A REVIEW OF COASTAL PROCESSES AND ANALYSIS OF HISTORICAL COASTAL CHANGE IN THE VICINITY OF APIA, WESTERN SAMOA

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SUMMARY

The area in the immediate vicinity of Apia, Western Samoa was studied through the use of air photo interpretations, literature reviews and ground surveys in order to develop an understanding of the processes which influence the coastal and nearshore sedimentary systems. The goal of the study was to provide information on which decisions regarding sand mining and other uses of the coast can be based. In the course of this study it was found that the seaward-facing shoreline on the Mulinu'u Peninsula has undergone variable degrees of change between 1954 and 1990. The most distal portions of the Peninsula (towards the Apia Observatory grounds) have experienced more erosion than locations closer to the town centre. The most severely eroded areas appear to be related to local current patterns on the reef top. The lesser and more variable coastal changes noted near town could be related to more extensive and persistent shore protection rather than any natural causes.

Aggregate resources which are presently being exploited off the end of the Peninsula do not appear to be jeopardising the coast, if sufficient distance from the shore are maintained. There are some concerns about dredging on the reef flats close to shore, especially in light of the design specifications of the newly installed shore protection. Alternate potential reverses at reef openings are targeted for further study.

As previous studies have indicated, most fairweather sediment movement is related to tradewind driven circulation from the east with modification by waves refracting and diffracting into the reef flat areas. There are indications that movement of sands off the reef flats does occur, but the frequency and magnitude of the movement is not known. Studies of circulation on the reef flat as well as in reef openings and reentrants are identified as a high priority for additional work. The degree of human modification of the coastal in the Apia area leads to the suggestion that investigations may be more effective if carried out in a somewhat more natural setting as well.

ACKNOWLEDGEMENTS

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INTRODUCTION

The primary objective of this report is to describe the coastal processes (both human and natural) which influence historical coastal changes to the beaches in the Apia area. The purpose of the work is to assist the Western Samoan government in management of the coastal zone and the development of a sand dredging plan. The methodology used for this study consists of the description and measurement of coastal change performed using existing air photos held at SOPAC Secretariat in Fiji, and a summary review of all reports and data which are relevant to the elucidation of coastal processes in the study area. These data include cyclone and storm climatology, reports of cyclone damage, interviews with representatives of government departments and dredging companies, bathymetry and subbottom acoustic surveys, surface sediment texture surveys, and coastal mapping. This study was successful in developing a preliminary description of the processes which affect the study area. Hypotheses are presented and recommendations for testing them and developing a more complete understanding of the coastal systems are presented.

STUDY AREA

Western Samoa is located just east of the International Date Line at about 14°S latitude, 177°W longitude (Figure 1a). It comprises two main islands; Savai'i to the northwest and Upolu to the southeast. The islands of Western Samoa are part of a volcanic archipelago 1200 km long. The study area is on the north side of the island of Upolu, in the immediate vicinity of the capital city, Apia (population about 35,000) (Figure 1b). The study area encompasses the region from the Port on the east side of Apia Harbour to just west of the proximal end of Mulinu'u Spit. Apia has been a centre of commerce for the region since the early to mid-1800s when Samoa was a port of call for whalers and traders (taking shipments of copra and cotton). In 1899, Western Samoa was annexed to Germany; then, in 1914, to New Zealand. It became independent in 1962 after a peaceful referendum. The harbour at Apia is one of the only natural deep lagoons with a reef opening capable of allowing ship traffic inside the reef. The reef opening exists because of the volume of fresh silty water emanating from the Vaisagano and Mulivai Rivers (Figure 2).

The study area comprises the harbour itself and the Mulinu'u Peninsula immediately to the west. The harbour contains the roll-on roll-off container facility and a ferry terminal. These were built on reclaimed land on the east side of the harbour mouth. Additional land reclamation behind a small reef inside the harbour is currently being developed. The Mulinu'u Peninsula is a low (less than 2 m above chart datum), narrow (maximum width <500m) strip of land which houses the

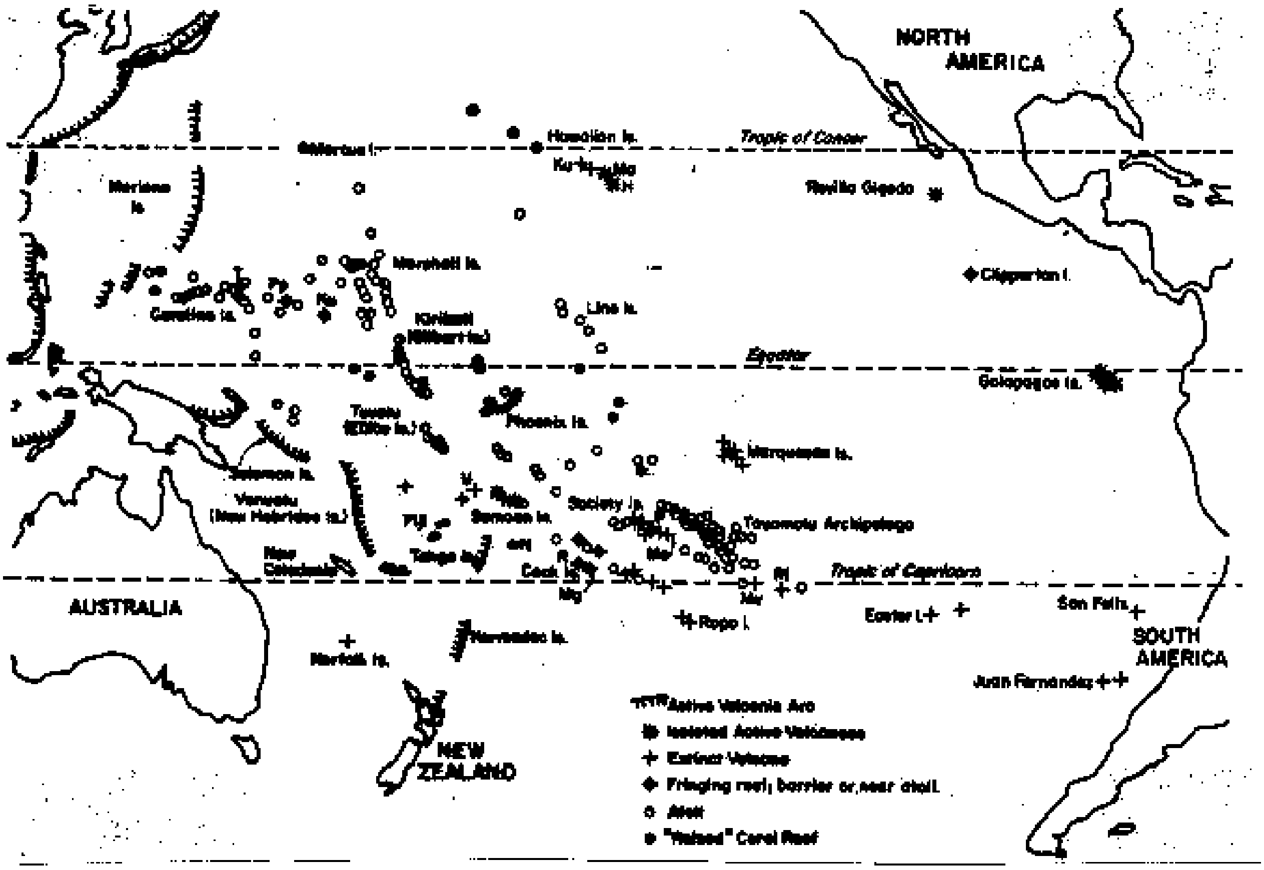

Figure1a. Map showing the location of Western Samoa.

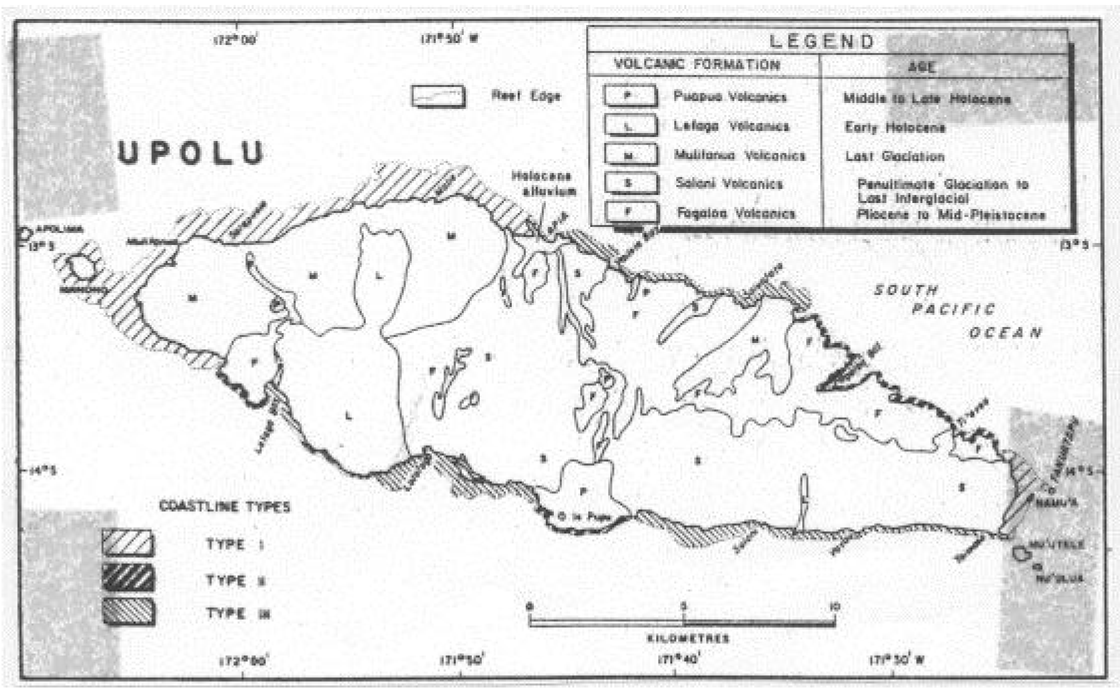

Figure 1b. Map showing the location of Apia on Upolu, Western Samoa and the volcanic units (map from Richmond, 1990).

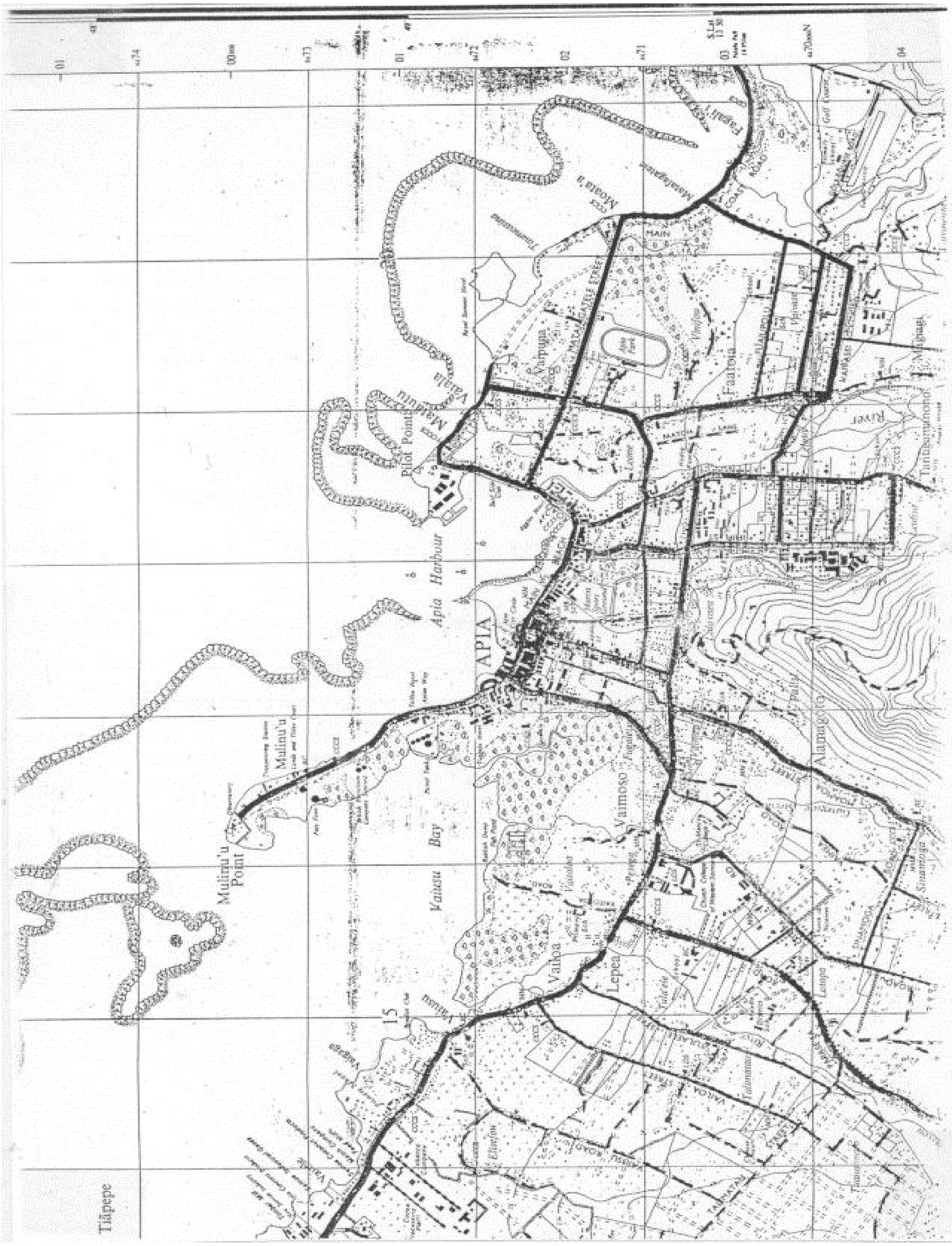

Figure 2. Map of the study area.

parliament buildings (Falefono), the Apia Observatory, several tombs of important personages, and two oil tank farms along with residential housing and some tourist facilities (Figures 2, 3). Vaiusu Bay lies to the west and in the lee of the Mulinu'u Peninsula. It is surrounded by a mangrove swamp and is fed by several small, low gradient streams. The rubbish dump lies along its southern shore. At the northwestern tip of the Peninsula, a sand mining operation has been developed using draglines to mine reef flat and lagoonal materials (Figure 3). The mining began prior to 1979 although the exact year was not available.

Upolu has a narrow to non-existent coastal plain backed by steep volcanic terrain (maximum elevation of 1858 m). Six volcanic formations have been identified by Kear and Wood (1959) on Upolu (Figure 1a). The oldest unit is the Fagaloa Volcanics of probable Late Pliocene to Early Pleistocene age. In ascending order, the remaining units are: Vini Tuff, Salani Volcanics, Mulifanua Volcanics, Lefaga Volcanics, and Puapua Volcanics. The hinterland of the study area is characterised by Salani and Mulifanua Volcanics while much of the Apia area is underlain by Holocene alluvium. The Tafagamanu Sand is described by Kear and Wood (1959) as a raised beach deposit of coral sand with some coral and basalt gravel. It may be related to a 1.5 m high stand of sea level, although there is no firm evidence for that. The unconsolidated alluvium comprising the Mulinu'u Peninsula has been assigned to the Tafagamanu Sand unit by Richmond (1991).

