
0.71	0.5	25.88	14.92	36.84
0.50	1.0	26.24	15.13	51.97
0.35	1.5	22.56	13.01	64.98
0.25	2.0	20.50	11.82	76.80
0.18	2.5	12.72	7.33	84.14
0.13	3.0	14.53	8.38	92.52
0.09	3.5	9.49	5.47	97.99
0.06	4.0	2.80	1.61	99.60
0.03	5.0	0.69	0.40	100.00
	TOTALS	173.42	100.00	100.00

MEAN GRAINSIZE	Medium sand	
TEXTURAL CLASS	Slightly gravelly sand	
SORTING	Poor	
SKEWNESS	Fine	
KURTOSIS	Platykurtic	
% GRAVEL	1	
% SAND	99	
% MUD	0	
GRAPHIC MEAN	0.36 mm	1.46phi
MOMENT MEAN	0.40 mm	1.32phi
GRAPHIC SORTING	1.33	
MOMENT SORTING	1.22	
GRAPHIC SKEWNESS	0.44	
MOMENT SKEWNESS	0.29	
GRAPHIC KURTOSIS	0.76	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.16	





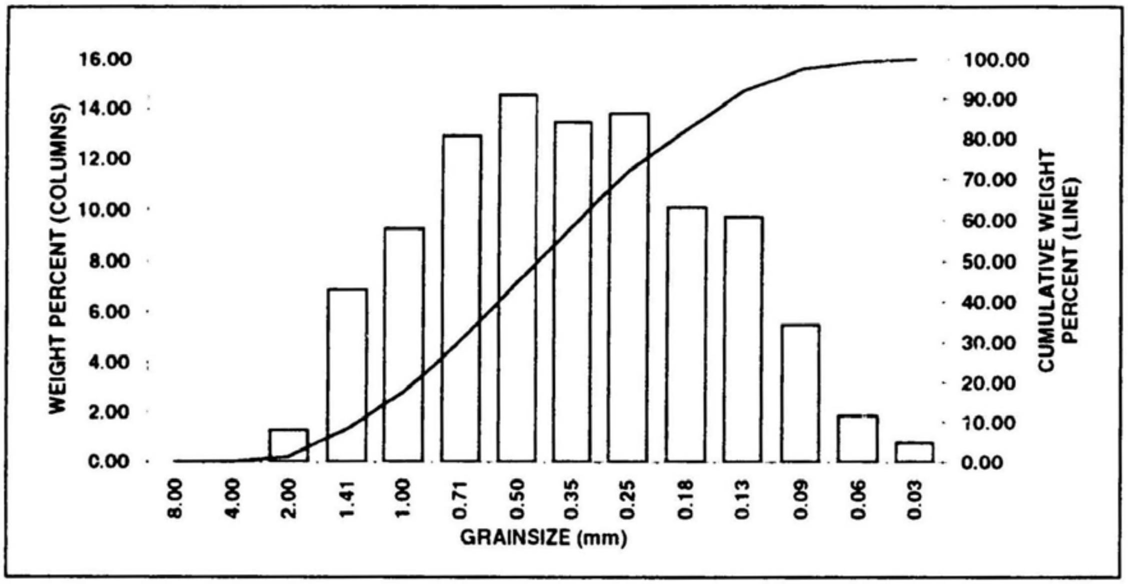


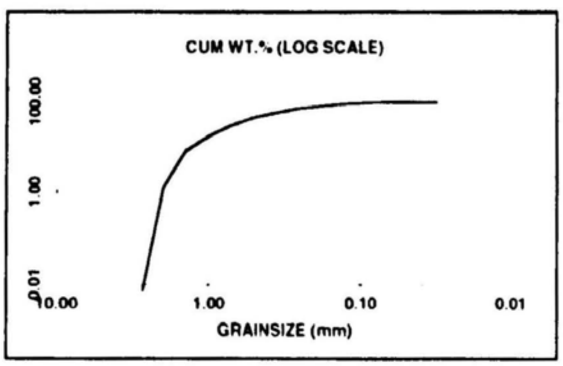
SIEVE DATA

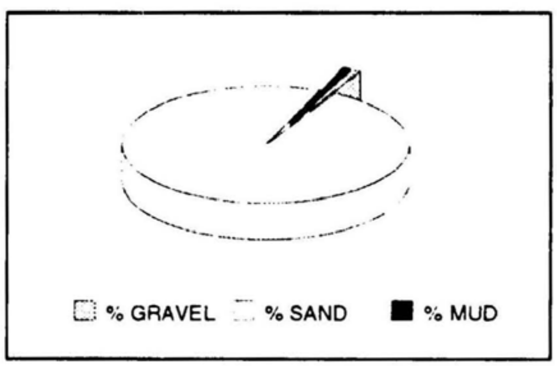
SAMPLE	**63**	**PROJECT**	CK.91.03
TOTAL WT.	66.80	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

RAW DATA				
MM	**PHI(Ø)**	**WT. RET.**	**WT. %**	**CUM. %**
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.00	0.00	0.00
2.00	-1.0	0.84	1.26	1.26
1.41	-0.5	4.58	6.87	8.13
1.00	0.0	6.17	9.25	17.38
0.71	0.5	8.61	12.91	30.30
0.50	1.0	9.69	14.53	44.83
0.35	1.5	8.96	13.44	58.27
0.25	2.0	9.21	13.81	72.09
0.18	2.5	6.73	10.09	82.18
0.13	3.0	6.48	9.72	91.90
0.09	3.5	3.67	5.50	97.41
0.06	4.0	1.23	1.84	99.25
0.03	5.0	0.50	0.75	100.00
	TOTALS	66.67	100.00	100.00

MEAN GRAINSIZE	**Medium sand**	
TEXTURAL CLASS	**Slightly gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**Fine**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	1	
% SAND	98	
% MUD	1	
GRAPHIC MEAN	0.36 mm	1.47phi
MOMENT MEAN	0.36 mm	1.49phi
GRAPHIC SORTING	1.19	
MOMENT SORTING	1.23	
GRAPHIC SKEWNESS	0.36	
MOMENT SKEWNESS	0.10	
GRAPHIC KURTOSIS	0.97	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.19	





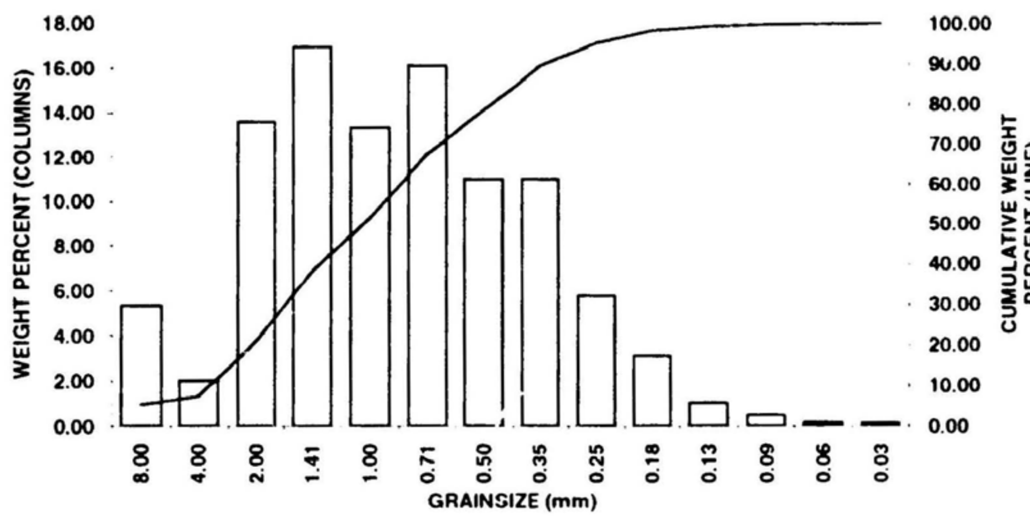


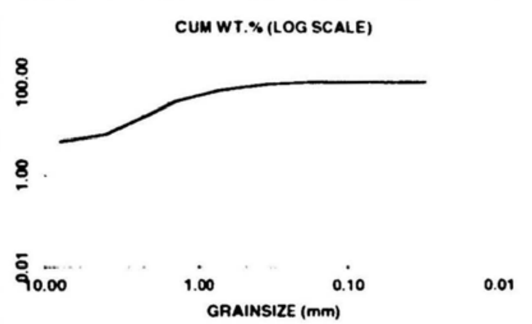
SIEVE DATA

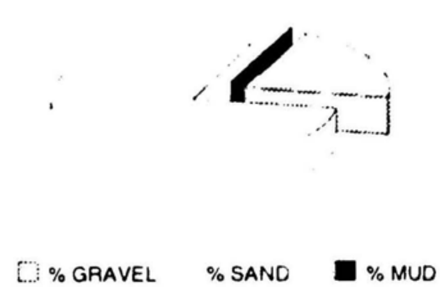
SAMPLE	**64**	**PROJECT**	CK.91.03
TOTAL WT.	137.18	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	7.29	5.34	5.34
4.00	-2.0	2.75	2.01	7.35
2.00	-1.0	18.55	13.58	20.93
1.41	-0.5	23.11	16.92	37.85
1.00	0.0	18.22	13.34	51.19
0.71	0.5	21.97	16.09	67.28
0.50	1.0	15.04	11.01	78.29
0.35	1.5	15.05	11.02	89.31
0.25	2.0	7.88	5.77	95.08
0.18	2.5	4.20	3.08	98.16
0.13	3.0	1.41	1.03	99.19
0.09	3.5	0.70	0.51	99.70
0.06	4.0	0.22	0.16	99.86
0.03	5.0	0.19	0.14	100.00
	TOTALS	136.58	100.00	100.00