Coral reefs ring the islands of Western Samoa, but they are not continuous. They vary in form from narrow fringing types to barrier reefs. In the study area, the reef crest is found about 0.5 to 1.5 km form the shore (Figure 2). The reef is a fringing type with a well developed reef flat consisting of an outer zone of cemented algal material and a very shallow inner zone of sand and marine flora (characteristically less than 1.5 m deep). The most prominent feature of the reefs in the study area is the large opening into the harbour as well as several smaller openings and "blue holes" which were likely formed at a lower sea level stand. The reef crest drops steeply (>5°) seaward to a depth of about 10 fathoms (18 m) then more gradually out to the shelf break at 100 fathoms (180 m) approximately 10 km offshore (about 1°).

CLIMATE

Wind climatology is dominated by the easterly trade winds. Winds from the east, southeast and northeast comprise more than 70% of the total winds in the region (Figure 4 from Holden, 1991). Average wind speeds from these three directions are about 20 km/h. Winds at Apia of less than 5 km/h prevail about 38% of the time while winds between 5 and 23 km/h prevail

Figure 3. Air Photo of the Mulinu'u Peninsula taken in 1992 showing place names referred to in the text.

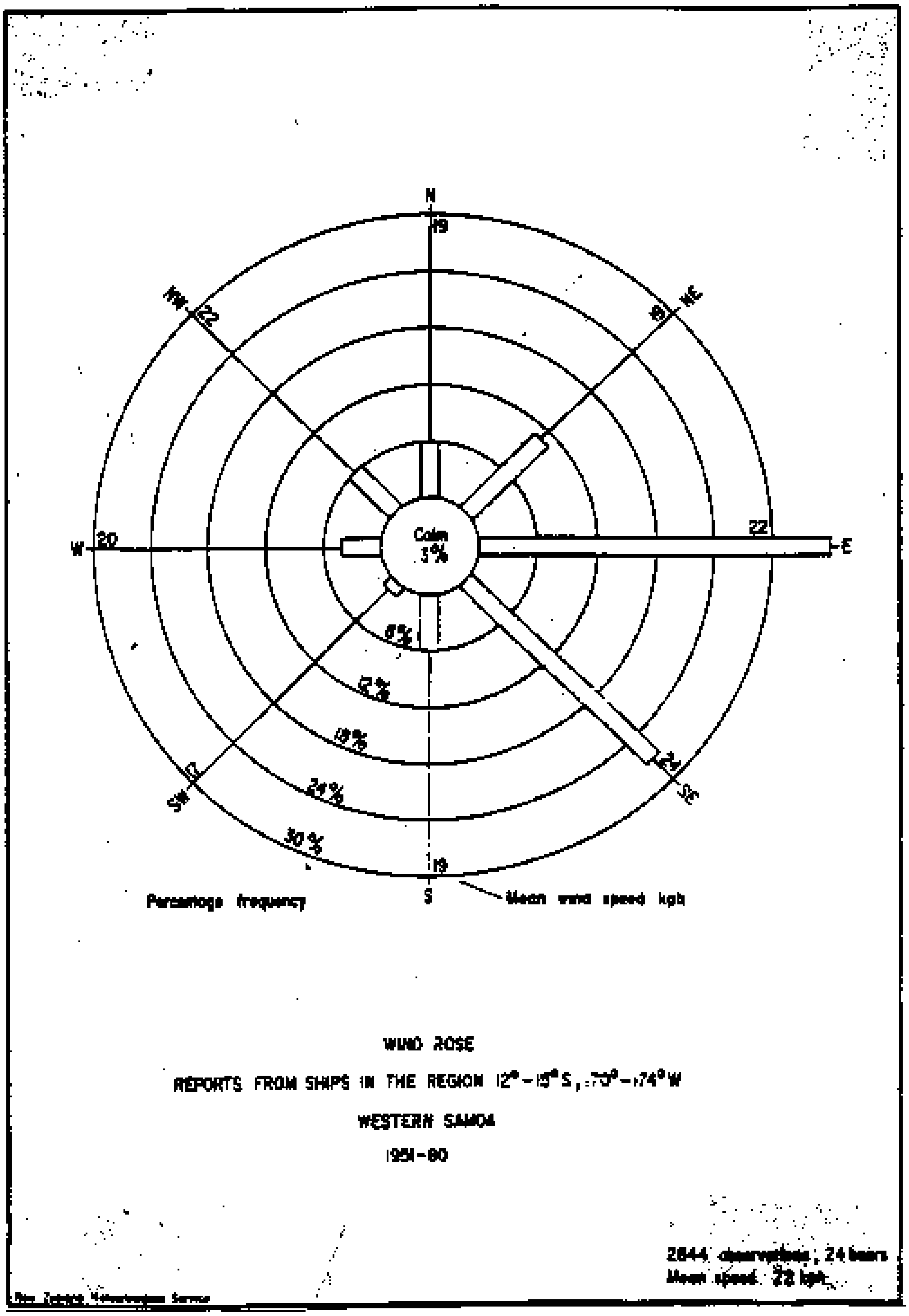

Figure 4. Wind rose for the years 1951-1981 taken from Holden (1991).

at about 50% of the time. Winds above 49 km/h occur less than 0.5% of the time. There are two main wind seasons in Western Samoa (Western Samoa Meteorological Office);

- June -October where trade winds prevail more than 50 % of the time (east and southeast winds).
- November - May where winds of greater distribution occur.

During the day time north-easterlies are more frequent on the northern coasts of Upolu and Savai'i while south-easterlies are more frequent on the southern side. A light southeasterly land breeze often prevails during the night on the northern side of the islands (and north-easterly on the southern side) (Burgess, 1987).

Mean wind speeds vary from 7 to 19 km/h in Western Samoa (Burgess 1987). Mean wind speeds at Apia are slightly higher between June and October than in other months, and are lower from March to May. Strong winds (greater than 40 km/h) from between southwest and southeast are uncommon on the northern side of the islands, mainly due to the sheltering by the hills in that sector (Burgess 1987). Most gales arise from cyclonic activity and are of short duration, occurring on average only once a year at Apia (Burgess 1987).

The northwest coasts of Upolu and Savai'i are drier than most parts of the two islands. This part of the islands get between 2200 and 2400 mm of rain annually (Kammer 1978). The highland areas receive about 5000 mm of rain annually.

With the exception of near-coastal and areas near the crest there appears to be a linear relationship between annual rainfall and altitude on the north and south slopes of central Upolu. The gradient is equivalent to 295 mm per 100 m (Kammer, 1978). In Apia the mean annual rainfall is given below in the periods as stated (Kammer, 1978).

Year period	**Mean annual rainfall (mm)**
1891-1977	2888
1891-1915	2666
1916-1940	3044
1946-1950	3417
1941-1965	2826

The record of cyclones traversing the 5 by 5 degree area around Western Samoa extends from 1831 to 1987 as presented in the list of cyclones (Pauga and Lefale, 1988). No data were found of cyclones occurring between 1891 and 1922. According to Pauga and Lefale (1988) no cyclones were reported either because higher scientific criteria were demanded before a blow might be termed a hurricane or, as a result of the switch from sail to steam.

Cyclone activity varies considerably between years and decades. For instance 11 events were recorded for the period of 1960 to 1969 whereas only 7 events for the following decade. An analysis of return frequencies of cyclones impacting the Western Samoan coast indicates that the average return period for a significant storm is about 7 years (Carter, 1987). There appears to be some connection between cyclone activity and the ENSO (El Nino Southern Oscillation) (N. Koop, pers. comm.). During ENSO events the frequency of cyclones declines, but the spawning area moves eastward and closer to Samoa so the chances of landfalls in the Samoan group are greater. In non-ENSO periods, more cyclones are spawned, but due to their point of origin they have less chance of hitting Samoa. Interestingly, during the very severe ENSO of 1982-83, the cyclone spawning area moved east beyond Samoa, so few cyclones were recorded in the vicinity.

The severity of the storms and their effect on the coast will vary considerably depending on the path taken and the duration. Major cyclones hit Western Samoa in the years 1990 (Cyclone Ofa) and 1992 (Cyclone Val); the latter apparently the more destructive of the two because of its longer duration and high winds. In contrast, although winds were high during Cyclone Ofa most of the destruction was accomplished by waves and high water levels.

Temperature in Western Samoa is almost constant throughout the year. The annual range in temperature is only 1 to 2°C throughout the islands, the mean daily temperature being about 26 or 27°C at sea level and 22°C at 700 meters decreasing at a rate of approximately 6.5°C per 1000 meters (Burgess 1987).

REVIEW OF PREVIOUS WORK

In order to develop an understanding of the coastal processes in the area of sand dredging around Apia, it was necessary to review and summarise previous work in region. There is an extensive “grey” literature in the form of consultant reports and SOPAC Technical reports on the nearshore and coastal regions around Apia and Mulinu’u Peninsula. Many of the reports are held at the office of the South Pacific Applied Geoscience Commission (SOPAC) headquartered at Suva, Fiji. Additional reports are held by the Western Samoa Department of Public Works, the Department of Lands and Environment, and South Pacific Regional Environment Programme (SPREP). In this section we have included short summaries of several reports which were deemed to be the most important. In several cases relevant reports were not available, and these have been noted. Where possible, the original data upon which the reports were based were scrutinised as well.

Hydrology

River discharges into Apia Harbour (Vaisagano R.) and Vaiusu Bay (Gasegase Stream and others) provide terrestrial clastic and organic material as well as pollutants to the receiving waters. Stream gauging of the Vaisagano River by the Apia Observatory is cited in Richmond (1991). Peak discharges of up to 186 m^3/s in 1976 at Alaoa East gauging station indicate that there is considerable potential to move sediments into the harbour. Using rating data from the Rio Grande River in New Mexico, Richmond estimates a potential sediment load of almost 46,000 m^3/day. This assumes that the sediment is available and that it is appropriately sized. Rubin (1984) provides independent estimates of flood stage potential sediment load at about 10,000 m^3/d. During the recent past, coarse sediments deposited at the mouth if the Vaisagano River have been removed by front loaders and used as an aggregate resource.

No information is available for the discharges into Vaiusu Bay. The smaller drainage areas and the low slope of the coastal plain in the downstream reaches of the basin suggest that only finer materials (clay, silt and fine sand) would be transported into the Bay. Protection afforded to the bay by the Mulinu'u Peninsula means that once deposited, the sediments are likely to remain in place. Large amounts of organic material are probably supplied by the mangrove swamp surrounding the bay. Estuarine peats may be present in the protected locations within the bay.

Sea Level

Sea level changes affect the coast by gradually altering the energy supplied by waves and currents. Under transgressive conditions (a rise in relative sea level), increasing water depths will generally cause erosion and retreat of the shoreline, although local areas may experience transient accretion and progradation. The rate of rise has significant implications for humans living along the coast. According to Richmond (1991), citing Bloom (1980) recent sea level has been rising at a rate of about 1 m/1000a and is attributed to tectonic subsidence. If this is true, then predictions of global sea level rise may cause an acceleration of the rate of erosion around the islands. Data presented by Nunn (1991) suggest that sea level rose to a maximum of about 2 m above present sea level 1300 years BP then fell to the present level. Both authors indicate that data is sparse. The difference between the two interpretations revolves primarily on the types of materials and the sites used for age dating. According to Richmond (1991) raised beach deposits and reefs used to support the emergence interpretations are within the range of present processes. In contrast, Richmond's reliance on the presence of pottery shards at the Mulifanua Ferry site as a submergence indicator is disputed by Nunn who contends that the shards show no signs of wear as would be consistent with time spent in the surf zone and their subsidence was therefore due to tectonics rather than sea level rise. Obviously more data is required to resolve the question of the late Holocene sea level history.

Waves and Water Levels

Deep water waves generated by cyclones can reach more than 10 m in significant wave height and, upon shoaling and breaking at the reef face the maximum height can reach 27 m (Carter, 1987). Wave reformation after breaking will result in waves of about 2 m propagating over the reef flat (assuming a storm water depth of 3 m. Refraction and frictional effects will result in a wave of approximately 1 m in height and a period of 3.5 seconds. A wind generated wave of 1 m will be generated based on the fetch over the reef flat; this combined with the reformed deep water wave will result in a maximum wave height of 2 m reaching the shoreline.

The tidal range at Apia is approximately 1 m on the spring tides. Actual water levels during storms are a function of wave set-up, storm surge (barometric tide plus wind setup), and astronomical tide. According to Carter's analysis, wave set-up is the greatest of the three and under 100 year storm conditions the total water level rise will be 2.3 m above msl. Since Mulinu'u Peninsula is 1-1.5 m above msl, significant submergence should be expected during a severe cyclone. A comparison between Cyclone Ofa (26 February ¾ 1 March 1990) and Carter's predictions is outlined in Rearic (1990). With sustained winds of 70 knots, Ofa produced a deep water wave height of 7.5 m and a maximum water level of 1.6 m which resulted in 0.5 m of submergence at the Apia Observatory. No observations of the wave heights at the coastline are available.

Bathymetry and Acoustic Stratigraphy

A subbottom survey was performed in Apia Harbour using an RTT1000 (Halunen, 1978). Virtually no subbottom penetration was achieved. The survey was restricted to the eastern side of the harbour immediately south of Pilot Point.

A survey was undertaken in 1981 to establish whether Apia Harbour was silting up (Gauss, 1981). The results were compared to the Royal New Zealand Navy chart index number 141S serial 49 (scale 1:5000). In addition to bathymetry and subbottom profiling, 72 grab sampling stations were occupied. The sediment distribution map indicates that the inner harbour area is floored mainly by silt and mud, whereas the outer harbour and entrance are floored by silty to medium sand. There appears to be a layer of fluid mud in the centre of the of the Inner Harbour which is transient. At the mouth of the Vaisagano R. the seabed forms a flat platform which is underlain by seaward dipping reflectors which may represent a form of delta progradation into the harbour. The raw data for the bathymetry, subbottom profiling, and sidescan sonar were not available for this study. In general, the bathymetry in the inner harbour slopes steeply down from the river mouth to about 10 m then slopes gently seaward to 21-24 m. There are some datum problems. If it is assumed that there is a 0.9 m datum shift compared to 1975, then the central and eastern parts of the harbour have silted up by about 0.9 m (90 cm/6 years = 15 cm/a). The subbottom profiling does not indicate any bedrock or reef within 25 m of the surface.

Rubin (1984) describes the bathymetry at Apia harbour and Mulinu'u Point based on surveys undertaken in 1984. At Apia Harbour, the objective was to ascertain whether or not the harbour was silting up. Seismic (boomer) profiles indicate that approximately 20 m of sediment has been deposited over the past 4000 years. The net rate of filling based on the area surveyed was estimated to be about 1500 m^3/a, although this rate does not include dredged material. The long-term shoaling rate is about 0.5 cm/a or about 30 times less than the short term estimate reported by Gauss (1981). Rubin estimates the potential sediment supplied by the Vaisagano River based on a calculation of its velocity at bank-full discharge (3-5 m/s). If the sand supply in the Vaisagano is unlimited, then it is competent to supply 10,000 m^3/day, or more than enough to supply the amount estimated for annual shoaling. At Mulinu'u Point a survey was undertaken to determine the volume of material present in the vicinity of the dredging site off of the northern tip of the Mulinu'u Peninsula and to profile the bathymetry in order to assist in the design of shore protection works. About 10 km of acoustics were run which included the dredged zone as well as the central portion of Vaiusu Bay. The dredged zone is deeply pitted and irregular with a maximum depth of about 3-4 m below the average seabed surface in the vicinity. He estimates that there are about 900,000 m^3 of material within 3 m of the seabed surface. In addition, the unit being mined extends to a depth of about 25 m below the seabed, so the reserves of material are quite high. However, a jet probing and sampling survey (Mata'afa et al., 1988) suggest that only 3-5 m of material overlie reef framework. This report estimates 1.1×10^6 m^3 of reserves. This agrees well with Rubin's estimate. Note that the bathymetry data from this cruise was not available.

As part of a program to estimate storm water levels and perform wave refraction analysis, four lines of bathymetry were run from Mulinu'u Point (Carter, 1987). Two lines ran essentially N-S across the reef flat and into a blue hole. The other two lines ran approximately E-W across the dredged area. The N-S lines indicate 1-2 m of water with an undulating bottom and, on the range 3 line, a blue hole was encountered with a maximum depth of about 22 m. At the start of the line across the dredge site there appears to be a series of 3 bars with a relief of about 0.5 m. They are very regularly spaced and may be a man-made artifact. Maximum dredge depths (uncorrected) are 4-5 m.

The report entitled “Apia Harbour Study” (Raudkivi, 1975) was not available.

Coastal Circulation

Dye tests were conducted during March, 1977 and float tests during June, 1977 (Hedgeland, 1977). These were titled stage I and stage II tests respectively. The stage I test involved dye release and air photography every several hours. Two results were carried obtained for each of high, ebb, low and flood conditions. No copies of the photographs were available to us. The results showed:

1. “poor currents seaward of the reef at Mulinu’u”;
2. “slow moving currents along the reef opposite Mulinu’u”;
3. “slow moving currents seaward of the reef at Taumesina and Vaiala” (east of Apia Harbour;
4. fast moving currents moving offshore and west in the harbour entrance.

Based on these results it was decided to conduct further tests within the harbour entrance. Float tests were performed at three sites in order to determine a location for a sewer outfall. The sites are outside of the east reef and about 500 to 1000 ft off of the main wharf. The tests involved releasing surface floats and drogues. Wind conditions comprised easterly winds at speeds up to 17 knots (31 km/h) and a range of tides from ebb to flood. The tests were conducted between June 8-29, 1977. Not all of the plots were available in the copy of the report held at SOPAC. Initial tests inshore indicated that during easterly winds the surface currents were directed onto the west reef (flow direction from east to west). The location designated as site 3 in Hedgeland’s report was selected as having very little shoreward drift; material would advance along the west reef front under conditions of easterly winds. No data was available for winds out of the north, when it would be expected that a sewage plume would flow inwards towards the city. However, Hedgeland suggests that north winds in excess of 13 knots (23 km/h) (those strong enough to cause onshore circulation) only blow for about 2% of the time so the lack of data is not considered critical.

In summarising Hedgeland (1977), Carter (1978) indicates that the winds were <6 knots and the seas calm for the March 1977 dye studies. Current velocities were typically 0.05 to 0.30 m/s with longshore currents outside the barrier reef (but <1000 m from the reef) of 0.3 to 0.49 m/s. Seaward directed currents in the harbour entrance were interpreted by Carter as resulting from return currents from behind the reef of water pumped into the lagoon by swells. Carter also cites a letter which states that turbid storm water from the Vaisagano and Mulivai rivers was diverted from the reef flats and lagoon by the reef current throughout the tidal cycle. The float studies confirm the dye studies according to Carter.

Following his summary, Carter reevaluated the Hedgeland data in terms of tide, wind speed and direction and swell. He found that winds <4.1 m/s (8 knots) result in little transport of floatables. Winds >4.1 m/s cause the development of Langmuir cells. Winds >6.7 m/s (13 knots) results in significant downwind transport at 0.22 m/s (1/30 windspeed in top 15 cm). Two tidal effects were noted during the experiments (under easterly wind conditions):

- high water and most of ebb
  Under low wind conditions (<8 knots) the current at near the East Reef is <0.08 m/s and the drift direction is easterly, back onto the reef.
- end of ebb, low water and most of flood
  Under low wind conditions, currents of 0.09 m/s set to the north/northwest
  Under high wind conditions (>8 knots), currents of 0.15 m/s set to north/northwest.

Swells increase the flow towards the reef on ebb. East winds >13 knots and swells caused an increase in current strength over times of no swell.

Carter performed additional surface current measurements in May, 1978 in order to collect data during times of north winds and to examine the disposition of floatables. His site ‘A’ is 46 m closer to the east reef than was Hedgeland’s site 3 in order to avoid conflicts with ship anchors. A floatables release occurred on May 11 during which winds were low except for a 4 h period of east wind between 10-12.6 knots. Subsurface drogues and spars indicated the same pattern as Hedgeland; surface floats moved at a higher speed. When winds freshened to 12 knots surface water was transported from the east reef over the west reef within 2.5 hours. Surface currents were between 0.09 m/s to 0.21 m/s.

During a May 18 release, under strong easterly winds, transport was observed into the west reef area and a zone of convergence was created just west of the reclaimed land at the head of the harbour. This zone of convergence forms during the daily slack water period. The following wind and tide cycle carried this material past Mulinu'u Point and into Vaiusu Bay. Current speed to the west was 0.15 m/s (1/31 of wind speed). 61% of floats were recovered from Mulinu'u and Vaiusu Bay within 24 hours of release.

A dye release during a northwest wind event (wind speed 8-14 knots) during the start of flood tide was observed to move north against the wind for 70 minutes, then in an easterly (downwind) direction. Surface drift speed was 0.12 m/s.

Sediment Characteristics

Within Apia Harbour sediments range from fine to medium sand to silt and mud (Gauss, 1981). Sand predominates in the outer harbour in water depths which are generally in excess of 8 m. Within the confines of the inner harbour (as defined by the main wharf on the east and the reclaimed land on the west silt and muds are most common except in the shoal areas and close to the mouth of the Vaisagano River. Richmond (1991) cites data collected by Mata'afa et al. (1988) which defines a shallow sub/intertidal delta at the river mouth. The river appears to drop its bedload within 150 m of the river mouth, beyond which mud is being deposited. In the cross section presented by Richmond (1991) there does not appear to be any progradation of the delta. In fact, muds are being deposited on top of previously deposited sand and gravel. This could be an indication that sea level is rising and drowning the delta. Alternatively it could be a recent deposit related to land reclamation and dredging. Gauss (1981) also identifies a fluid mud layer at the mouth of the inner harbour which is transient and may be deposited during a period of high river discharge. Sediments within the inner harbour are primarily terrestrially-derived volcanics with biogenic carbonates becoming increasingly important offshore.

Sediment distribution along the Mulinu'u peninsula and Vaiusu Bay is described in Richmond (1991), although the source of the information is not cited (it is probably from the field survey by Mata'afa et al. (1988)). In general, sediments coarsen from nearshore to the reef crest. The finest sediments are sandy muds associated with mangrove swamps along the nearshore coast in the lee of Mulinu'u Peninsula. The band of fine sediments is about 500 to 1000 m wide. Further offshore is a zone of “slightly muddy sand” which is mined for aggregate off Mulinu'u Point. The Apia concrete dredging activities are located within the muddy sand facies. Muddy sands are also found along the seaward coast of the Mulinu'u Peninsula. This facies grades seaward to coarse sand and then to coral at the reef crest. According to Mata'afa et al. (1988), the dredged materials consist of a mixture of back-reef calcareous sand, rubble and in situ corals with 20-30% terrestrially derived volcanic material. Jet probing was performed with a 3 m probe, so penetration was limited to that depth. The report concludes that the deposits being dredged overlie reef framework at about 3-5 m (the maximum depth of dredging operations). Shallow seismic data (boomer) collected by Rubin (1984) suggest that there is at least 25 m of unconsolidated sediment in the area. There is no information on the collection parameters of the seismic data, but there is considerable penetration of the seismic signal which would not be consistent with a reef framework environment. The Mata'afa et al. (1988) survey did collect come acoustic information, but it appears that only an RTT1000 subbottom profiler was used and examined briefly for this study; it appears that very little penetration was achieved. Thick deposits of sediment would be consistent with river discharge inhibiting reef growth. At this time, it is unclear whether the aggregate reserves at the site should be calculated using the 3-5 m thickness or the 25 m thickness. This may be a moot point depending on the depth capabilities of the draglines in use.

As part of a study of port development in Western Samoa (JICA 1987), bathymetric surveys were performed and a borehole was drilled west of the Mulinu'u Peninsula off Cape Ti'apepe. The borehole was sited within 200-300 m of the reef crest in <0.5 m water depth. It encountered 18.5 m of unconsolidated carbonate sand and coral fragments with a Standard Penetration Count (SPT) of less than 3 blows per 30 cm except at the base where the blow count was 9 blows/30 cm in firm sand.

Coastal Morphology and Stability

Coastal morphology and shoreline stability have been summarised by Richmond (1991) for all of Upolu, Western Samoa. He divides the coast into three types based on reef characteristics, depositional features, and inshore geology. Type I coasts have wide fringing reefs transitional to barrier reefs, with poorly developed coastal deposits consisting of mixed carbonate/terrigenous sediments and a hinterland of gently sloping Mulifanua and Salani Volcanics. Type II coasts are cliffed, with little or no reef and limited depositional features; cliffs are composed of either Holocene Puapua Volcanics (lava flow) or Plio/Pleistocene? Fagaloa Volcanics. Type III coasts are characterised by either (a) fringing reef with a narrow coastal strip of storm-derived carbonate (and some terrigenous) sand or (b) beaches, barriers, and coastal swamps associated with rivers and streams. Type III coasts are fronted by fringing reefs with prominent gaps where freshwater output is high. Inshore geology is predominantly Salani Volcanics and includes Lefaga and Fagaloa Formations. The study area consists of a combination of Type I and Type III coasts. Coastal erosion is typical throughout Upolu and is attributed to "direct wave attack" (Bakx, 1987); sea level rise, sand mining, poorly designed shore protection, destruction of vegetation (Richmond, 1991) and interruption of natural sediment pathways by land reclamation and shore protection (Holden, 1991). An additional factor not listed is a long-term trend towards increased storminess or natural variations in the number and severity of storms which produce large waves and high water levels.

Erosion measurements in the study area have been made by Carter (1991) and Bakx (1987). Carter's measurements were based on a combination of air photos (1970 and 1980) and field measurements made on 1 November 1990 (after Ofa). The study area was at the west-facing tip of the Mulinu'u Peninsula, north of the dredging causeway and south of the groin fields a distance of about 150 m). Although no estimate of errors is provided, the data suggest that erosion was greater for the period of 1970-1980, with a maximum of about 12 m of erosion for the total period. Deepening of the area immediately offshore from this area by dredging in the late 1970s is blamed for the rapid erosion by focusing waves on this section of coast and allowing larger waves to reach the shoreline; subsequent restriction of dredging activity to more than 300 m from shore in 1983 is credited with reducing the erosion rate.

Erosion on the reef-facing, northeast side of Mulinu'u Peninsula is described by Carter (1991). Failure of a rubble seawall constructed in 1962 is attributed to erosion of both the footing and backfill allowing settlement of the rock and wave attack at the shoreline. The exact location of the failed seawall is not noted. West of the Apia market, in front of the Tusitala Hotel, the vertical seawall is also cited as being in danger of failure as a result of exposure to large waves from the harbour mouth and a reduction in the supply of volcanic sediment by the land reclamation project immediately to the east. No mention is made of the role of dredging immediately in front of the seawall during the construction of the Tusitala during the 1970s?? Recommendations are made to install shore protection works along the exposed shoreline of the Mulinu'u Peninsula where necessary; to construct a seawall on the west end of the Mulinu'u Peninsula to bring the shoreline back to the 1970 position; and to consider reclaiming land along the seawall in front of the Tusitala to protect the road.

Bakx (1987) performed erosion estimates from air photos along several stretches of coastline (including the study area) using photos from 1970, and 1981. Errors were estimated to be about 2.5 m using photos at a scale of 1:5000. They identified difficulties in tracing the coastline due to clarity and contrast in the photos as well as masking by trees. He found that

415 m of shoreline on the western side of Apia Harbour (presumably the Mulinu'u Peninsula) retreated at a maximum rate of 0.9 m/a over an 11 year period.

History of Human Activities

Dredging and Beach Mining

Small scale mining of beaches has been practised in Samoa for a considerable time. It is presently done by individuals, families or villages with shovels and cars. People have been observed mining sand caught on the updrift (east) side of groins at Mulinu'u Point. Large scale dredging adjacent to Mulinu'u Point commenced sometime after 1970; the exact date has not been ascertained. According to Carter (1991), between the years 1970 and 1983 sand and gravel was mined to a depth of about 8 m within a few metres of the shoreline (Carter, 1991). Shoreline erosion concerns resulted in a recommendation that dredging be restricted to a distance of 300 m from the western end of Mulinu'u Point. Nearshore dredging was discontinued in 1983 (Carter, 1991). During the years 1979-1980, a commercial dragline (1.5 cu. yd) and a government owned 0.75 cu. yd dragline were being used to dredge 260,000 cu. yds of aggregate in 2 years. The material was used to produce 52,000 cu. yds of screened sand (Carter, 1991). An additional 219,700 cu yds was dredged to build a causeway for further dredging and a private operation dredged 19,300 cu. yds in the same 2 year period for a grand total of 490,000 cu. yds. Recent estimates of dredged volumes (Mata'afa et al, 1988) are on the order of about 30,000 m^3/a (~40,000 cu yds/a); the amount certainly varies from year to year with the demand. It is expected that demand increases after severe storms. A conservative estimate of the dredged volumes in 15 years of operations (as of 1990) is 28,000 m^3/a or a total of 420,000 m^3. The material is a poorly sorted silty, sandy gravel derived from both reef and terrestrial sources.

A second, much smaller scale operation is located west of Mulinu'u Peninsula at Apia Concrete Products, where 8000 m^3/a were mined over an 8 year period (to 1990 ¾ Richmond, 1990). There appears to be a discrepancy between the start of mining as cited by Richmond (8 years prior to 1990) and the presence of the dredging causeway in the 1980 air photograph. Here the deposits are similar to those at Mulinu'u Peninsula except that they are overlain by about 1 m of fine sediment. According to an oral communication cited by Richmond, the dredged areas are partially infilled after storms by westward flowing currents.

In the 1970s the Tusitala Hotel was constructed at the proximal end of the Mulinu'u Peninsula. During the course of the construction, sand was dredged from in front of the hotel site on the reef flat. The volume of material dredged is not known although personal communications suggest that dredging down to depths of 3-5 m occurred within 100 m of the shoreline directly in front of the vertical seawall considered to be in jeopardy by Carter (1990). Dredging has taken place in the harbour in order to perform land reclamation and to maintain navigable depths. Flood material deposited in the harbour at the mouth of the Vaisagano River is removed regularly by heavy equipment. Most recently dredging has been initiated on the reef flat in front of Le Godinet Beach Hotel on the Mulinu'u Peninsula. A small cutter head suction dredge is removing sand within 30 m of the shoreline and pumping it behind a breakwater in order to form an area of reclaimed land west of the bus parking lot and in front of the vertical seawall and the Tusitala Hotel.