MEAN GRAINSIZE	**Coarse sand**	
TEXTURAL CLASS	**Gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**#N/A**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	21	
% SAND	79	
% MUD	0	
GRAPHIC MEAN	0.88 mm	0.19phi
MOMENT MEAN	0.88 mm	0.19phi
GRAPHIC SORTING	1.48	
MOMENT SORTING	1.32	
GRAPHIC SKEWNESS	-1.05	
MOMENT SKEWNESS	-1.05	
GRAPHIC KURTOSIS	1.06	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.44	





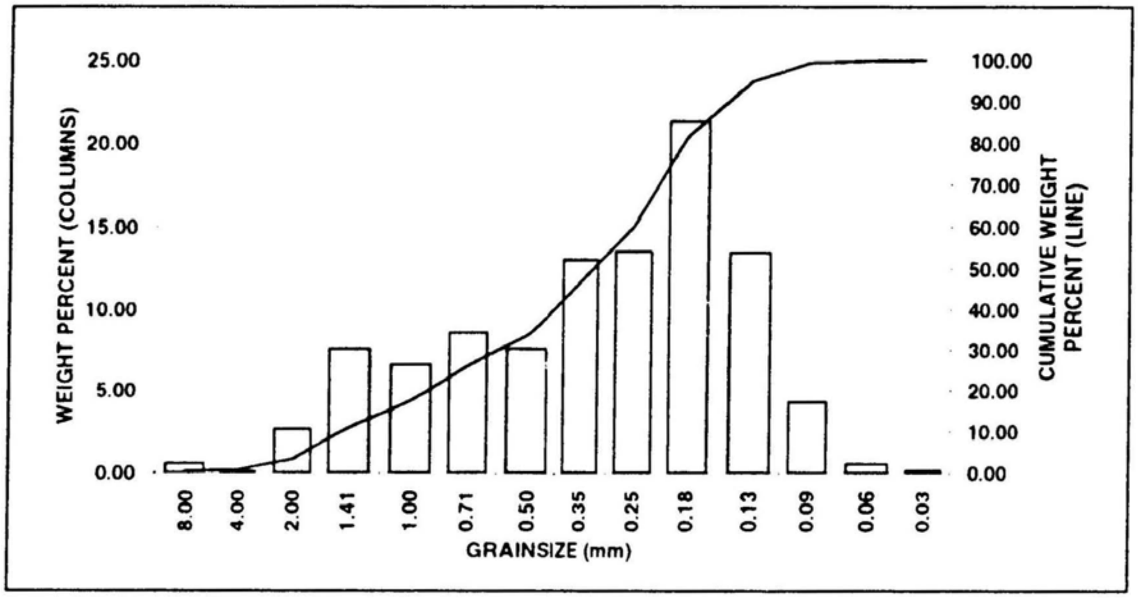


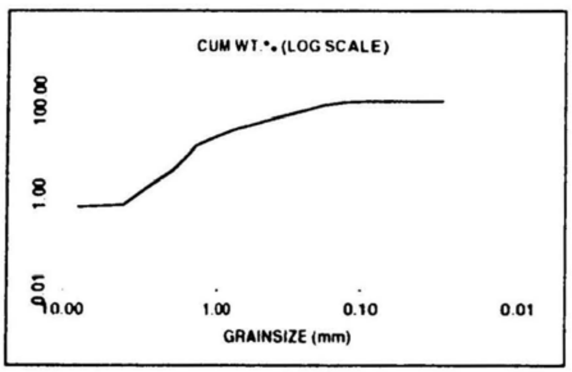
SIEVE DATA

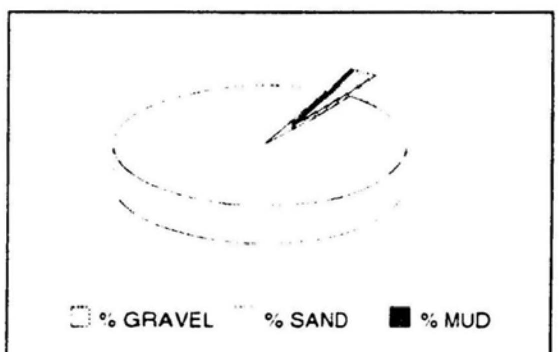
SAMPLE	65	**PROJECT**	CK 91 03
TOTAL WT.	107 29	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8 00	-3 0	0 59	0 55	0 55
4 00	-2 0	0 05	0 05	0 60
2 00	-1 0	2 82	2 64	3 24
1 41	-0 5	8 10	7 59	10 83
1 00	0 0	7 05	6 61	17 44
0 71	0 5	9 18	8 60	26 04
0 50	1 0	8 12	7 61	33 65
0 35	1 5	13 91	13 03	46 68
0 25	2 0	14 45	13 54	60 22
0 18	2 5	22 78	21 34	81 56
0 13	3 0	14 38	13 47	95 03
0 09	3 5	4 56	4 27	99 31
0 06	4 0	0 58	0 54	99 85
0 03	5 0	0 16	0 15	100 00
	TOTALS	106 73	100 00	100 00

MEAN GRAINSIZE	**Medium sand**	
TEXTURAL CLASS	**Slightly gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**Coarse**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	3	
% SAND	97	
% MUD	0	
GRAPHIC MEAN	0 34 mm	1 57phi
MOMENT MEAN	0 33 mm	1 62phi
GRAPHIC SORTING	1 24	
MOMENT SORTING	1 26	
GRAPHIC SKEWNESS	-0.72	
MOMENT SKEWNESS	-0.30	
GRAPHIC KURTOSIS	0 96	
MOMENT KURTOSIS	1 03	
PROCESSING ERROR(%)	0.52	





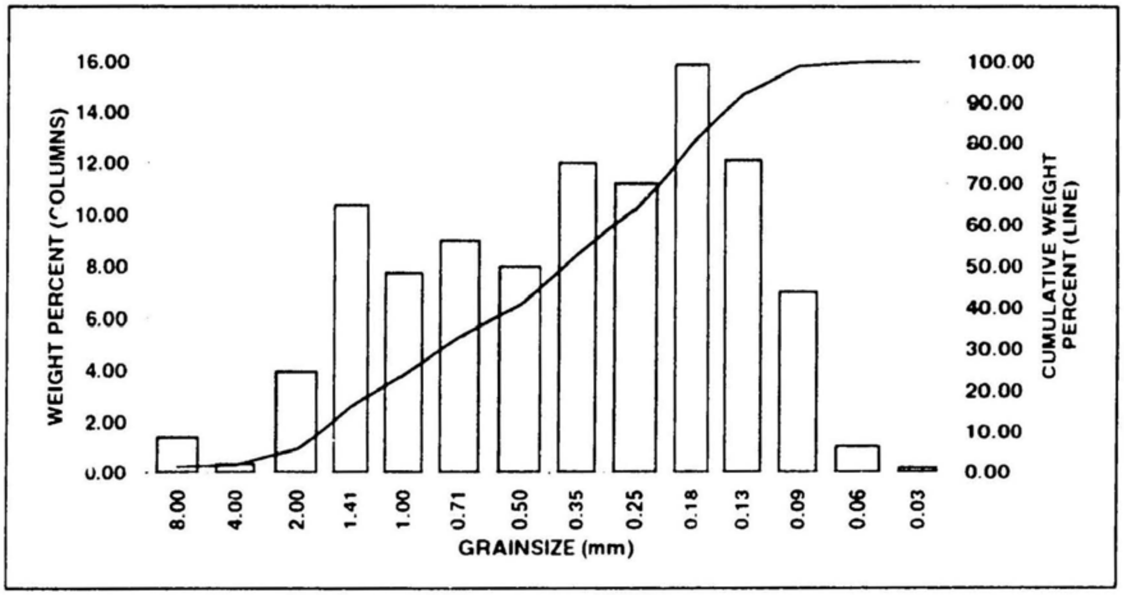


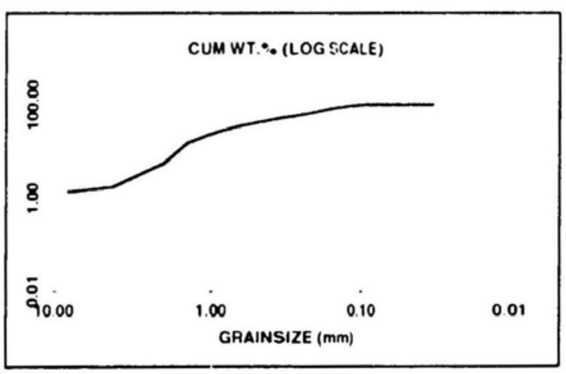
SIEVE DATA

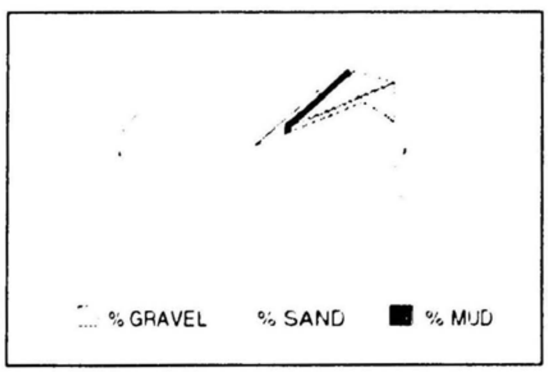
SAMPLE	66	PROJECT	CK 91.03
TOTAL WT.	131.67	DATE	1/22/96
SAMPLE LOCATION	Lagoon	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(O)	WT. RET.	WT. %	CUM. %
8.00	-3.0	1.82	1.39	1.39
4.00	-2.0	0.44	0.34	1.72
2.00	-1.0	5.15	3.93	5.65
1.41	-0.5	13.54	10.33	15.98
1.00	0.0	10.13	7.73	23.71
0.71	0.5	11.78	8.99	32.70
0.50	1.0	10.48	7.99	40.69
0.35	1.5	15.73	12.00	52.69
0.25	2.0	14.66	11.18	63.87
0.18	2.5	20.78	15.85	79.72
0.13	3.0	15.87	12.11	91.83
0.09	3.5	9.18	7.00	98.83
0.06	4.0	1.32	1.01	99.84
0.03	5.0	0.21	0.16	100.00
	TOTALS	131.09	100.00	100.00

MEAN GRAINSIZE	Medium sand	
TEXTURAL CLASS	Gravelly sand	
SORTING	Poor	
SKEWNESS	Strongly coarse	
KURTOSIS	Platykurtic	
% GRAVEL	6	
% SAND	94	
% MUD	0	
GRAPHIC MEAN	0.38 mm	1.38phi
MOMENT MEAN	0.37 mm	1.44phi
GRAPHIC SORTING	1.53	
MOMENT SORTING	1.44	
GRAPHIC SKEWNESS	-2.14	
MOMENT SKEWNESS	-0.49	
GRAPHIC KURTOSIS	0.74	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.44	





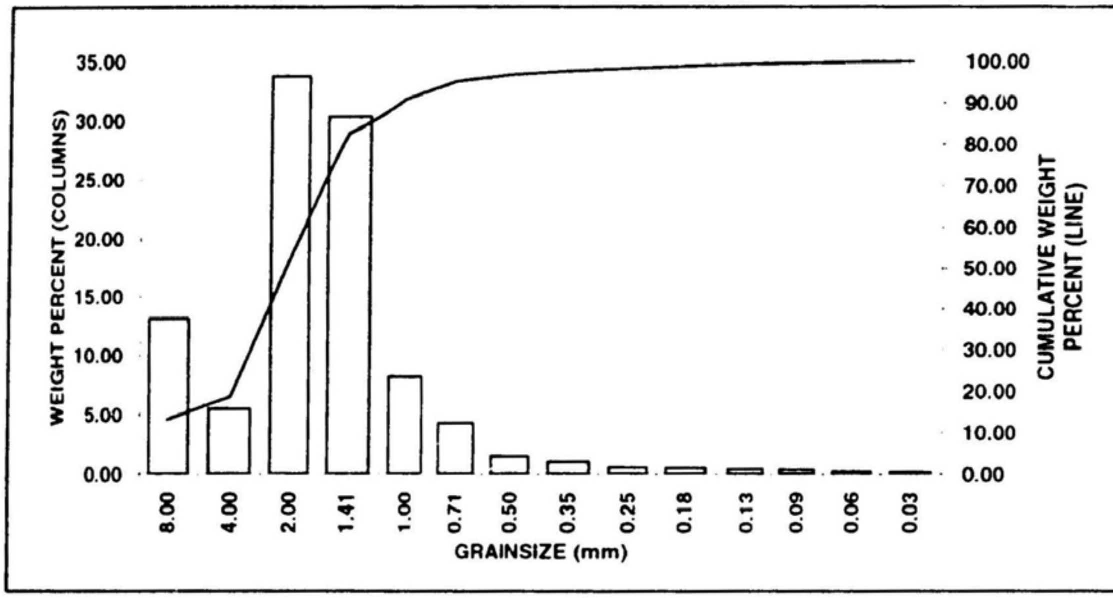


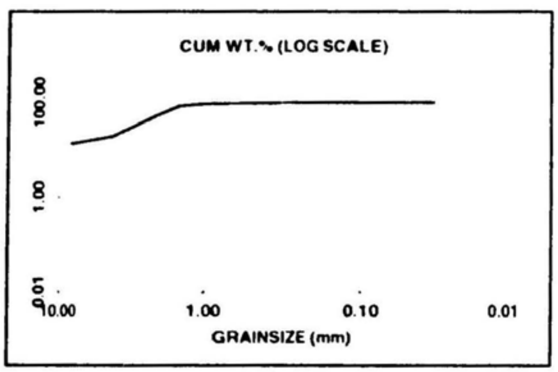
SIEVE DATA

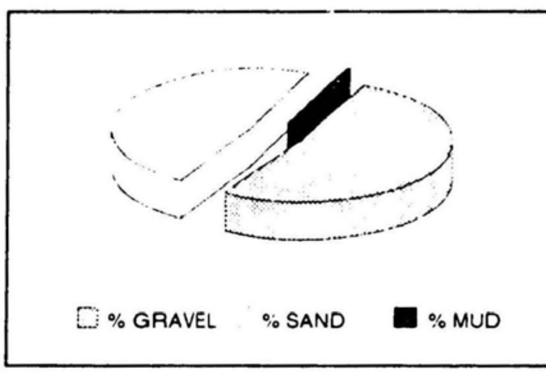
SAMPLE	67	PROJECT	CK 91.03
TOTAL WT.	131 78	DATE	1/22/96
SAMPLE LOCATION	Lagoon	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	17.15	13.11	13.11
4.00	-2.0	7.22	5.52	18.63
2.00	-1.0	44.16	33.75	52.38
1.41	-0.5	39.69	30.34	82.72
1.00	0.0	10.76	8.22	90.94
0.71	0.5	5.62	4.30	95.24
0.50	1.0	1.98	1.51	96.75
0.35	1.5	1.38	1.05	97.81
0.25	2.0	0.74	0.57	98.37
0.18	2.5	0.66	0.50	98.88
0.13	3.0	0.55	0.42	99.30
0.09	3.5	0.46	0.35	99.65
0.06	4.0	0.26	0.20	99.85
0.03	5.0	0.20	0.15	100.00
	TOTALS	130.83	100.00	100.00

MEAN GRAINSIZE	Granules	
TEXTURAL CLASS	Sandy gravel	
SORTING	Poor	
SKEWNESS	Strongly coarse	
KURTOSIS	Mesokurtic	
% GRAVEL	52	
% SAND	47	
% MUD	0	
GRAPHIC MEAN	2.46 mm	-1.30phi
MOMENT MEAN	1.84 mm	-0.88phi
GRAPHIC SORTING	1.14	
MOMENT SORTING	1.14	
GRAPHIC SKEWNESS	-0.73	
MOMENT SKEWNESS	-0.74	
GRAPHIC KURTOSIS	1.07	
MOMENT KURTOSIS	1.06	
PROCESSING ERROR(%)	0.73	





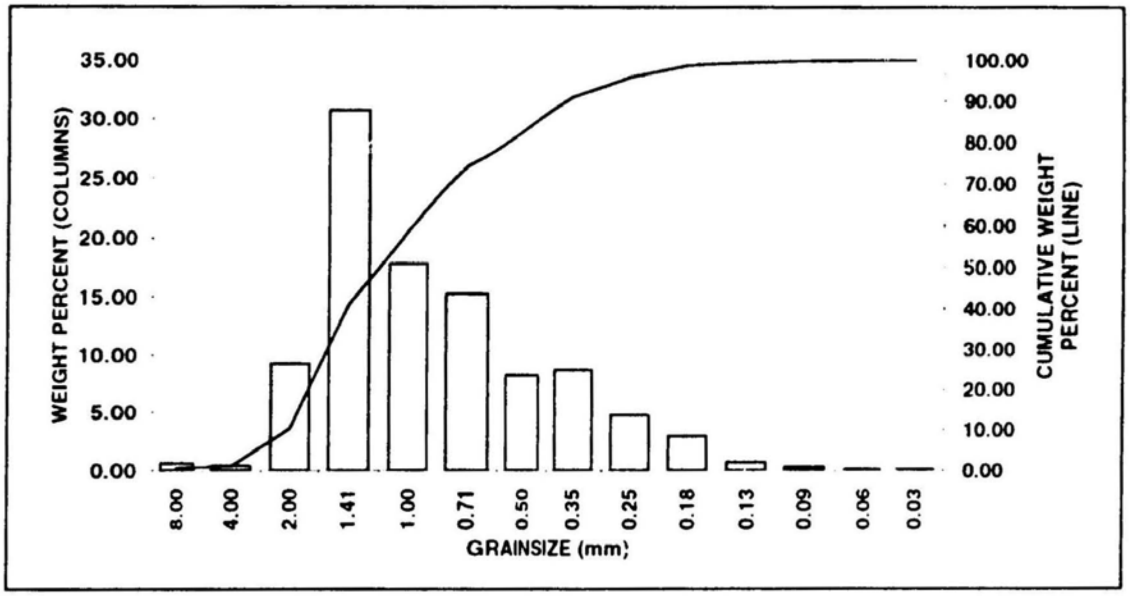


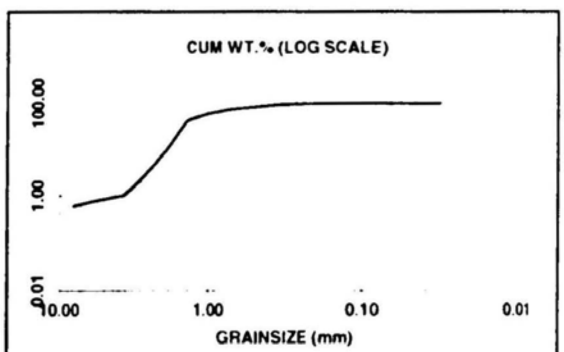
SIEVE DATA

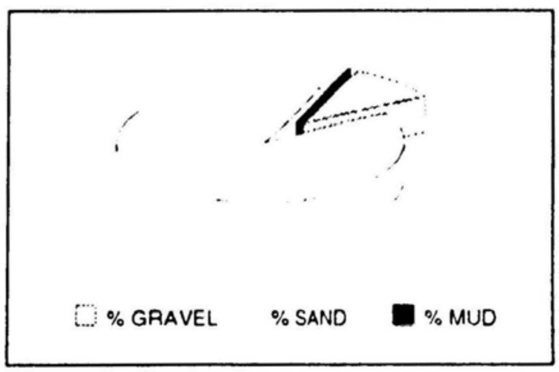
SAMPLE	**68**	**PROJECT**	CK 91 03
TOTAL WT.	116 28	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.70	0.61	0.61
4.00	-2.0	0.48	0.42	1.02
2.00	-1.0	10.67	9.25	10.27
1.41	-0.5	35.42	30.71	40.98
1.00	0.0	20.56	17.83	58.81
0.71	0.5	17.59	15.25	74.06
0.50	1.0	9.52	8.25	82.31
0.35	1.5	10.05	8.71	91.03
0.25	2.0	5.48	4.75	95.78
0.18	2.5	3.44	2.98	98.76
0.13	3.0	0.83	0.72	99.48
0.09	3.5	0.34	0.29	99.77
0.06	4.0	0.15	0.13	99.90
0.03	5.0	0.11	0.10	100.00
	TOTALS	115.34	100.00	100.00