Land Reclamation and Shore Protection

Major dredging and construction began in Apia Harbour in 1964 (Gauss, 1981) when the main wharf was constructed and the land area to the west of the Inner Harbour was reclaimed. This land reclamation included creation of the bus parking lot and the land on which the produce and fish markets are built.

An extensive Japanese-funded project to protect Apia Harbour and the Mulinu'u Peninsula is presently underway. It consists of a rubble mound seawall along the entire perimeter of the Harbour to the end of the Peninsula. Not having seen the design or the engineering specification, we can only comment on the parts which have been constructed as of 3 December 1993. On the east side of the harbour close to the port facilities the seawall has a slope of about 30° and is composed of boulders 0.3-1 m in diameter. There is a cement cap extending 1 m above the sidewalk and road; grated drains are provided every 15-20 m. The seawall extends approximately 2.5 m above the high tide line. There appears to be finer material beneath the boulders, but it is difficult to see. Towards the west, where it is more exposed to the southerly directed swell, the seawall rises to a height of about 3-4 m above the high tide line. The average boulder size is 0.5 m and the slope is estimated to be slightly steeper than to the east (about 35-40°). In front of the reclaimed land in front of the clock tower, the seawall is about 2.5 m above high tide with a 20° slope and an average boulder size of about 1 m (up to 2.5 m). Construction is presently concentrating in this area. Additional construction is occurring at the market reclamation (as described above) and along BP beach. At the beach, basalt boulders are being dumped along the shoreline, presumably in preparation for placement. It is not known whether a concrete cap will be used along the entire design length. There does not appear to be an filter being applied beneath the boulders at the beach.

From the west edge of the reclaimed land to the west end of the produce market (including the small boat anchorage and the fish market) protection is provided by a vertical concrete seawall of unknown age, but probably of pre-World War II vintage. Along the seaward edge of the bus parking lot a rubble mound seawall of small (<0.5 m) basalt boulders is topped by a series of small shops on pilings which extend slightly beyond the seawall. These shops were all destroyed by cyclone Ofa in 1990, but they have since been rebuilt.

Along the road behind the present reclamation project, an old vertical concrete seawall rests on a bed of sand and basalt boulders. The footing is exposed for its entire length and at several places there are small holes in the roadbed immediately behind the wall. This may be evidence of subsidence caused by removal of material at the base and behind the wall. Approximately 10-15 m of the wall have been rebuilt recently (not sure when).

OBSERVATIONS

Methods

Beach and nearshore observations were undertaken during the course of a six day field trip to Western Samoa (29 November to 4 December 1993). Descriptions of beach and coastline morphology and materials were made based on informal field surveys. Reconnaissance-level snorkelling surveys on the reef flat were performed at the Apia Observatory and from Le Godinet Hotel to Curry’s Gap. These informal surveys are documented photographically. Drilling was performed on the Apia Observatory Grounds using a government rotary water well drilling rig.

Beach Observations December 1993

The east (seaward) side of the Mulinu’u received the most attention, partially because it is the most active environment and partially because of the nearshore dredging operation occurring on the reef flats. The Peninsula beaches have all had some form of seawall shore protection in the past. In most cases the seawall consisted of piles of small (0.2-0.3 m) basalt boulders presumably placed over the toe of an eroding bluff or in front of tombs and houses which were threatened by erosion. Under storm conditions, these structures were either undermined and/or overwashed and collapsed. In some cases, the seawalls were dramatically overstepped and are now seen 10 or more metres offshore from the present coastline.

The beaches are often backed, at the top of the high tide line, by a vine locally known as fue. It is also present within basalt boulders where these form the upper beach. The fue establishes itself rapidly and acts to hide the extent of vegetation retreat after storms when mapping from air photos. While the entire coastline of the Mulinu'u Peninsula appears to be retreating, there are zones with accretional tendencies. Low tide beaches in the accretional zones (e.g. BP tank farm) are 10-15 m wide with a slope of about 8°. The sand is coarse and predominantly carbonate at BP Beach, but is more volcanic at beaches further updrift. Below the low tide step the slope flattens abruptly and there is a gravel lag present at the base of the beach. Large mats of sea grass are found just offshore from the BP Beach and the water depth over the grass is about 0.25-0.5 m. This vegetated zone represents an area of accretion or stability. Stabilisation by vegetation in front of the beaches may act as a buffer against storms, but it may also prevent sand from reaching the beaches from the reef flat. The water depth just offshore from the grass mats is slightly greater (0.75-1 m) then slopes gently up towards the reef crest and cyclone banks.

The width of the nearshore grass mat zone decreases proceeding northward from the BP beach. Thus, the width of the zone of stabilised or accreting material is decreasing in the erosional zone to the north. Its width reaches a minimum just north of the Falefone where it becomes difficult to trace. It is replaced by a series of vegetated banks at the toes of the beaches just below the low tide line.

The series of groins in front of the Apia Observatory have effectively trapped sand on their updrift sides. Since Cyclone Ofa, the shoreline has retreated to the point where at least one of the groins is no longer attached and is acting like an offshore node with a tombolo formed behind it. Beach sediments are dominantly volcanic (60-90%) and coarse to granular in size with occasional rounded volcanic pebbles and angular fragments of coral. At the base of the swash zone is a lag accumulation of oblate volcanic pebbles and angular coral fragments overlying poorly sorted fine to coarse grained silty sand. The lag zone slopes seaward at about 3° whereas the beach slopes much more steeply (>10°). Seaward of the lag zone is a burrowed zone without pebbles and which contains a fine grained sand component which is all carbonate sand and a coarser grained sand which contains about 50% volcanic particles. This grades seaward into a subtidal zone of aquatic plants (leafy seaweed) in poorly sorted, muddy carbonate sand with volcanic granules.

A moat or shallow channel about 50 m wide is present just seaward of the vegetated banks and the ends of the groins at the Observatory. The moat is up to 0.5 m deeper than the surrounding banks and reef flats. It extends southward and becomes difficult to follow around the BP tank farm. Its origin is unknown, but it may represent a tidal channel. Flood tidal currents within the channel are much stronger than ebb currents (D.A.P. Muller, pers. comm., 1993). Within the past 15 years the channel was used by small boats entering near the market. There were no current-formed features in it during the one week of field work, but that does not preclude activity during storms or spring tides.

At the northernmost groin a small spit platform of coarse grained carbonate and volcanic sands is growing from the end of the groin. Along the palm-fringed, northwest facing coast the lag zone is only present in the vicinity of the groin. Further along the coast, towards the dredging causeway, the beach consists of an intertidal swash zone with muddy sand at the low tide line. Volcanic and carbonate sediments are present in approximately equal amounts. The palms along the beach are being actively undercut; any remaining seawall has been bypassed. Coral material, probably emplaced during strengthening of the groins and seawalls during the 1970's (D.A.P. Muller, pers. comm., 1993), shows a distinct alongshore trend from coarse (20 cm) close to the groin to finer (5 cm) towards the dredging causeway indicating a north to south component of longshore drift which may have occurred during cyclone Ofa. South of the causeway, dredging by Public Works has completely removed a spit which was present in the 1954 air photos. Dredging down to a depth of about 8-9 m occurred within several metres of the shoreline (Carter, 1991).

Drilling

As part of this study two holes (BH1 and BH2) were drilled at the end of the Mulinu'u Peninsula on the Apia Observatory grounds using a rotary drill rig. The reason for drilling the holes was to explore the possibility that there was some structural control on the morphology of the Mulinu'u Peninsula; in particular, whether bedrock (coral or basalt existed within the upper 5-10 m. The holes were within one metre of each other, the second drilled to confirm the findings of the first. The boreholes showed that there is no bedrock down to a depth of 7 m at that location. The uppermost 2 m consisted of a gradational fining-upward sequence of equally mixed carbonate and volcanic sand, with coral fragments and volcanic pebbles becoming more abundant at the base of the section. The remainder of the core was difficult to interpret due to the abundance of washed material and the poor recoveries of fine material. However, it is reasonably certain that the next 1.5 m consists of volcanic gravel with coral fragments in a fine-grained sandy mud matrix. The upper portion of each core section was washed gravel with a 10-20 cm recovery of muddy material. It is believed that the washed material was a result of using water to drill down the casing. The remainder of borehole 2 (3.5 m to 4.5 m) is carbonate sand, muddy in part with coral rubble and virtually no volcanic component. In BH1 the interval from 4.2 to 7 m was penetrated in one shelby tube push, so that bulldozing of the material below 5 m occurred. Penetration was easy, so that the material was obviously soft, but its composition was not ascertained.

Beach Profiling

Beach profiles were surveyed as part of an in-country training seminar on beach monitoring (Howorth and Woodward, 1993). Profiles were measured at 8 sites along the Mulinu'u Peninsula and several profiles were measured over the cyclone banks. The beach profiles can be grouped by type into three sets. Profiles 1 to 3 (Figure 5) are in the area identified by air photo analysis as relatively stable to accretionary and are characterised by an indistinct, shallow (<1 m) moat within 30 m of the shoreline and a maximum depth of 1.59 m (at the outer end of P2); all three show a generally increasing depth in their outer portions. P1 is notably shallower (<1 m) throughout; it traverses the vegetated sand bank offshore from Le Godinet Hotel. The bank is therefore a positive morphological feature. Profiles 4 to 6 (Figure 6) are in the zone described as erosional and include the groin field at the Apia Observatory. These profiles have a distinct moat within 30 m of the shoreline with depths > 1 m and a maximum depth of 1.5 m. There is a tendency for depths to decrease with distance from the moat which is 30-50 m wide. The third set of profiles (P7, P8) (Figure 7) was measured off of the west end of the Peninsula facing the Mulinu'u Point dredging operation and approximately parallel to the dredging causeway. The beaches slope steeply to a bench at -1.5 m water depth at about 50 m from shore, the profile then drops abruptly to -2.5 m within 100 m of the shoreline. The depth and steepness of the drop-off surely represents the presence of a dredged area approximately 100 m from the present shoreline. Its age cannot be ascertained.

The cyclone bank profiles all have a similar shape with a maximum height of up to 1.5 m above mean sea level; the maximum height is located at the seaward edge. The bank slopes are about 7-10° on the landward side and 15-20° on the seaward side. Original observations by Rearic (1990) indicate that landward slopes of 40° have been considerably modified, however seaward slopes were similar to those observed in 1993. It is possible that wave reworking of the seaward side occurs during or soon after deposition, whereas the landward side is modified by a combination of small waves and creep. Observations by a knowledgeable resident suggest that the height of the banks was reduced by about 2/3 during cyclone Val in 1992. This agrees with original estimates of 2-3 m height (Rearic, 1990). Estimates of bank width by Rearic (1990) are in rough agreement with the present widths.

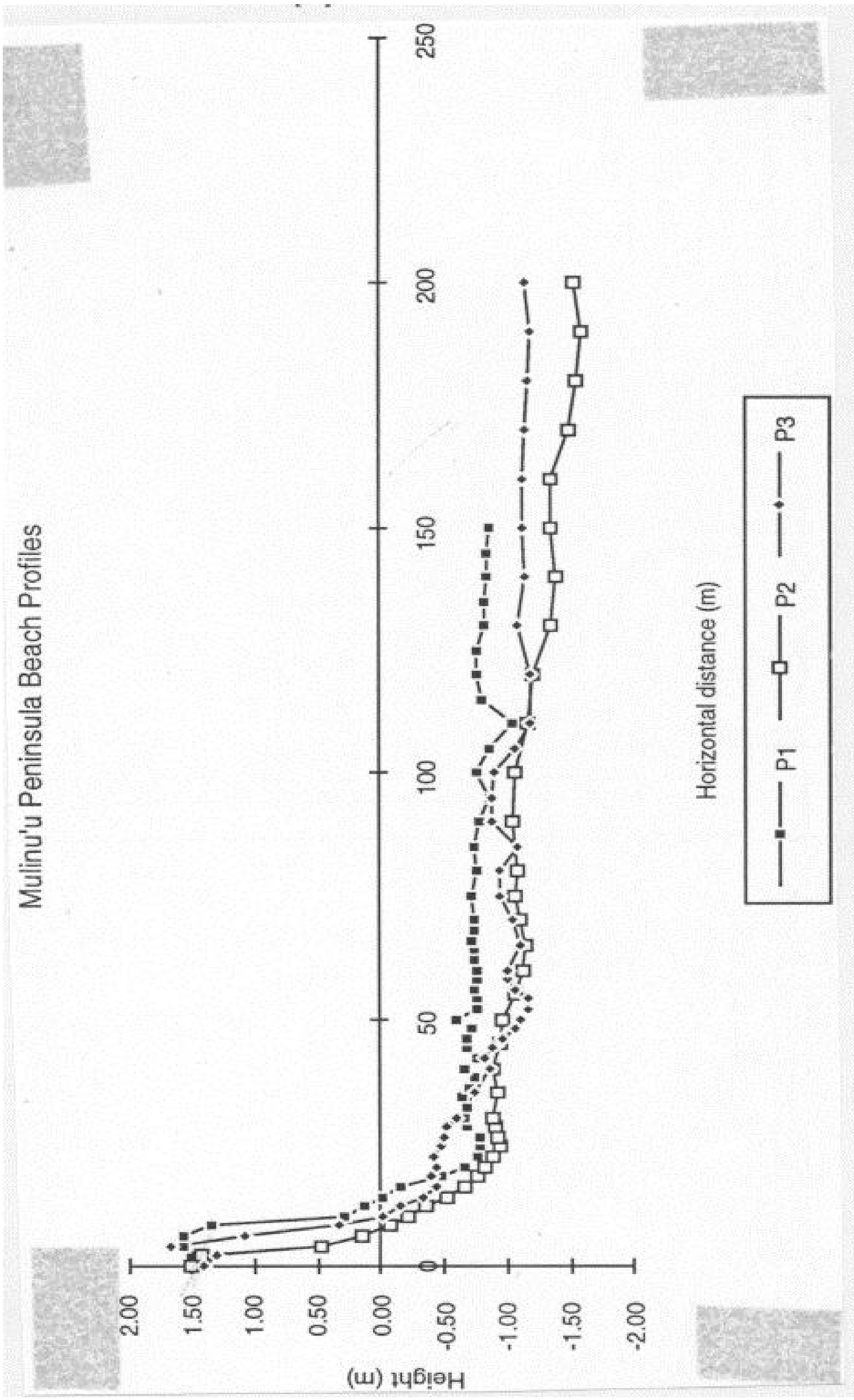

Figure 5. Beach profiles 1, 2, and 3 from the relatively stable proximal end of the Mulinu'u Peninsula. Note the difference in average water depth at P1.