MEAN GRAINSIZE	**Coarse sand**	
TEXTURAL CLASS	**Gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**Strongly fine**	
KURTOSIS	**Leptokurtic**	
% GRAVEL	10	
% SAND	90	
% MUD	0	
GRAPHIC MEAN	0.91 mm	0.13phi
MOMENT MEAN	0.85 mm	0 23phi
GRAPHIC SORTING	1.09	
MOMENT SORTING	1.01	
GRAPHIC SKEWNESS	0 47	
MOMENT SKEWNESS	0 47	
GRAPHIC KURTOSIS	1 41	
MOMENT KURTOSIS	1 04	
PROCESSING ERROR(%)	0 81	





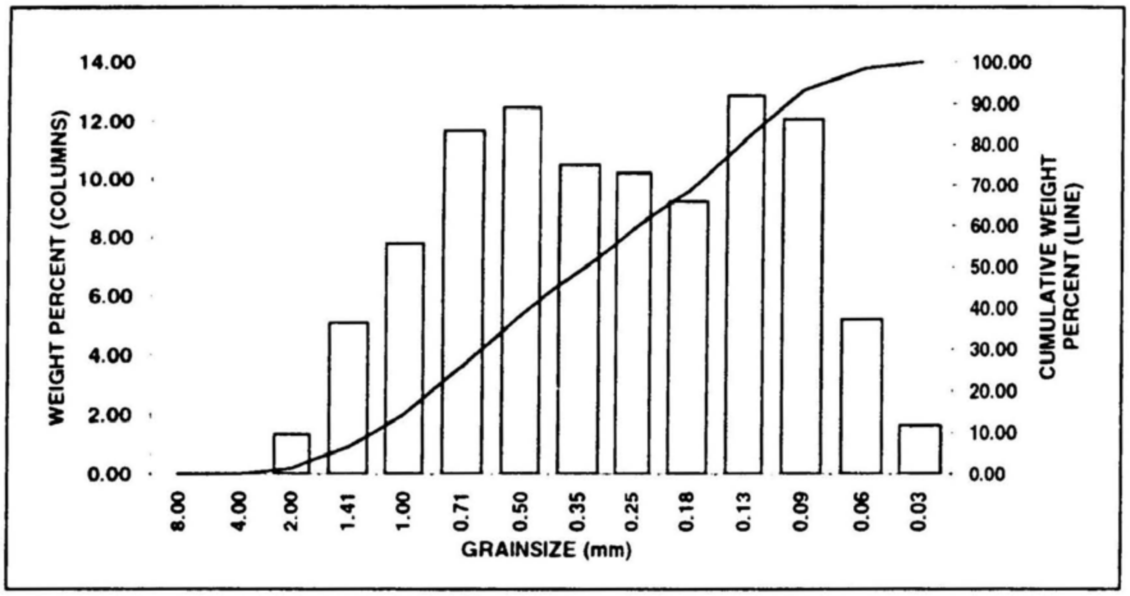


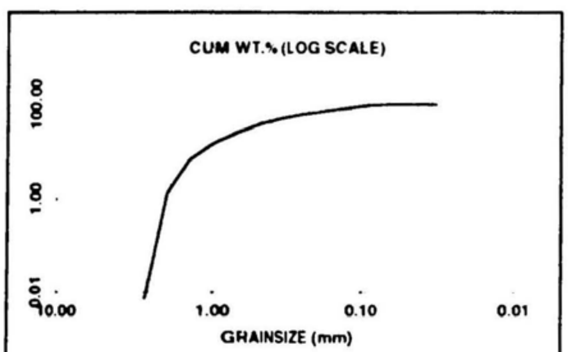
SIEVE DATA

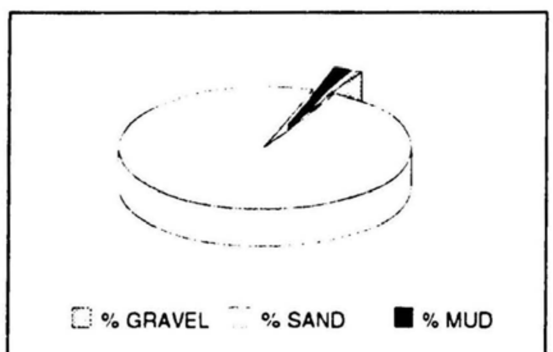
SAMPLE	69	**PROJECT**	CK 91.03
TOTAL WT.	111 40	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.00	0.00	0.00
2.00	-1.0	1.49	1.34	1.34
1.41	-0.5	5.67	5.09	6.43
1.00	0.0	8.67	7.78	14.21
0.71	0.5	12.99	11.66	25.87
0.50	1.0	13.88	12.46	38.33
0.35	1.5	11.67	10.48	48.81
0.25	2.0	11.37	10.21	59.02
0.18	2.5	10.24	9.19	68.21
0.13	3.0	14.34	12.87	81.08
0.09	3.5	13.44	12.07	93.15
0.06	4.0	5.79	5.20	98.35
0.03	5.0	1.84	1.65	100.00
	TOTALS	111.39	100.00	100.00

MEAN GRAINSIZE	Medium sand	
TEXTURAL CLASS	Slightly gravelly sand	
SORTING	Poor	
SKEWNESS	Near symmetrical	
KURTOSIS	Platykurtic	
% GRAVEL	1	
% SAND	97	
% MUD	2	
GRAPHIC MEAN	0.31 mm	1.67phi
MOMENT MEAN	0.28 mm	1.83phi
GRAPHIC SORTING	1.39	
MOMENT SORTING	1.38	
GRAPHIC SKEWNESS	0.29	
MOMENT SKEWNESS	0.01	
GRAPHIC KURTOSIS	0.81	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.01	







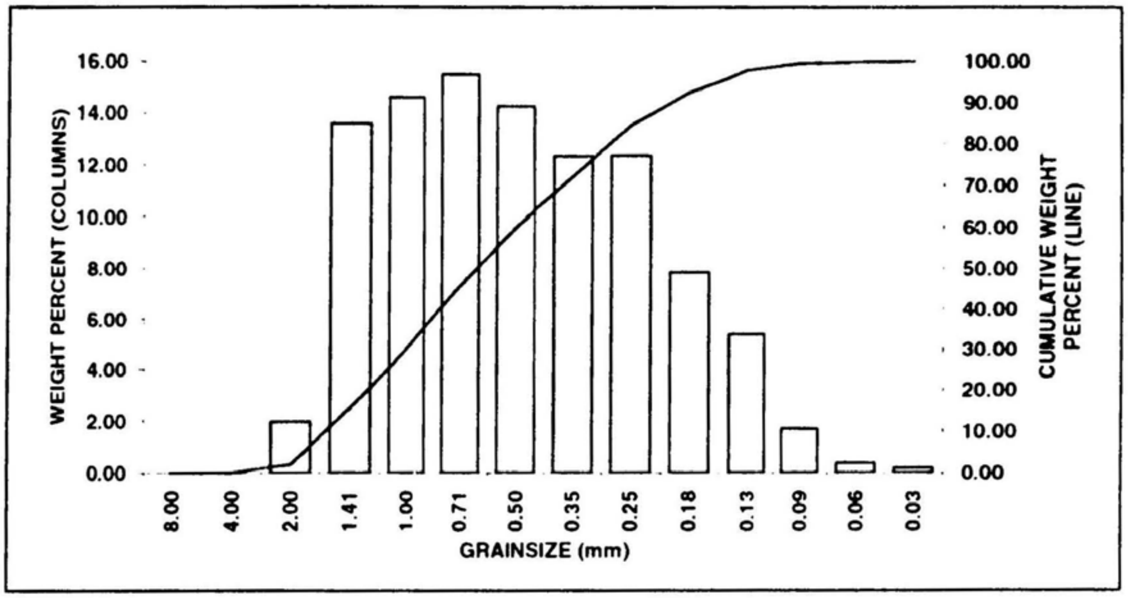
SIEVE DATA

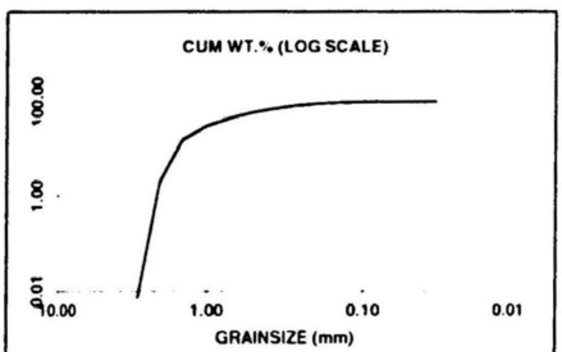
SAMPLE	70	PROJECT	CK 91 03
TOTAL WT.	91.90	DATE	1/22/96
SAMPLE LOCATION	Lagoon	SCIENTIST	Bill Collins