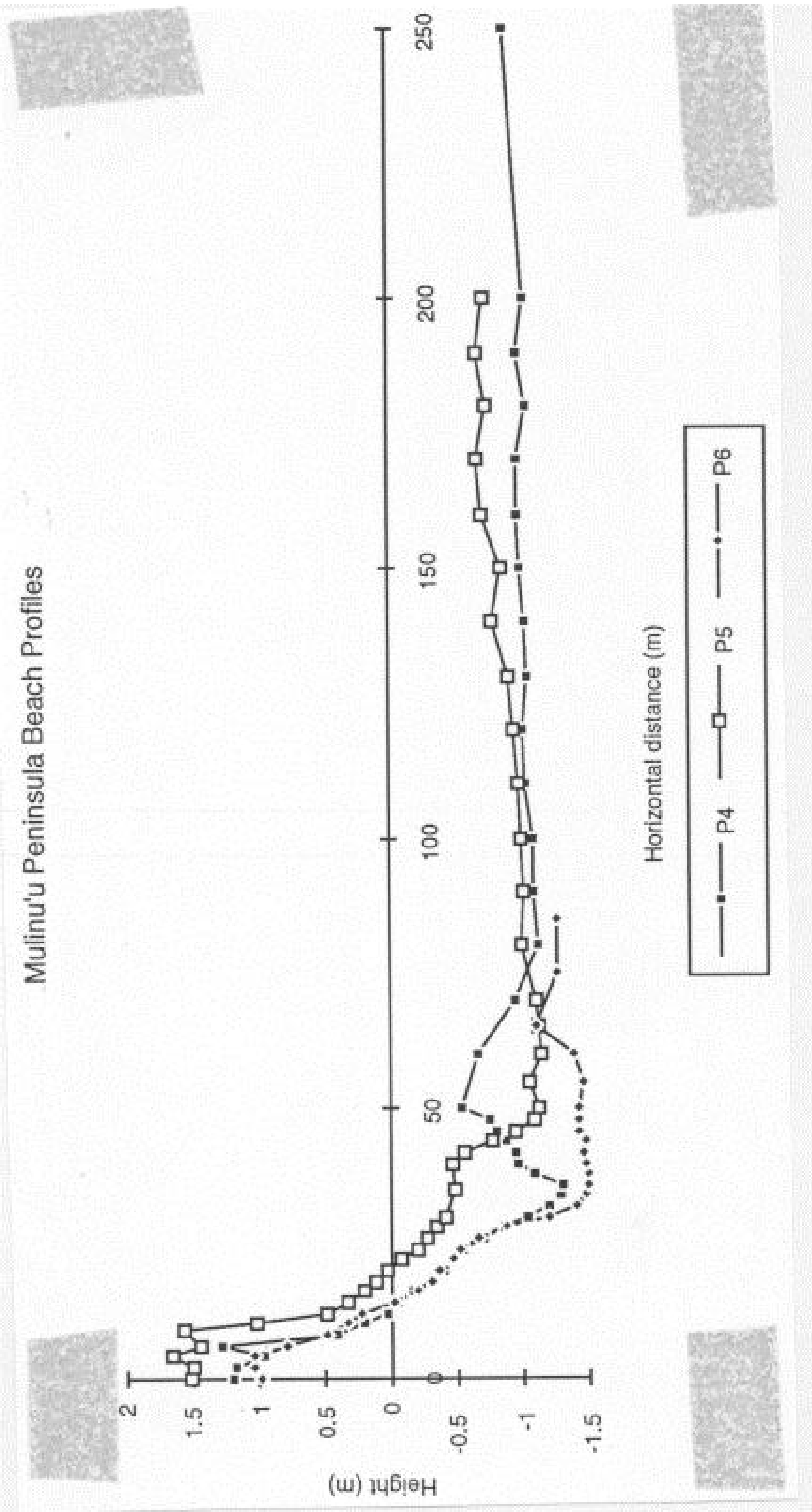

Figure 6. Beach profiles 4, 5, and 6 at the distal, more erosional end of the Mulinu'u Peninsula. There is a moat at the base of the beach which represents the deepest part of the profile.

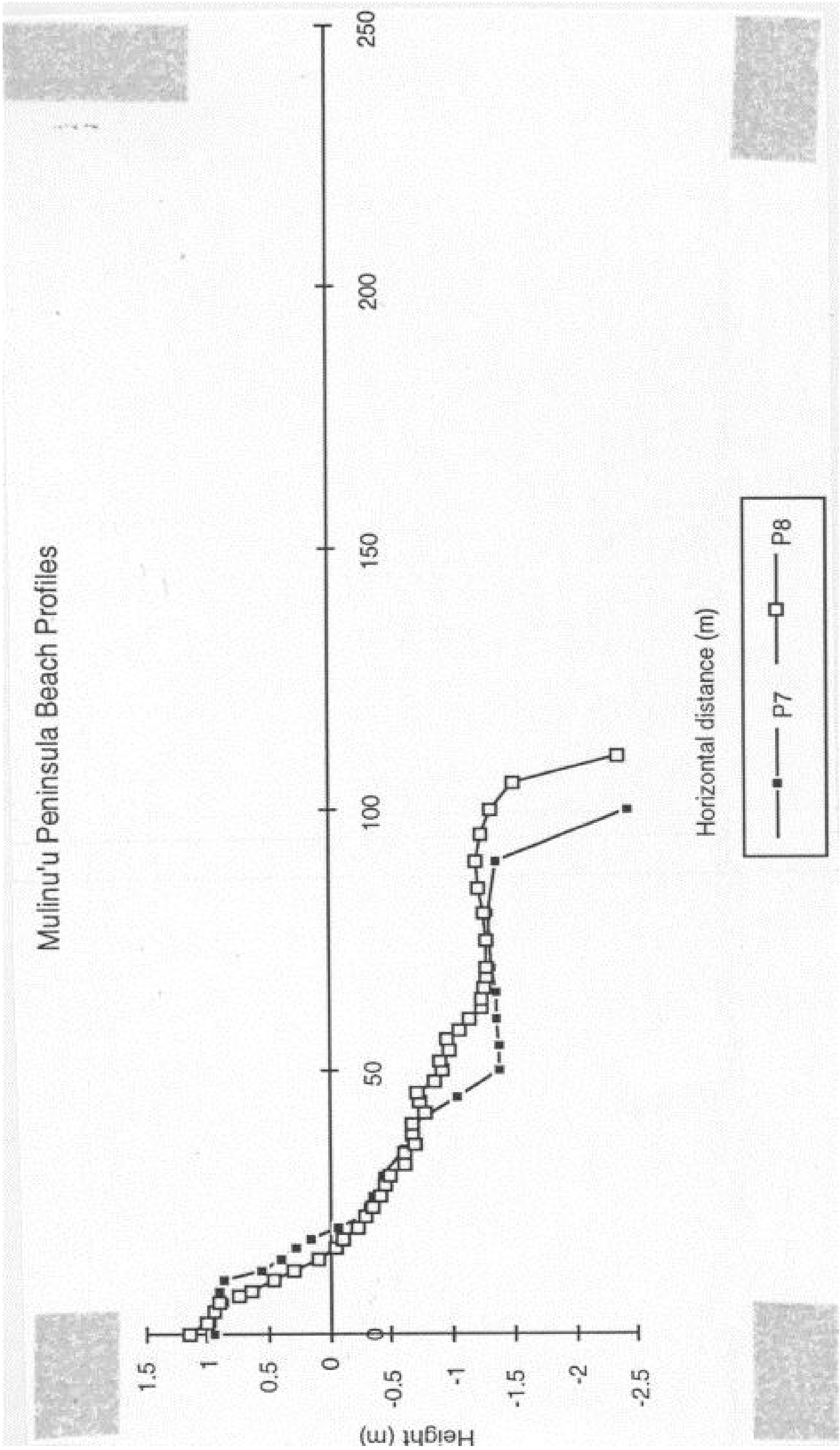

Figure 7. Beach profiles 7 and 8 at the west end of the Mulinu'u Peninsula facing the dredging operations and roughly parallel to the dredging causeway. The steep drop-off at the end of the profile represents a dredge hole within 100 m of the shoreline.

Qualitative Coastal Change (air photo analysis)

Mulinu'u Peninsula, Apia Harbour and Moata'a - 1954 (Figure 8)

In 1954 very little development had taken place along the Mulinu'u Peninsula. At the Apia Observatory, the groin field consisting of 4 rubble groins with a spacing of about 30-50 m ending at the Point was in place. There was well-developed sedimentation on the up drift side and bypassing occurring around the ends. A recurved spit is seen developing off of the end of the peninsula and the Ulberg aggregate deposit appears as a localised area of shoal water. Sand shoals are present along the east-facing shoreline at several locations. A dark band of water immediately off the coast at the northwestern end of the peninsula along its east facing shore may represent a moat of deeper water and/or a zone of dense sea grasses. Bands of dark and light water probably denote varying densities of vegetation which in one place appear to define a lineation leading toward the reef opening informally known as Curry's Gap. The reef flat area south of the present BP tank farm consists of an extensive mobile sand blanket with little vegetation and large scale bedforms elongated parallel to the coast. The bedforms suggest onshore movement of material. This material is likely to be the source of the shoals present along the shoreline. A tide gauge hut can be seen on the reef flat off the Apia Observatory in an area which appears to consist of algal cemented flat with a patchy sand cover. According to Philipp Muller (former director of the Apia Observatory) this site was occupied by thickets of live branching coral which had to be cleared away when the hut was constructed. At the present time (December, 1993) there is no live coral, only a few microatolls with rubble and sand on the seabed.

On the southwestern side of the Peninsula, land reclamation was not yet extensive, however, it is difficult to ascertain how much of the natural spit form has been retained. As mentioned above there is a recurved portion of the spit which appears to be related to deposition of westerly directed longshore drift. In addition there is a easterly trending spit off the tip of the peninsula which may be caused by eastward flowing currents caused by less frequent north and west winds.

Port and land reclamation has not yet commenced in the Harbour at the time of the photography, however, several wharves are present off the area now occupied by the market. Although no sediment is seen accumulating against them, these wharves would have been an effective barrier to sediment movement alongshore from the east (e.g. from the Vaisagano and Mulivai Rivers). Much of the harbour appears to be protected by either vertical seawalls or rubble revetments.

Figure 8. 1954 air photo of the study area.

It is interesting to note the presence of a Mulinu'u-type of spit developed at Moata'a. In this case, the lagoon is virtually filled and protected from the easterly winds by the barrier spit. As in the case of the Mulinu'u Peninsula, the source of the spit is not an eroding headland. The source appears to be a combination of erosion of an east facing coast further to the south, and sand derived from the reef flat. It would be interesting to compare the composition of the spit material to the Mulinu'u Peninsula.

Mulinu'u Peninsula, Apia Harbour, and Moata'a - 1970 (Figure 9)

The photography available for this study consists of a single high level (approximately 1:40,000 scale) frame. The most obvious changes at this scale are the harbour developments. The large land reclamation just east of the present market had been completed as were the port facilities on the east side of the harbour. Sand shoals still appear along the shoreline for about 2/3 of the length of the east-facing side of the peninsula. The mobile sand sheet south of the Mobil tank farm is also present. The Mobil tank farm has been built and the BP tank farm was under construction at this time. Land reclamation appears to be underway at the Falefono site and much of the east trending recurved spit has disappeared (presumably by dredging). The tide gauge hut on the reef flat is barely visible and still appears to be in a zone of patchy sand cover. The Moata'a site appears to be unchanged since 1954.

Mulinu'u Peninsula - 1980 (Figure 10)

The dredging operation at the tip of Mulinu'u is well established at this time with causeways extending more than 0.5 km from the shoreline. The Falefone has been constructed and there is considerable infill of the lagoon behind it. The groins at the Apia Observatory appear to have a rubble seawall behind them. Sand continues to be trapped on the eastern side of the groins indicating a net longshore transport from east to west consistent with trade wind direction. On the exposed eastern side of the peninsula the sand shoals look somewhat less well developed than in previous years. There is a prominent line of semicircular sea grass meadows about 100 m from the shore which roughly define the edge of the moat seen in the 1954 photo. These appear to trend away from shore opposite the BP tank farm towards the reef opening at Curry's Gap. The mobile sand sheet opposite the Mobil tank farm is present but appears to be reduced in size. The Tusitala Hotel has been constructed by this time at the proximal end of the Peninsula. During its construction, material reportedly was dredged from the area immediately offshore the shoreline to depths of several metres. A darkened area of apparently deeper water may represent the

Figure 9. 1970 air photo of the study area.

dredged zone. The tide gauge hut on the reef flat is visible, however, the reef flat appears to have a more continuous cover of lightly vegetated sand at this time.

Mulinu'u Peninsula - 1985

In 1985 coastal video was flown starting on the east side of Apia Harbour and out along the east coast of Mulinu'u Peninsula. The video survey did not extend into Vaiusu Bay, but continues along its west coast from a point opposite from the dredge causeway. The detail in the video is helpful in clarifying certain aspects which were uncertain in the photography. Beginning at Apia Harbour, Vaiala Beach, east of Pilot's Point is unprotected and consists of a white beach backed by vegetation. The spit projecting from Pilot's Point is intact. From the market north to the BP tank farm there is a rubble seawall. North of the BP tank farm there is a narrow beach backed by large stands of trees. Houses are built immediately behind the beach and many of them are fronted by informal seawalls consisting of basalt boulders dumped on the beach. From a point just south of the observatory grounds there is a section of overstepped seawall which identifies a former coastline. A grave at the coast is being threatened now that it is directly exposed to the sea. The groin fields at Mulinu'u Point begin at the Apia Observatory grounds. In 1985 they are intact and attached to the beach. They all exhibit accumulation on the eastern side and lesser accumulation on the west side indicating the dominant transport direction as being from the east. Beyond the last groin there is no protection and the beaches are narrow and exhibit a low wave cut notch into the Tafanamagu (Holocene) sands.

Along the west side of Vaiusu Bay, there are no beaches. Mangroves extend into the shallow and bedrock (basalt?) is seen occasionally outcropping on the coast. The Apia Concrete Products dredge causeway is well vegetated along its flanks attesting to the stability and quiescence of that environment.

Mulinu'u Peninsula, Apia Harbour, and Moata'a - 1987 (Figure 11)

A single small scale (about 1:50,000) frame was available for this study. A vegetation-defined channel (?) is seen trending towards Curry's Gap on the east side of the Peninsula. Dredging continues from causeways at the tip of the peninsula and southward along the sand flats on the Vaiusu Bay side. The dredging in the latter location appears to be done utilising small suction dredges rather than draglines. Much of the original form of the distal end of the peninsula is obscured by dredging at this time. The tide gauge hut is not visible at this scale. The scale of

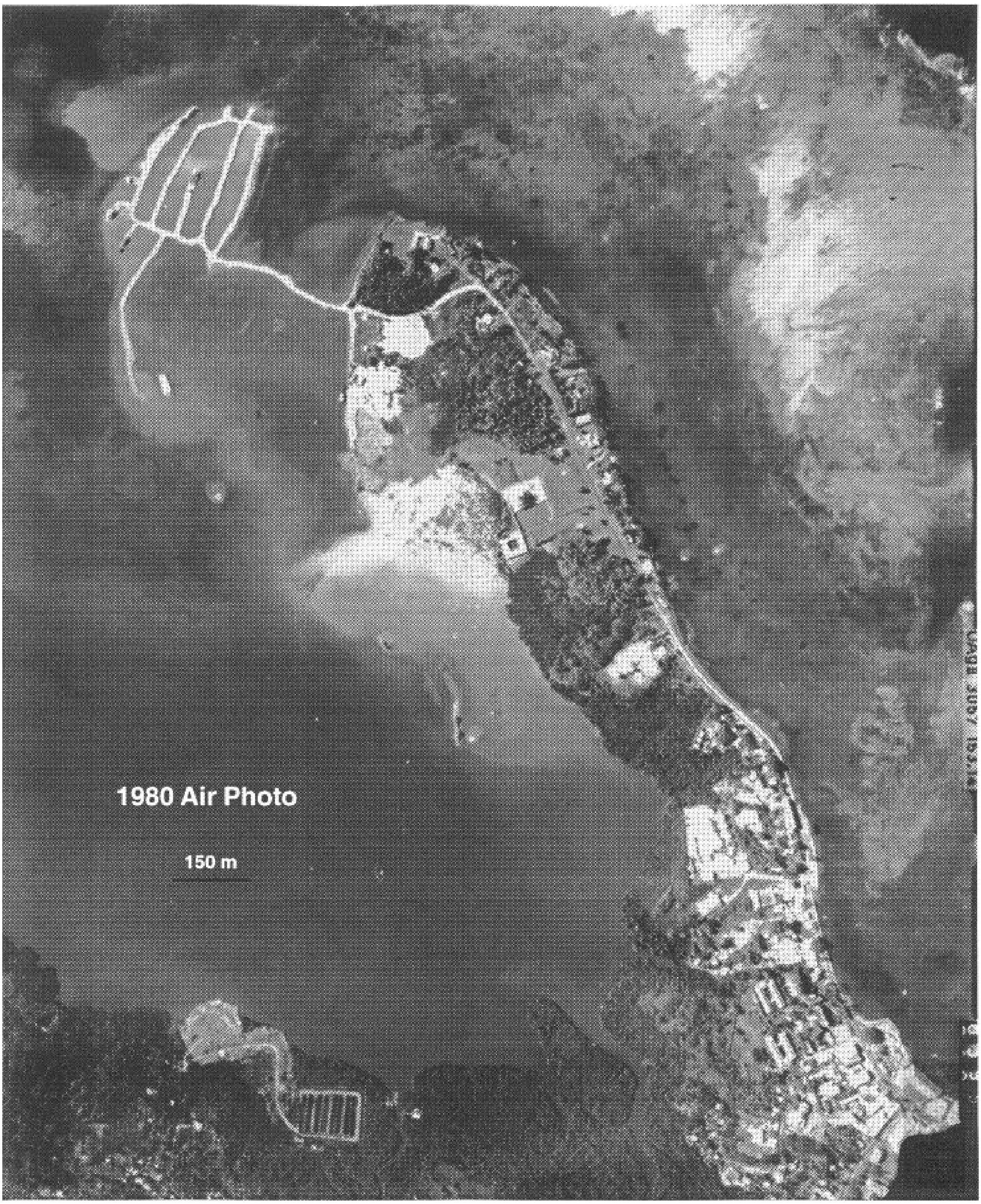

Figure 10. 1980 air photo of the study area.

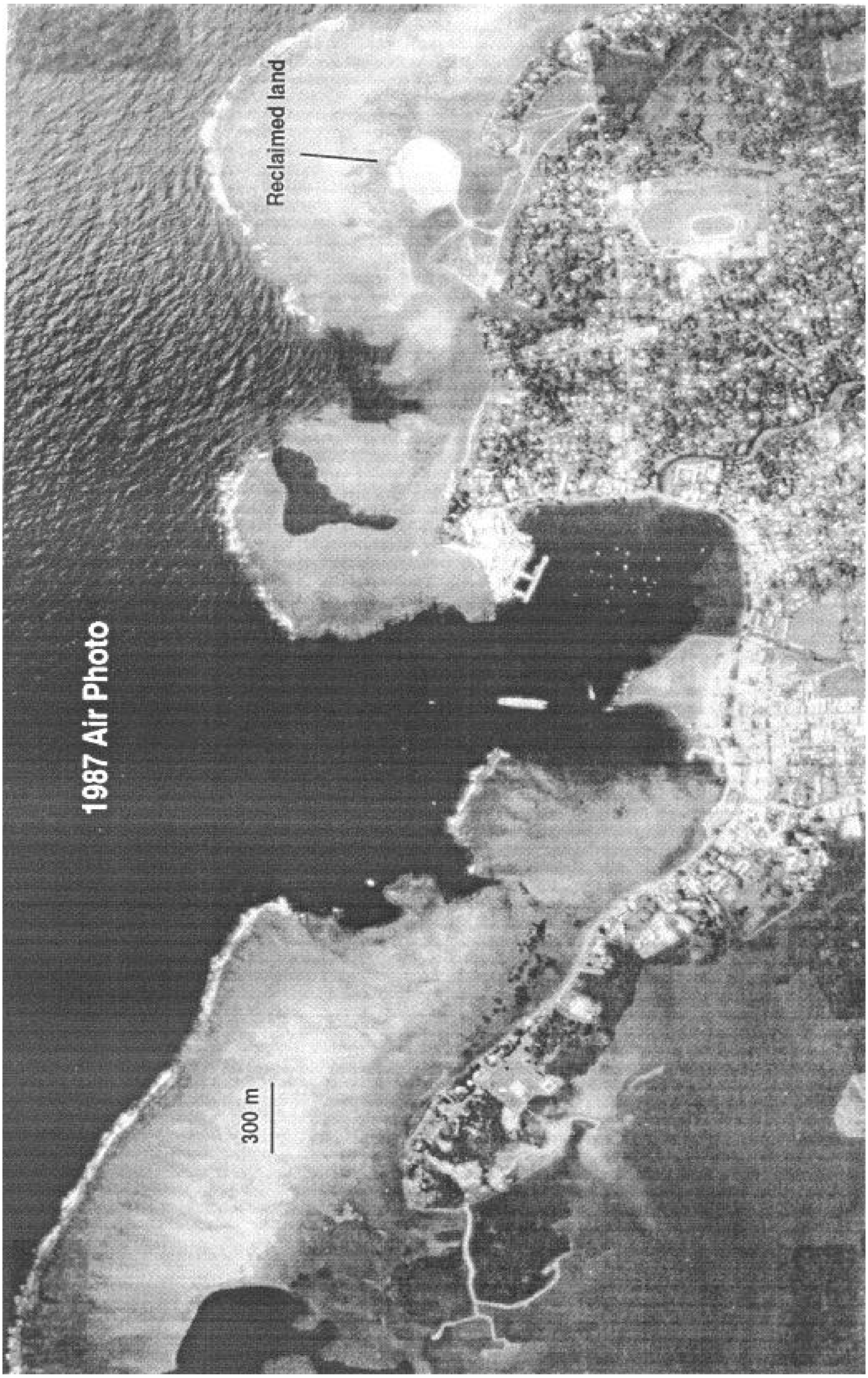

Figure 11. 1987 air photo of the study area.

the photography precludes detailed analysis, however, changes in the Moata'a area are worthy of mention. A large area of reclaimed land is visible just north of the end of the Moata'a Peninsula. This area was reclaimed for hotel construction, probably by dredging the sand from the adjacent reef flats. The infilled lagoon has been drained and the river diverted through an channel cut at the proximal end of the peninsula.

Mulinu'u Peninsula - 1990 (Figure 12)

The 1990 photography was flown several months after Cyclone Ofa struck the coastline. Considerable change had been wrought since the 1980 photography; the extent to which the changes are attributable to the cyclone is not known but reports of cyclone damage due to high water levels and waves suggest many of the changes are cyclone-related. Proceeding northward along the exposed east coast of the Peninsula, the shore protection works dominate. There have been 2 rubble groins added in front of the Mobil tank farm which indicate longshore sediment transport from east to west. The unprotected tree-backed beach is now devoid of trees apparently cut down for aesthetic or construction purposes). The groin field at the Observatory has become detached from the coast as a result of coastal retreat. Most of the sediment between the groins has been removed or moved so that it is attached to the groins giving the suggestion of tombolo or pocket beach formation. Moving to the southwest from the point along the western terminus of the Peninsula, the unprotected beach no longer terminates in a spit. The spit appears to have been removed by dredging. A dredge is seen operating at that location in the photograph. Much of the sand flat area to the south also appears to have been dredged as far as the parliament buildings. The dredging causeway is still in the same position although there is no dredging taking place to the north of the causeway; only on its south side.

Sand shoals are not visible along the shoreline, however, the mobile sand blanket off of the BP tank farm is well-developed. It has a scattering of semicircular sea grass meadows which appear to be eroded. The edges of the sand sheet are well-defined, especially on the eastern edge. This may be a function of water depth at a break in slope or it may represent the edge of the sheet. Along its northwestern edge the sheet is bounded by a series of thick sea grass meadows which define one side of a channel-like feature trending in the direction of Curry's Gap.

The darkened (deeper?) water off the Tusitala Hotel is still present and there is a channel which extends from behind the market into the dredged area. There appear to be a few patches of sea grass along the side of the channel. The reclaimed land east of the market was severely

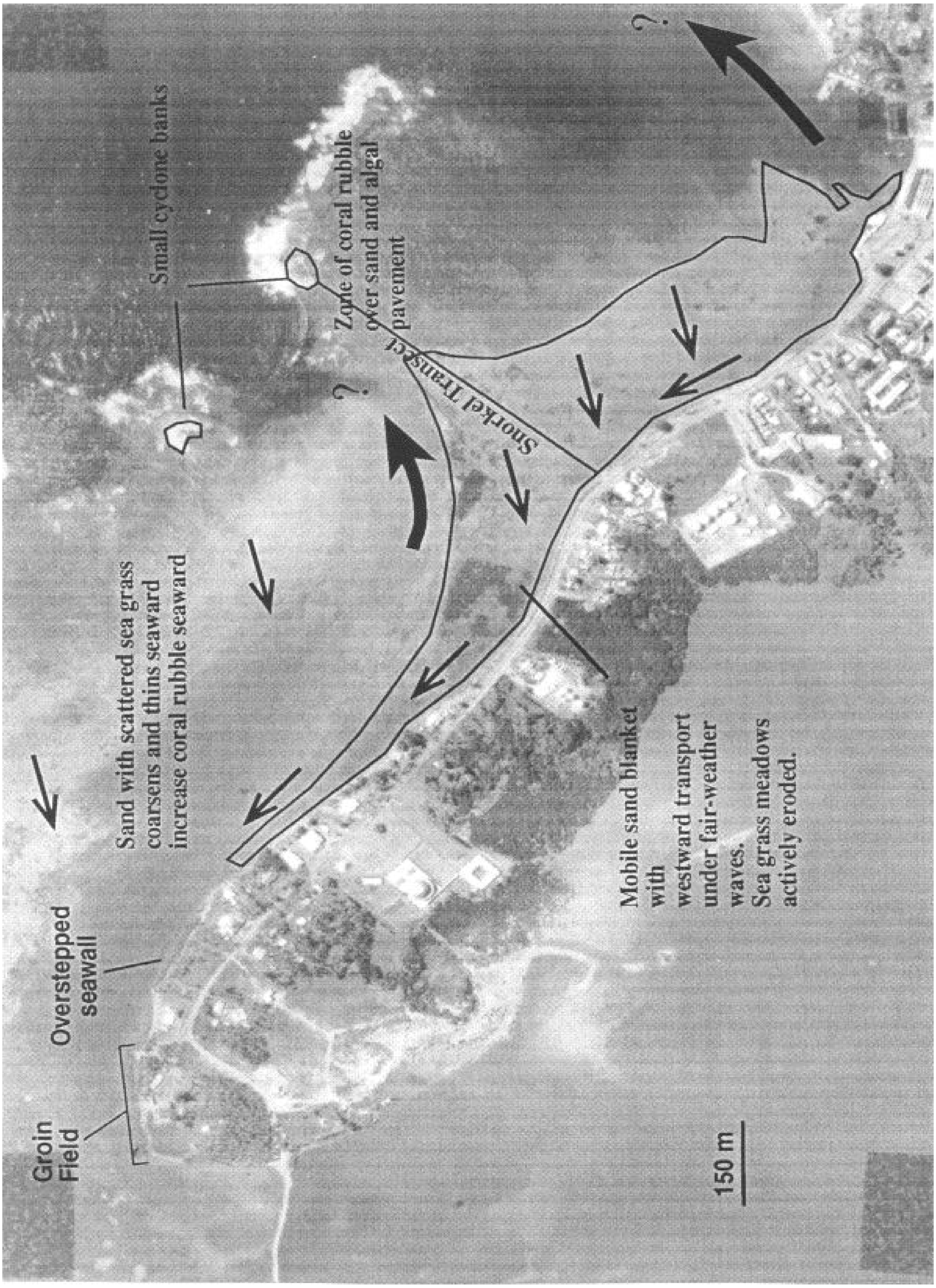

Figure 12. 1990 air photo of the study area illustrating general sediment transport patterns and morphological features referred to in the text.

eroded by the cyclone and a ferry which was beached during the storm can still be seen on the land.

The 1990 photos available for this study do not include entire reef flat area, however, the eastern edge of the cyclone banks deposited during Ofa can be seen just landward of the reef crest. The tide gauge station on the reef flat is not included on the photos.

Mulinu'u Peninsula - 1992

Large-scale (1:3000) colour photographs were taken (February, 1992) in order to assess damage caused by Cyclone Val (December, 1991). This storm was characterised by high winds, which caused considerable damage to homes and forests; however, damage by high seas was not as severe as during Ofa. By 1992 much of the unprotected beach appears to have some form of rubble seawall (looks like boulders dumped along the beach rather than engineered). It is possible that many of these structures have been there all along, but were either obscured by trees or could not be seen because of unfavourable scale. The groin field at the Observatory is in much the same state as in 1990. The dredge causeway has remained in place and dredging has recommenced on the north side of the causeway. Dredging has continued on the west side of the peninsula approximately to the same extent as in 1990. The river mouths at the time of the photos are very turbid and large mudflat areas are exposed, indicating progradation of the delta.

The photography does not extend over the entire reef flat. The northern most portion of the cyclone bank named Observatory Bank (Rearic, 1990) is visible in a single frame. The coverage of the flats includes good views of the vegetated sand flats on the inner reef flat area and a reasonably well-defined moat as described in previous photos. The moat trends offshore towards Curry's Gap as before, with the nearshore edge defined by luxuriant sea grass meadows. Off the Mobil tank farm the sand sheet is visible at the edge of the photo with scattered eroding sea grass banks (less than 30 m in diameter). The deepened area off the Tusitala appears to be mostly filled in with sand and the channel is no longer visible.