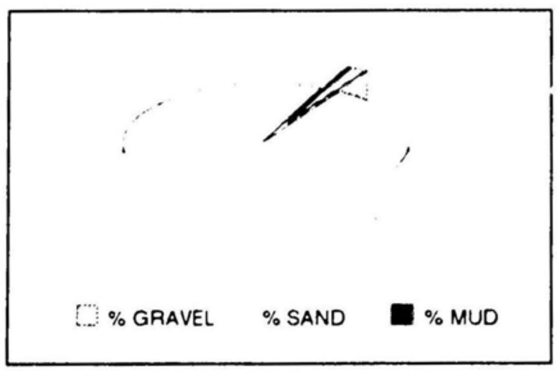
RAW DATA

MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.00	0.00	0.00
2.00	-1.0	1.80	1.96	1.96
1.41	-0.5	12.48	13.58	15.54
1.00	0.0	13.42	14.60	30.13
0.71	0.5	14.22	15.47	45.60
0.50	1.0	13.10	14.25	59.86
0.35	1.5	11.32	12.32	72.17
0.25	2.0	11.35	12.35	84.52
0.18	2.5	7.22	7.85	92.37
0.13	3.0	4.96	5.40	97.77
0.09	3.5	1.55	1.69	99.46
0.06	4.0	0.34	0.37	99.83
0.03	5.0	0.16	0.17	100.00
	TOTALS	91.92	100.00	100.00

MEAN GRAINSIZE	Coarse sand	
TEXTURAL CLASS	Slightly gravelly sand	
SORTING	Poor	
SKEWNESS	Strongly fine	
KURTOSIS	Mesokurtic	
% GRAVEL	2	
% SAND	98	
% MUD	0	
GRAPHIC MEAN	0.52 mm	0.93phi
MOMENT MEAN	0.50 mm	1.00phi
GRAPHIC SORTING	1.30	
MOMENT SORTING	1.13	
GRAPHIC SKEWNESS	0.62	
MOMENT SKEWNESS	0.50	
GRAPHIC KURTOSIS	0.98	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.02	





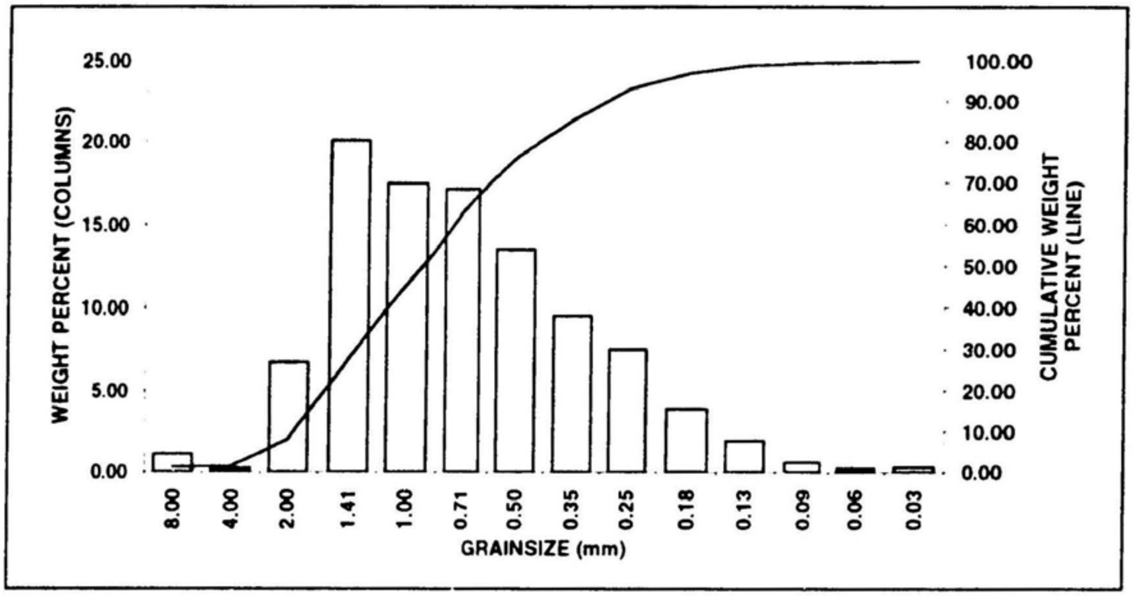


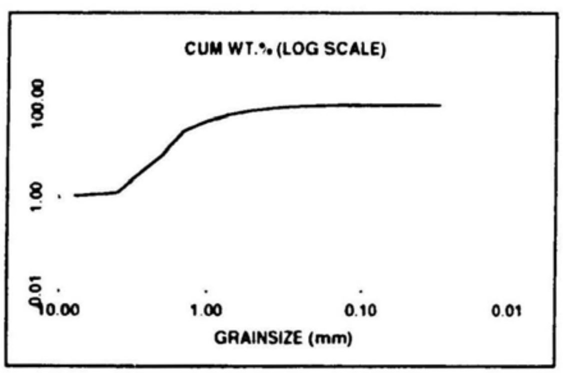
SIEVE DATA

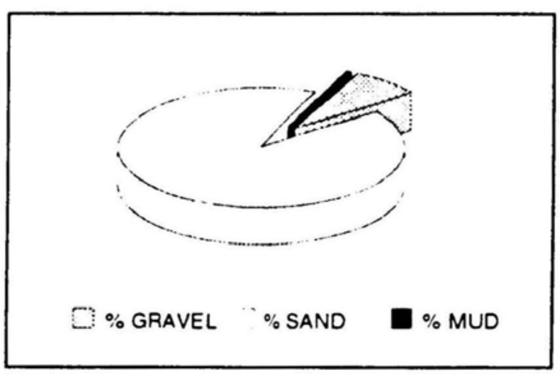
SAMPLE	71	**PROJECT**	CK.91.03
TOTAL WT.	92.10	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

RAW DATA				
MM	**PHI(Ø)**	**WT. RET.**	**WT. %**	**CUM. %**
8.00	-3.0	1.00	1.09	1.09
4.00	-2.0	0.19	0.21	1.29
2.00	-1.0	6.17	6.70	7.99
1.41	-0.5	18.45	20.04	28.03
1.00	0.0	16.06	17.44	45.48
0.71	0.5	15.75	17.11	62.58
0.50	1.0	12.43	13.50	76.08
0.35	1.5	8.74	9.49	85.58
0.25	2.0	6.90	7.49	93.07
0.18	2.5	3.57	3.88	96.95
0.13	3.0	1.80	1.96	98.90
0.09	3.5	0.54	0.59	99.49
0.06	4.0	0.20	0.22	99.71
0.03	5.0	0.27	0.29	100.00
	TOTALS	92.07	100.00	100.00

MEAN GRAINSIZE	**Coarse sand**	
TEXTURAL CLASS	**Gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**Strongly fine**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	8	
% SAND	92	
% MUD	0	
GRAPHIC MEAN	0.71 mm	0.50phi
MOMENT MEAN	0.70 mm	0.51phi
GRAPHIC SORTING	1.20	
MOMENT SORTING	1.12	
GRAPHIC SKEWNESS	0.92	
MOMENT SKEWNESS	3.97	
GRAPHIC KURTOSIS	1.03	
MOMENT KURTOSIS	1.04	
PROCESSING ERROR(%)	0.03	







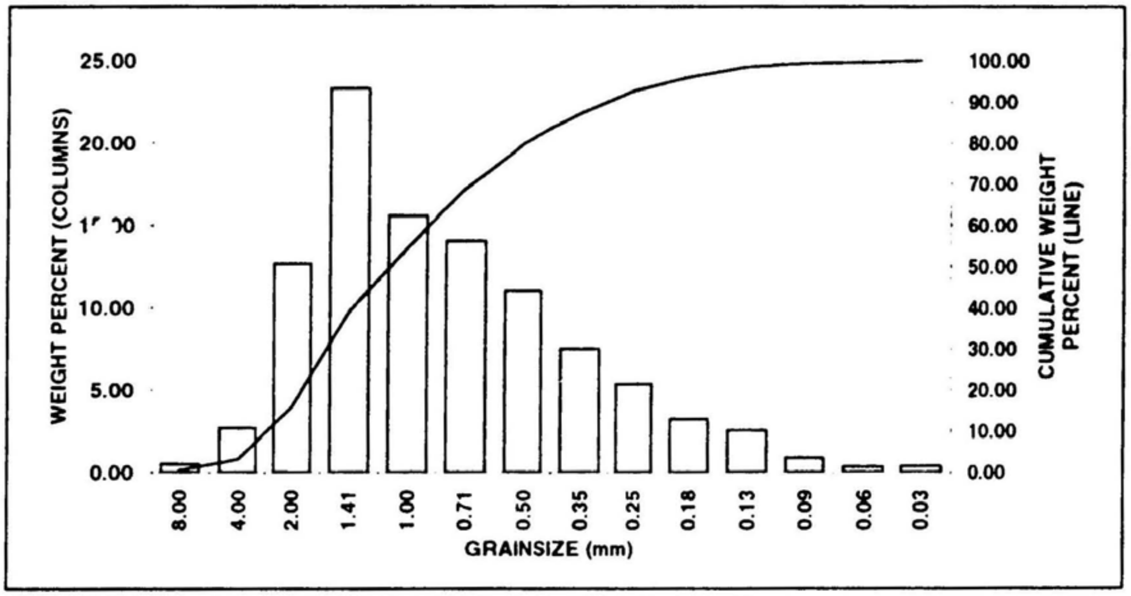
SIEVE DATA

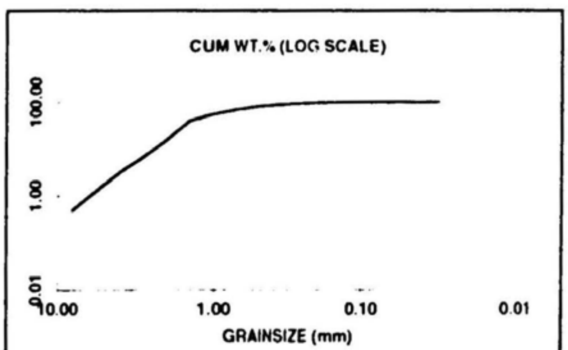
SAMPLE	72	**PROJECT**	CK 91 03
TOTAL WT.	111.50	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