Cyclone Banks - Cyclone Ofa

Cyclones can have disastrous effects along the coast of island nations where low lying coastal development is subject to flooding from high water levels and attack by waves. A nearly direct hit on Samoa by Cyclone Ofa in February 1990 resulted in considerable damage to roads and coastal buildings as well as the loss of several lives and damage to crops. In addition large banks were built several 10s of m shoreward of the reef crest along some of the northerly exposed reefs Rearic, 1990). The banks are composed entirely of dead coral fragments (mostly branching coral) several 10s of cm in size. The bank opposite from the Apia Observatory was estimated to be 2-3 m high, 2 km long and 50 m wide or 150,000 to 300,000 m^3 in volume (depending on whether a triangular or rectangular cross-section is specified). It has an asymmetrical shape; steeper towards the shore (est. 40° slope) and gentle towards the ocean (2°). The seaward face undergoes reworking by ocean swells. There is no information regarding the ultimate fate of these banks. The volume of material is comparable to the total amount of dredging over 15 years, therefore periodic input by cyclones might be necessary for the long term maintenance of sediment supply for dredging. Certainly, if there is onshore movement of any of the cyclone generated material that is a positive element in the sediment budget. Whether it is sufficient to offset the losses which may occur due to offshore transport during the cyclone is not known.

Quantitative Observations of Erosion

The shorelines along the Mulinu'u Peninsula have been mapped into GRASS (Geographic Resources Analysis Support System), a public domain geographic information system (GIS) installed on an HP 900 series workstation using the Unix operating system. Air photos from 1954, 1970, 1980, and 1990 (Table 1) were rectified to a common scale using a linear transformation and the quality of the rectification was checked by observing the fit of each photo to common, stable, low-lying ground control features. In this case the road along the eastern coast of the Peninsula was used and the fit was adequate for the purposes of coastline change mapping. The photos were rectified into an arbitrary co-ordinate system and measurements of coastal changes were made using a scale factor (0.57) derived from known distance between identifiable ground points. Mapping limitations were encountered due to the scale of the photography (especially the 1970 photograph), the definition of the coastline, and the presence of trees obscuring the coastline. Based on the approximate pixel scales and errors involved in rectification, the errors in estimation of position of the coastline are ±3 m; less in the case of the larger scale 1980 and 1990 photography. Neither the 1987 or the 1992 photography was used in this study; the former because the scale was too small and the latter because the interval between the photo years was considered to be too short.

The coastline was defined as the vegetation line in any given year (Figures 13-17)*. The waterline at the time of the photo was considered, but dismissed because of the difficulty in identifying its position in several photos. The vegetation line, while not perfect is considered to be a representation of the mean higher high water mark below which terrestrial vegetation cannot grow. In some cases the vegetation is the ground vine locally known as fue. Estimation of the vegetation line in the presence of trees presented an insurmountable difficulty in some places. In addition to problems with parallax, large canopies and the tendency for the trees to lean out over the water created considerable uncertainty in some of the retreat measurements. The ubiquity of shore protection works is an additional complication and where accretion has been identified it is not possible to rule out the possibility that human activity rather natural processes are the cause.

Table 1. Air Photos.

Year	Approximate Scale	Scanning Density (DPI)	Nominal Pixel Size
1954	1:23000	800	0.7 m
1970	1:43000	800	1.4 m
1980	1:13000	600	0.4 m
1987	1:50000	NA	NA
1990	1:15000	600	0.7 m
1992	1:3000	NA	NA

Measurements along the coastline of the Mulinu'u Peninsula were made along 34 shore-normal transect lines spaced at approximately 30-80 m intervals (Appendix A). Examination of the data resulted in the establishment of eight sites (A-H) with relatively consistent behaviour. The results are presented in Table 2.

*Figure 13 onwards from page 47 to page 53

Table 2. Erosion (negative values) and accretion (positive values) in metres for three time intervals at eight sites (A-H) along the shore of the Mulinu'u Peninsula.

SITE	1954-1970		1970-1980		1980-1990	
(Transects)	Mean	Range	Mean	Range	Mean	Range
A(1-2)	-7.1	(-7.7,-6.5)	0.4	(-1.6,2.3)	6.4	(5.8,6.9)
B(3-7)	see Table 3 for large scale measurements					
C(8-11)	-1.2	(-3.1,0.0)	-0.1	(3.4,-2.4)	-4	(-6.7,0.8)
D(12-17)	-12.7	(-18.8,-7.4)	2	(-5.7,4.8)	-5.2	(-14.3,1.7)
E(18-24)	-2.9	(-5.6,5.2)	-0.8	(-2.3,1.5)	-0.5	(-2.9,2.3)
F(25-28)	-1.9	(-3.2,0.6)	4.1	(3.5,5.1)	0.3	(-1.0,1.7)
G(29-30)	-5.9	(-6.1,-5.8)	7.1	(6.1,8.2)	-1.9	(-3.7,0.0)
H(31-34)	3.1	(-1.2,6.7)	5.9	(4.9,7.7)	-4.4	(-7.3,-1.2)

Note: erosion or accretion of less than about 3 m is within the measurement errors of the techniques used.

Site A (Transects 1,2) - South of the dredging causeway (Figure 14)
This site has been heavily influenced by human activities related to the dredging after the 1970 photography. On average this portion of the peninsula eroded between 1954 and 1970 but remained stable or accreted thereafter.

Site B (Transects 3-7) - West end of Mulinu'u Peninsula (Figure 14, 18)
Erosion between 1970 and 1990 at site B was measured by Carter (1991) using analog methods. He reports a total of 12 m of erosion during this time interval. Our results based on the photos identified in Table 1 are considered to be unreliable because of the presence of trees obscuring the shoreline in all photos and the unfavourable scale of the 1970 photo. It was not possible to define a shoreline at transects 3 and 4 at site B (Figure 14). See below for a detailed analysis of this site.

Site C (Transects 8-11) - Groins at Apia Observatory (Figure 15)
Continuous erosion has occurred at locations 8 and 10 since 1954. Locations 9 and 11 eroded between 1954 and 1970 then accreted between 1970 and 1980. Between 1980 and 1990 location 9 eroded 6 m while 11 accreted 1 meter.

Site D (Transects 12-17) - Concave, exposed, NE facing (Figure 15)
This site exhibits the most severe erosion along the peninsula. Between 1954 and 1970 this portion of Mulinu'u peninsula eroded by 13 m. It accreted 2 m until 1980 and then further retreated 5 m by 1990.

Site E (Transects 18-24) - Exposed, E facing (Figure 16)
The vegetation line was obscured by trees in the 1980 air photograph at locations 18-21 therefore no data was obtained. Between 1954 and 1970 all locations eroded 4 m except 22 which accreted 5 m. Between 1970 and 1980 locations 22 and 24 eroded 2 m while location 23 gained 2 m. Between 1980 and 1990 location 22 accreted 2 m but 23 and 24 eroded 2 m on average. The site was erosional between 1954-1970 and relatively stable from 1970-1990.

Site F (Transects 25-28) - Convex, exposed, NE facing (Figure 17)
Between 1954 and 1970 all of these locations show erosion except 28 which accreted about a meter. The vegetation line advanced 4 m by 1980 and then eroded a meter at locations 26 -27 by 1990. Locations 25 and 28 accreted by 1990. In general, the site was slightly erosional from 1954-70 and stable from 1970-90.

Site G (Transects 29-30) - Concave, opposite Curry's Gap (Figure 17)
This portion of the Mulinu'u Peninsula eroded 6 m on average between 1954 and 1970. It accreted 7 m by 1980, then stabilised after that.

Site H (Transects 31-34) - Exposed, east facing open to harbour swell (Figure 17)
This site accreted until 1980 but eroded 4 m between 1980 and 1990. It has been heavily affected by human activities.

Detailed Analysis at Site B (Figure 18)

The large scale 1970 and 1980 photos used by Carter for his studies were located and used for a more detailed analysis (Figure 18, Table 3). The 1980 photo had a series of transect lines which were presumably used by Carter to make his measurements. Carter Transects (CT) 4 to 13 were used for this study as well (CT4 to CT13 in Table 3). Erosion of 2 m to 11 m (average 6 m) was measured between 1970 to 1980 based on the water line (as was used by Carter). The vegetation was very difficult to define even in 1:1000 photography because of trees and exposure. The 1980 to 1990 erosion rates were very similar; a maximum of 16 m of erosion based on the waterline was measured between 1970 to 1990. This is considered to be a reasonable comparison with Carter's measurements.

Table 3. Erosion (in metres) at Site B using large-scale photos.

Carter Transect	70-80	80-90	70-90
CT4	-7	-5	-12
CT5	-8	-6	-14
CT6	-7	-7	-14
CT7	-7	-7	-14
CT8	-11	-5	-16
CT9	-7	-1	-8
CT10	-4	-9	-13
CT11	-3	-9	-12
CT12	-4	-7	-11
CT13	-2	-6	-8

All sites except site H were eroded during the interval from 1954 to 1970, the most severe erosion occurring at site D where a seawall was apparently overstepped and along the west end of the Peninsula (site B). With the exception of the site B large-scale measurements, the interval 1970 to 1980 can be characterised as a relatively stable to accretionary period. Some of the accretion may be related to human shore protection measures, but that is not apparent from the photos. From 1980 to 1990 (a period which included cyclone Ofa), erosion dominated the shoreline, especially at sites B, C, D, and H. The west end of the peninsula south of the dredging causeway (site A) appears to have accreted to some degree. The period of time between 1954 and 1970 was noteworthy in terms of the number of cyclones (16) which entered the 5 degree area around western Samoa. In contrast, there were 7 documented cyclones in 1969-1979 and 12 cyclones in 1979-1990 including cyclone Ofa. Wind records as cited in Carter (1987) indicate that a cyclone with a maximum wind speed of 82 knots (148 km/h or 41 m/s) from the south occurred on January 29, 1966 and a storm of similar magnitude (39 m/s from the NW) occurred on February 10, 1968. Cyclone Ofa (26 February - 1 March 1990) had a maximum wind speed of 70 knots (126 km/h or 35 m/s)from the north. Storms which occurred in the 1970s were characterised by wind speeds of 19-25 m/s. These data, while not conclusive, suggest that erosive intervals may be related to periods with more frequent and/or higher intensity storms. It is interesting to note however, that a turn of the century photograph taken from the Mulinu'u Peninsula and looking back towards Apia depicts erosion around palms along the coast (Figure 19). It is difficult to identify the exact location of the picture; it is likely closer to the proximal end. This photo suggests that erosion along the Peninsula is not a recent phenomenon.

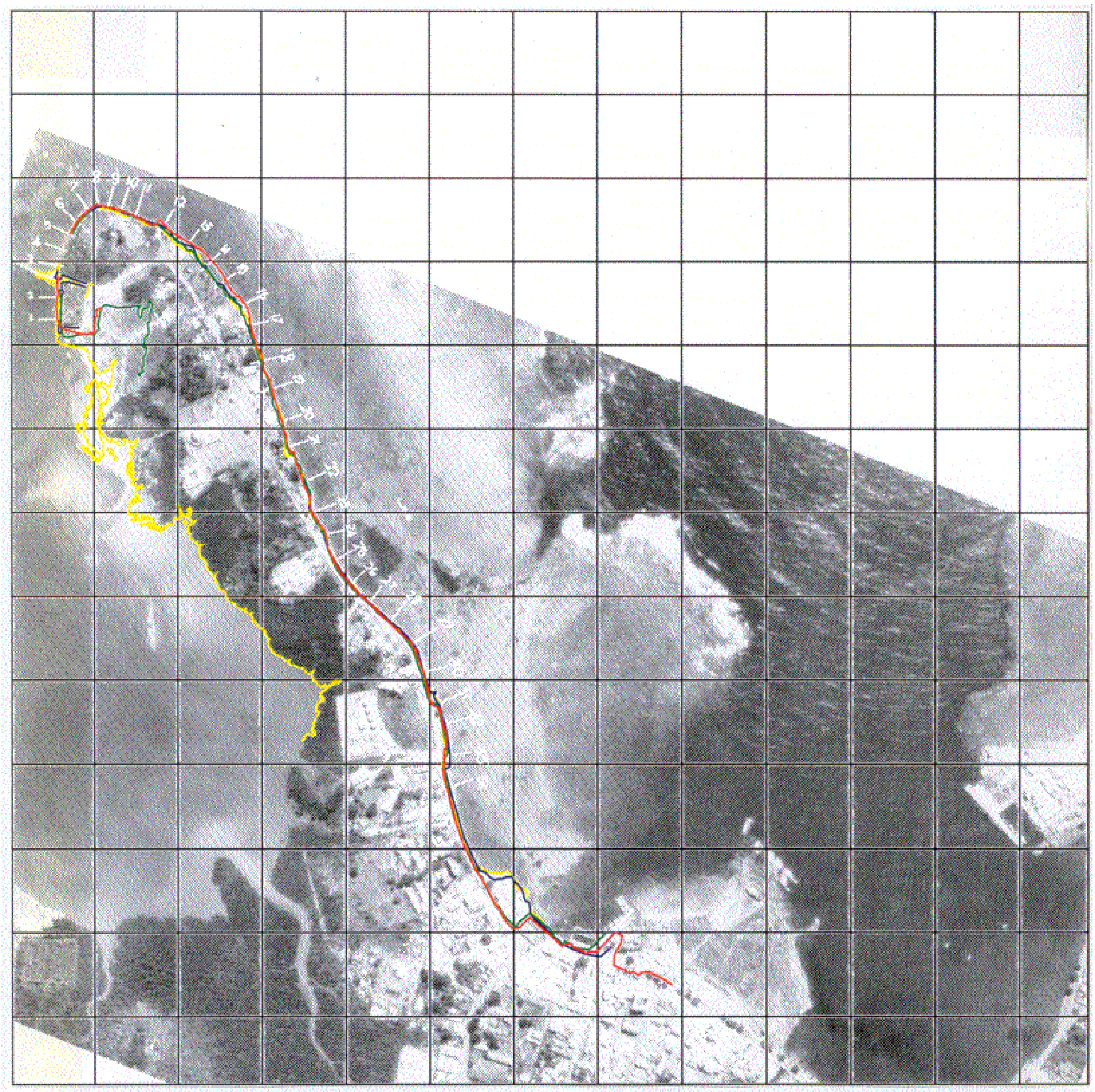

Figure 13. Shorelines for the Mulinu'u Peninsula based on vegetation for the years 1954 (red), 1970 (green), 1980 (blue), and 1990 (yellow) superimposed on the 1990 air photo. The gridlines are 200 m apart. The measurement transects are numbered from 1 to 34 in white.