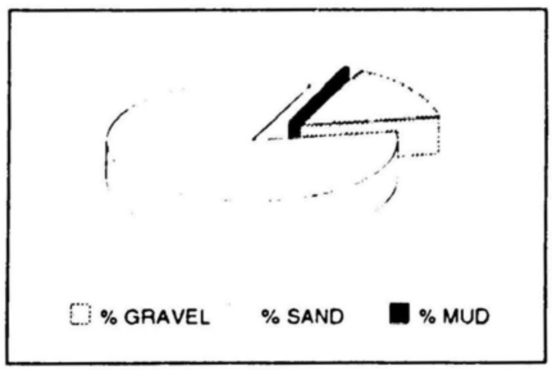
RAW DATA

MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.55	0.49	0.49
4.00	-2.0	2.98	2.66	3.15
2.00	-1.0	14.19	12.68	15.84
1.41	-0.5	26.11	23.33	39.17
1.00	0.0	17.41	15.56	54.73
0.71	0.5	15.73	14.06	68.78
0.50	1.0	12.36	11.05	79.83
0.35	1.5	8.39	7.50	87.33
0.25	2.0	6.02	5.38	92.71
0.18	2.5	3.59	3.21	95.92
0.13	3.0	2.86	2.56	98.47
0.09	3.5	0.95	0.85	99.32
0.06	4.0	0.37	0.33	99.65
0.03	5.0	0.39	0.35	100.00
	TOTALS	111.90	100.00	100.00

MEAN GRAINSIZE	**Coarse sand**	
TEXTURAL CLASS	**Gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**Fine**	
KURTOSIS	**Leptokurtic**	
% GRAVEL	16	
% SAND	84	
% MUD	0	
GRAPHIC MEAN	0.84 mm	0.25phi
MOMENT MEAN	0.81 mm	0.31phi
GRAPHIC SORTING	1.32	
MOMENT SORTING	1.20	
GRAPHIC SKEWNESS	0.27	
MOMENT SKEWNESS	0.27	
GRAPHIC KURTOSIS	1.12	
MOMENT KURTOSIS	1.04	
PROCESSING ERROR(%)	0.36	





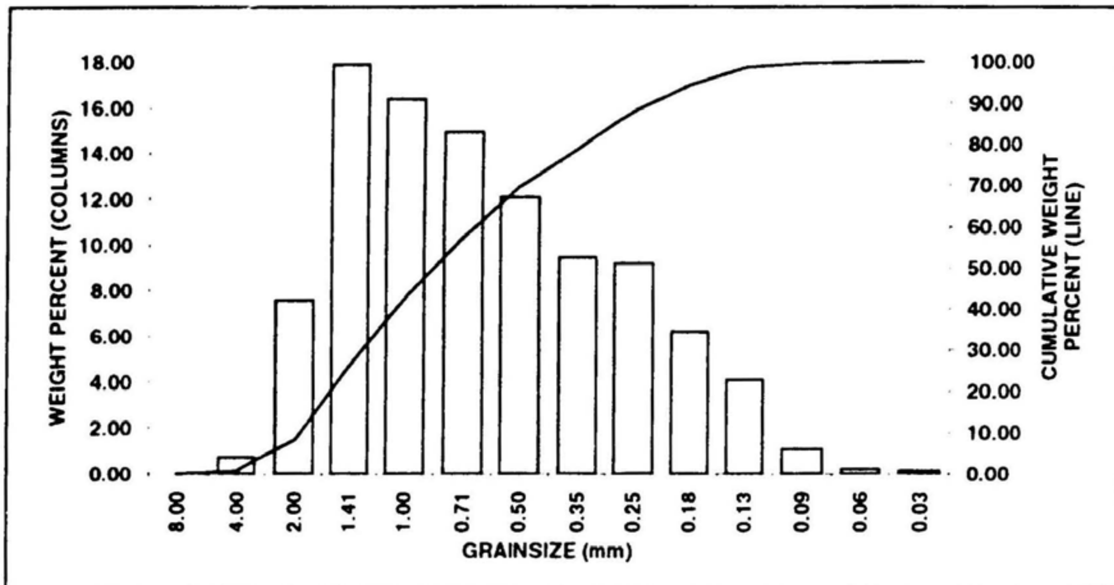


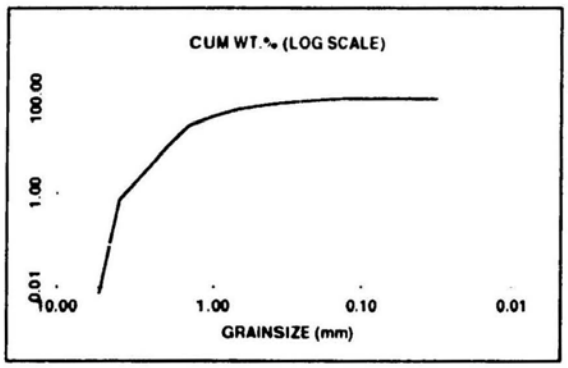
SIEVE DATA

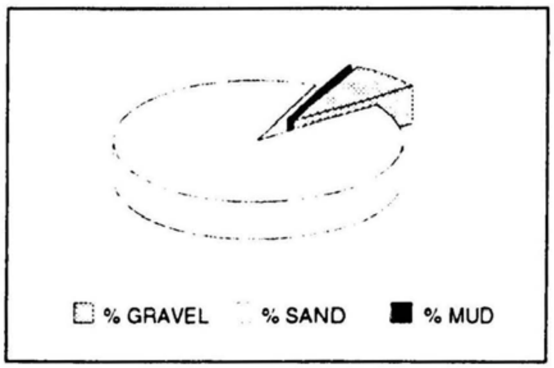
SAMPLE	73	**PROJECT**	CK 91.03
TOTAL WT.	128 70	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.92	0.72	0.72
2.00	-1.0	9.67	7.56	8.28
1.41	-0.5	22.88	17.89	26.16
1.00	0.0	20.95	16.38	42.54
0.71	0.5	19.12	14.95	57.49
0.50	1.0	15.48	12.10	69.59
0.35	1.5	12.12	9.47	79.07
0.25	2.0	11.77	9.20	88.27
0.18	2.5	7.94	6.21	94.47
0.13	3.0	5.23	4.09	98.56
0.09	3.5	1.40	1.09	99.66
0.06	4.0	0.28	0.22	99.88
0.03	5.0	0.16	0.13	100.00
	TOTALS	127.92	100.00	100.00

MEAN GRAINSIZE	**Coarse sand**	
TEXTURAL CLASS	**Gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**Strongly fine**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	8	
% SAND	92	
% MUD	0	
GRAPHIC MEAN	0.63 mm	0.66phi
MOMENT MEAN	0.63 mm	0.67phi
GRAPHIC SORTING	1.26	
MOMENT SORTING	1.18	
GRAPHIC SKEWNESS	0.64	
MOMENT SKEWNESS	2.49	
GRAPHIC KURTOSIS	1.02	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.61	





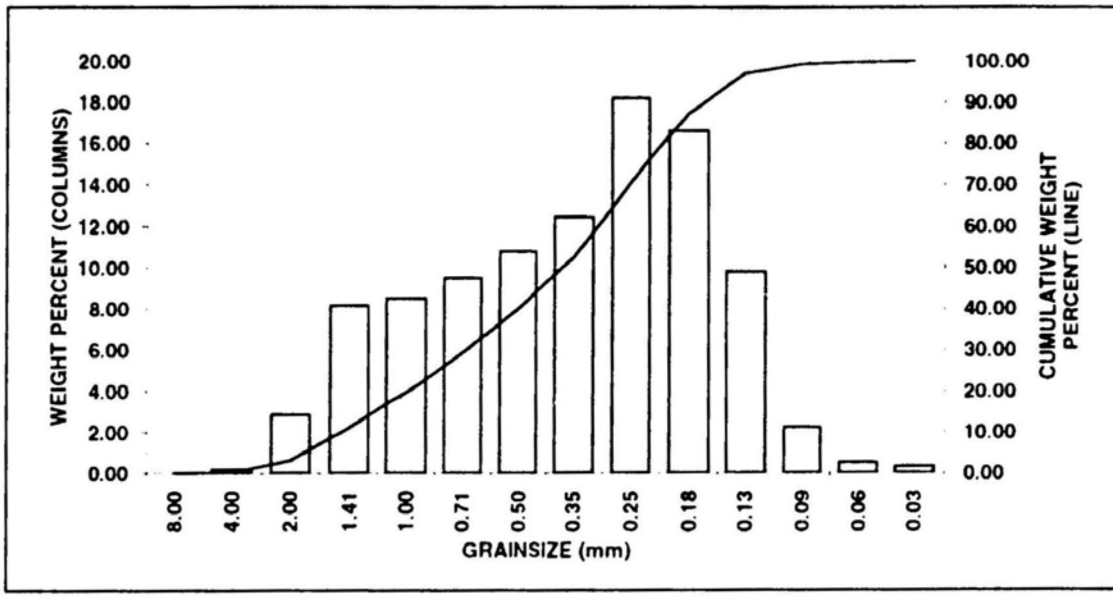


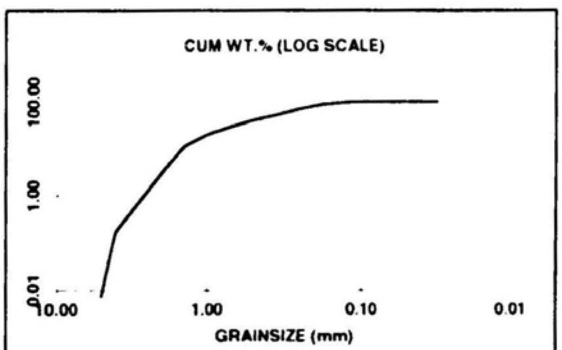
SIEVE DATA

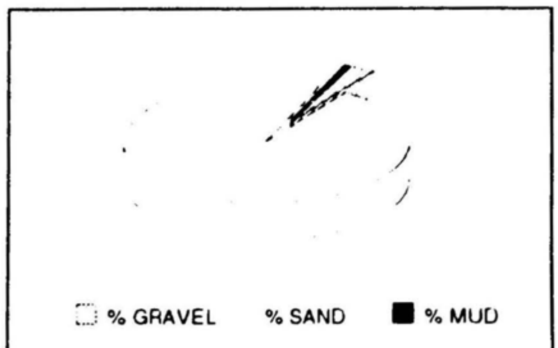
SAMPLE	74	**PROJECT**	CK.91.03
TOTAL WT.	101.00	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.17	0.17	0.17
2.00	-1.0	2.90	2.87	3.04
1.41	-0.5	8.21	8.14	11.18
1.00	0.0	8.55	8.47	19.65
0.71	0.5	9.59	9.50	29.16
0.50	1.0	10.89	10.79	39.95
0.35	1.5	12.56	12.45	52.40
0.25	2.0	18.34	18.18	70.57
0.18	2.5	16.75	16.60	87.18
0.13	3.0	9.85	9.76	96.94
0.09	3.5	2.25	2.23	99.17
0.06	4.0	0.52	0.52	99.68
0.03	5.0	0.32	0.32	100.00
	TOTALS	100.90	100.00	100.00

MEAN GRAINSIZE	**Medium sand**	
TEXTURAL CLASS	**Slightly gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**Coarse**	
KURTOSIS	**Mesokurtic**	
% GRAVEL	3	
% SAND	97	
% MUD	0	
GRAPHIC MEAN	0.34 mm	1.56phi
MOMENT MEAN	0.36 mm	1.46phi
GRAPHIC SORTING	1.29	
MOMENT SORTING	1.19	
GRAPHIC SKEWNESS	-1.14	
MOMENT SKEWNESS	-0.15	
GRAPHIC KURTOSIS	0.98	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.10	





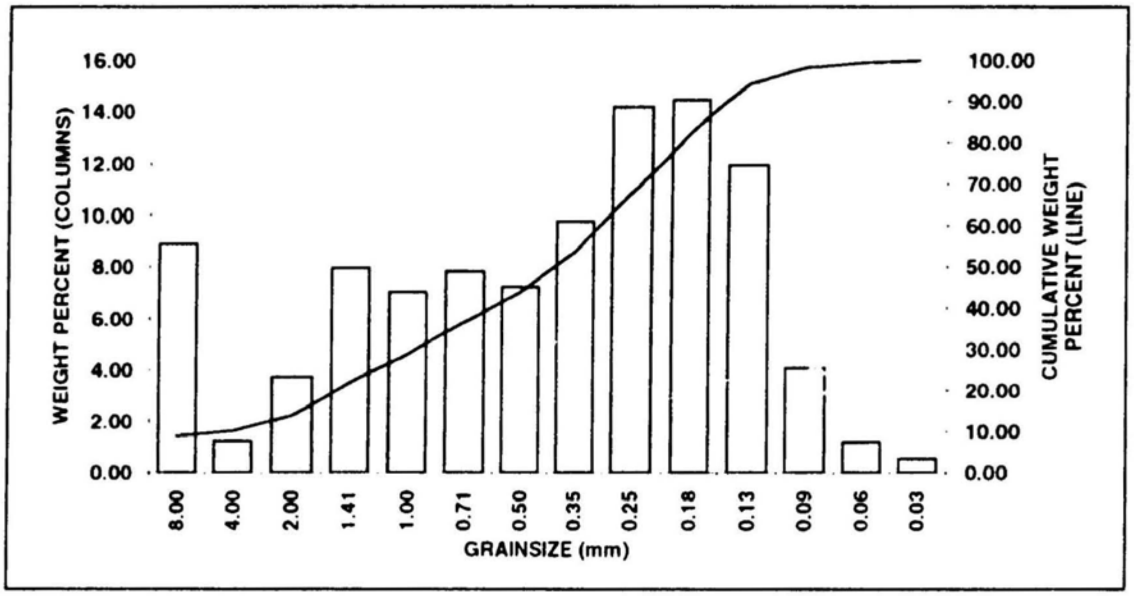


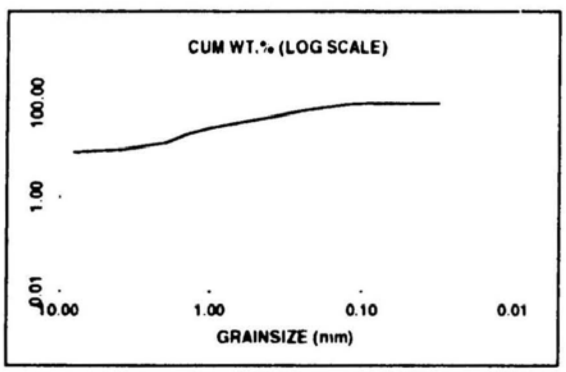
SIEVE DATA

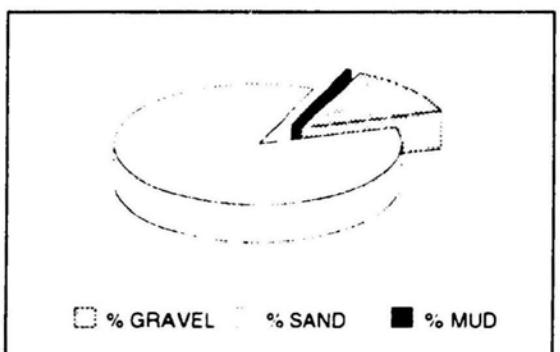
SAMPLE	75	PROJECT	CK.91.03
TOTAL WT.	54.30	DATE	1/22/96
SAMPLE LOCATION	Lagoon	SCIENTIST	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	4.82	8.90	8.90
4.00	-2.0	0.67	1.24	10.13
2.00	-1.0	2.02	3.73	13.86
1.41	-0.5	4.32	7.97	21.84
1.00	0.0	3.80	7.01	28.85
0.71	0.5	4.23	7.81	36.66
0.50	1.0	3.92	7.24	43.90
0.35	1.5	5.28	9.75	53.65
0.25	2.0	7.69	14.20	67.84
0.18	2.5	7.83	14.45	82.30
0.13	3.0	6.46	11.93	94.22
0.09	3.5	2.21	4.08	98.30
0.06	4.0	0.64	1.18	99.48
0.03	5.0	0.28	0.52	100.00
	TOTALS	54.17	100.00	100.00

MEAN GRAINSIZE	Medium sand	
TEXTURAL CLASS	Gravelly sand	
SORTING	Poor	
SKEWNESS	#N/A	
KURTOSIS	Mesokurtic	
% GRAVEL	14	
% SAND	86	
% MUD	1	
GRAPHIC MEAN	0.44 mm	1.18phi
MOMENT MEAN	0.46 mm	1.11phi
GRAPHIC SORTING	1.76	
MOMENT SORTING	1.83	
GRAPHIC SKEWNESS	-2.51	
MOMENT SKEWNESS	-3.59	
GRAPHIC KURTOSIS	0.99	
MOMENT KURTOSIS	1.03	
PROCESSING ERROR(%)	0.24	





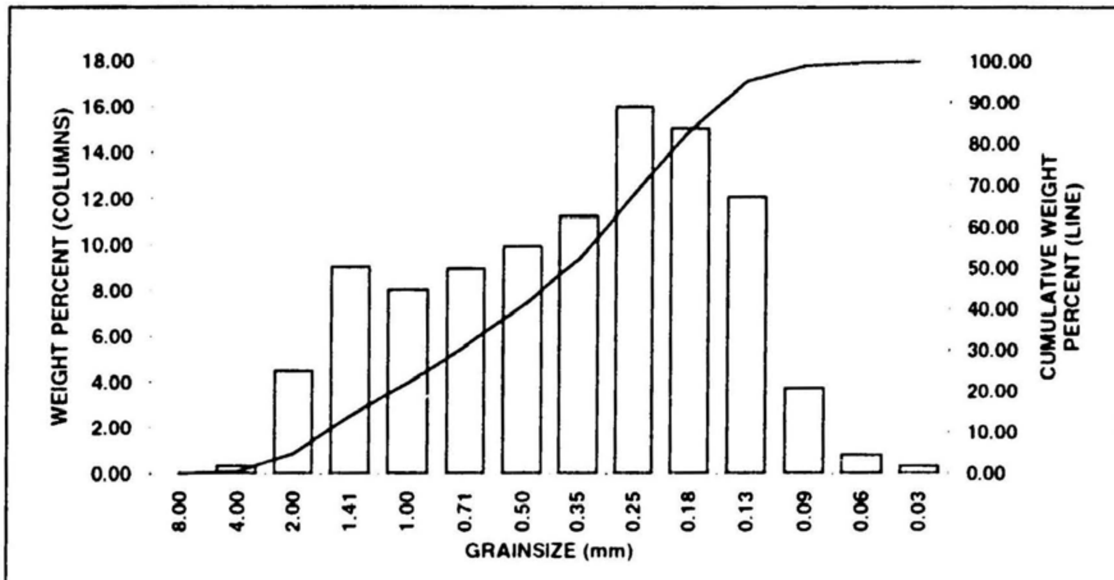


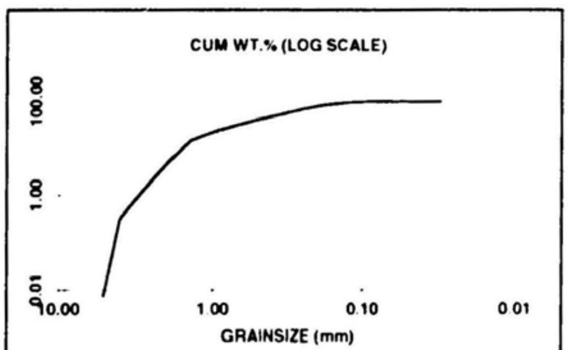
SIEVE DATA

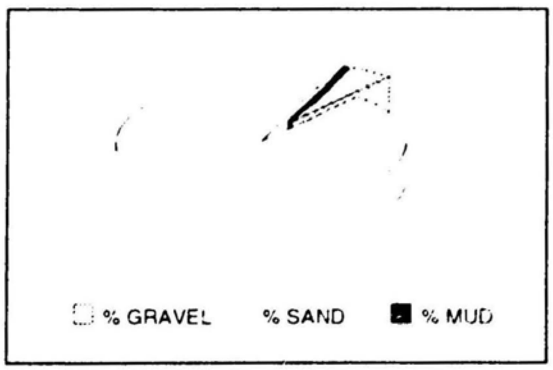
SAMPLE	**76**	**PROJECT**	CK 91 03
TOTAL WT.	76 10	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4.00	-2.0	0.24	0.32	0.32
2.00	-1.0	3.41	4.48	4.80
1.41	-0.5	6.87	9.03	13.83
1.00	0.0	6.10	8.02	21.86
0.71	0.5	6.82	8.97	30.83
0.50	1.0	7.54	9.92	40.74
0.35	1.5	8.54	11.23	51.97
0.25	2.0	12.17	16.00	67.98
0.18	2.5	11.45	15.06	83.04
0.13	3.0	9.20	12.10	95.13
0.09	3.5	2.85	3.75	98.88
0.06	4.0	0.61	0.80	99.68
0.03	5.0	0.24	0.32	100.00
	TOTALS	76.04	100.00	100.00

MEAN GRAINSIZE	**Medium sand**	
TEXTURAL CLASS	**Slightly gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**Coarse**	
KURTOSIS	**Platykurtic**	
% GRAVEL	5	
% SAND	95	
% MUD	0	
GRAPHIC MEAN	0.38 mm	1.39phi
MOMENT MEAN	0.36 mm	1.45phi
GRAPHIC SORTING	1.37	
MOMENT SORTING	1.29	
GRAPHIC SKEWNESS	-1.95	
MOMENT SKEWNESS	-0.18	
GRAPHIC KURTOSIS	0.87	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.08	





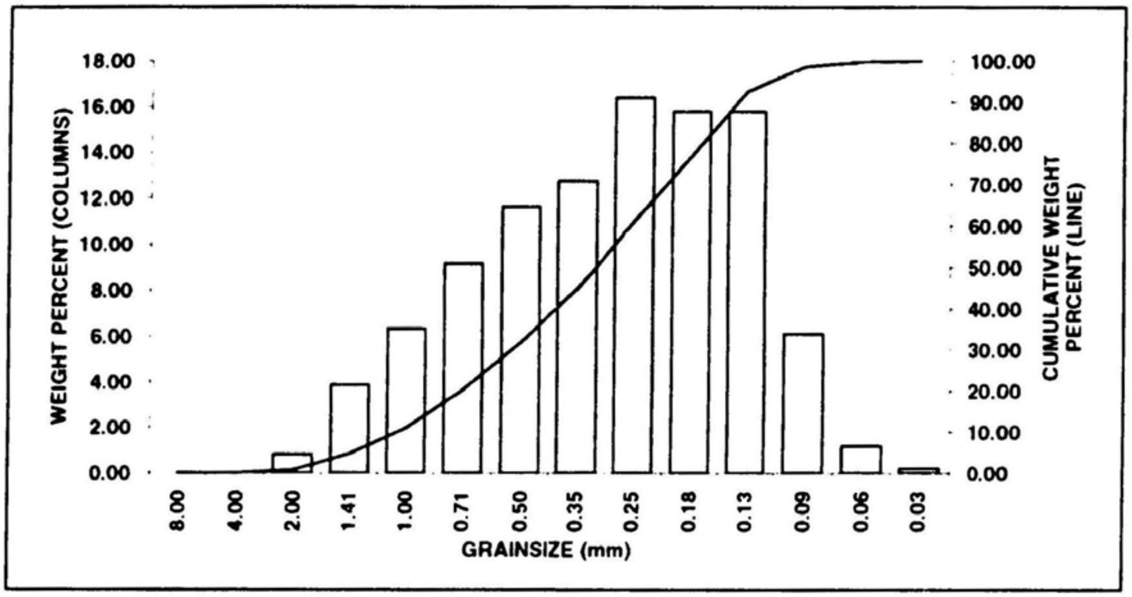


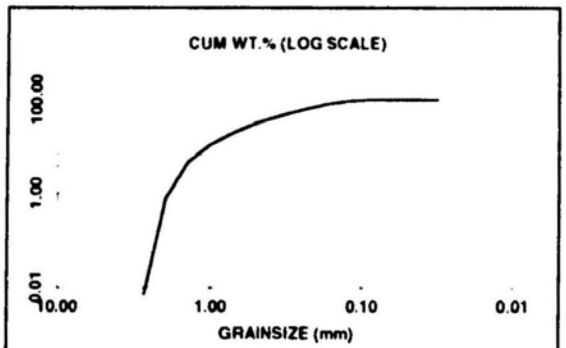
SIEVE DATA

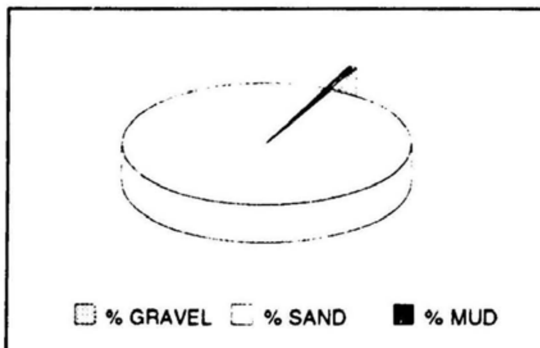
SAMPLE	77	**PROJECT**	CK.91.03
TOTAL WT.	78 80	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

RAW DATA				
MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	0.00	0.00	0.00
4 00	-2.0	0.00	0.00	0.00
2.00	-1.0	0.62	0.79	0.79
1 41	-0.5	3.05	3.88	4.67
1.00	0.0	4.97	6.32	10.99
0.71	0.5	7.21	9.17	20.17
0.50	1.0	9.13	11.62	31.78
0.35	1.5	10.02	12.75	44.53
0.25	2.0	12.88	16.39	60.92
0.18	2.5	12.41	15.79	76.70
0.13	3.0	12.43	15.81	92.52
0.09	3.5	4.79	6.09	98.61
0.06	4.0	0.93	1.18	99.80
0.03	5.0	0.16	0.20	100.00
	TOTALS	78.60	100.00	100.00

MEAN GRAINSIZE	**Medium sand**	
TEXTURAL CLASS	**Slightly gravelly sand**	
SORTING	**Poor**	
SKEWNESS	**Near symmetrical**	
KURTOSIS	**Platykurtic**	
% GRAVEL	1	
% SAND	99	
% MUD	0	
GRAPHIC MEAN	0.29 mm	1.78phi
MOMENT MEAN	0.29 mm	1.79phi
GRAPHIC SORTING	1.18	
MOMENT SORTING	1.13	
GRAPHIC SKEWNESS	-0.29	
MOMENT SKEWNESS	-0.08	
GRAPHIC KURTOSIS	0.80	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	0.25	







SIEVE DATA

SAMPLE	78	**PROJECT**	CK 91.03
TOTAL WT.	103.40	**DATE**	1/22/96
SAMPLE LOCATION	Lagoon	**SCIENTIST**	Bill Collins

RAW DATA

MM	PHI(Ø)	WT. RET.	WT. %	CUM. %
8.00	-3.0	17.83	17.05	17.05
4.00	-2.0	13.03	12.46	29.50
2.00	-1.0	14.44	13.80	43.31
1.41	-0.5	10.40	9.94	53.25
1.00	0.0	8.08	7.72	60.98
0.71	0.5	8.79	8.40	69.38
0.50	1.0	9.40	8.99	78.37
0.35	1.5	8.28	7.92	86.28
0.25	2.0	6.80	6.50	92.78
0.18	2.5	3.53	3.37	96.16
0.13	3.0	1.88	1.80	97.95
0.09	3.5	0.74	0.71	98.66
0.06	4.0	0.45	0.43	99.09
0.03	5.0	0.95	0.91	100.00
	TOTALS	104.60	100.00	100.00

MEAN GRAINSIZE	**Very coarse sand**	
TEXTURAL CLASS	**Sandy gravel**	
SORTING	**Poor**	
SKEWNESS	**Strongly coarse**	
KURTOSIS	**Platykurtic**	
% GRAVEL	43	
% SAND	56	
% MUD	1	
GRAPHIC MEAN	1.31 mm	-0.39phi
MOMENT MEAN	1.27 mm	-0.34phi
GRAPHIC SORTING	1.95	
MOMENT SORTING	1.84	
GRAPHIC SKEWNESS	-0.41	
MOMENT SKEWNESS	-0.41	
GRAPHIC KURTOSIS	0.69	
MOMENT KURTOSIS	1.02	
PROCESSING ERROR(%)	1.15