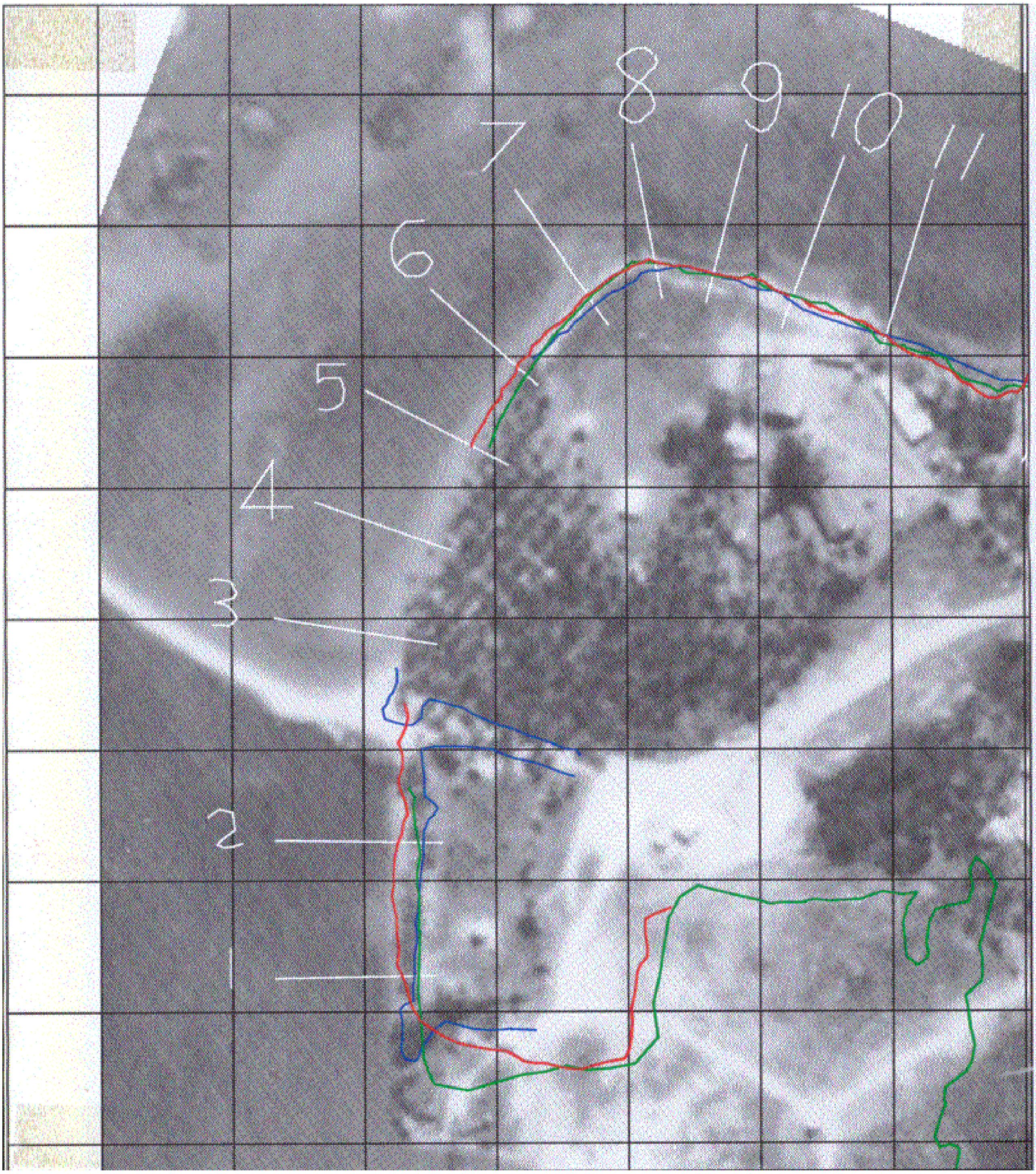

Figure 14. Shorelines at sites A, B, and C on the Mulinu'u Peninsula based on vegetation for the years 1954 (red), 1970 (green), 1980 (blue) superimposed on the 1990 air photo. The gridlines are 50 m apart. The measurement transects are illustrated in white. The vegetation line on the 1970 and 1980 air photos could not be defined at transects 3 and 4 (see Figure 18).

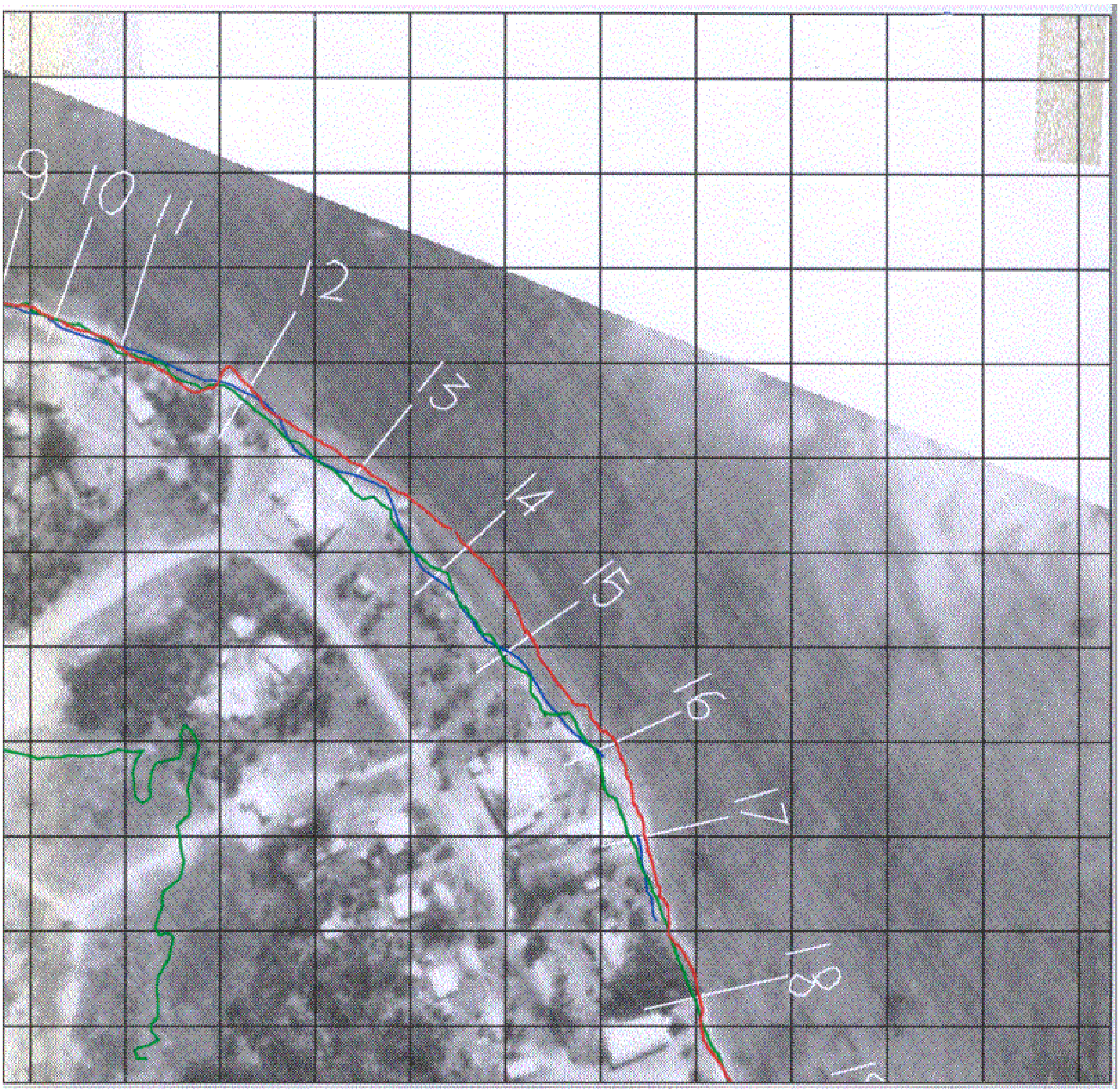

Figure 15. Shorelines at site D on the Mulinu'u Peninsula based on vegetation for the years 1954 (red), 1970 (green), 1980 (blue) superimposed on the 1990 air photo. The gridlines are 50 m apart. The measurement transects are illustrated in white.

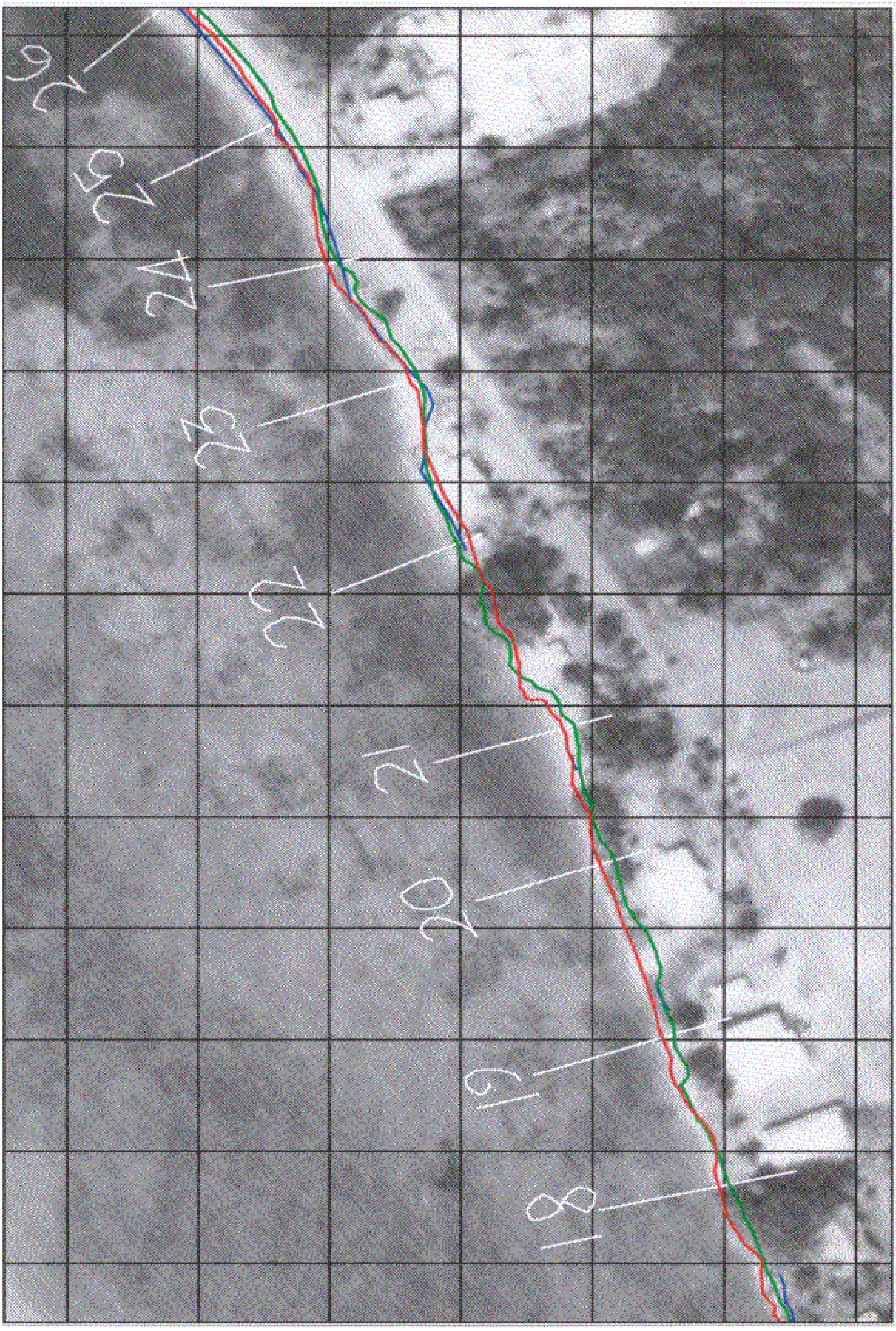

Figure 16. Shorelines at site E on the Mulinu'u Peninsula based on vegetation for the years 1954 (red), 1970 (green), 1980 (blue) superimposed on the 1990 air photo. The gridlines are 50 m apart. The measurement transects are illustrated in white.

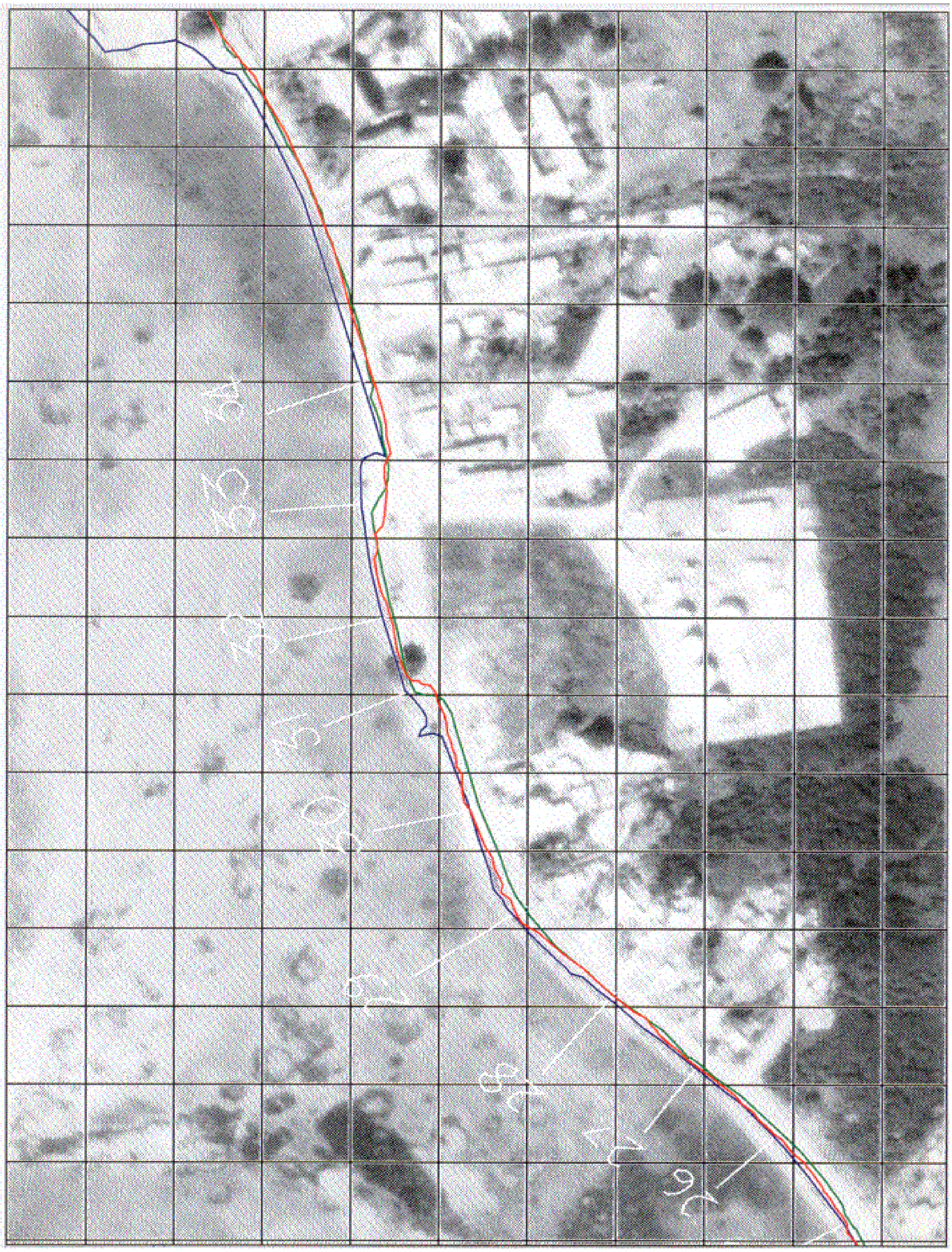

Figure 17. Shorelines at sites F, G, and H on the Mulinu'u Peninsula based on vegetation for the years 1954 (red), 1970 (green), 1980 (blue) superimposed on the 1990 air photo. The gridlines are 50 m apart. The measurement transects are illustrated in white.

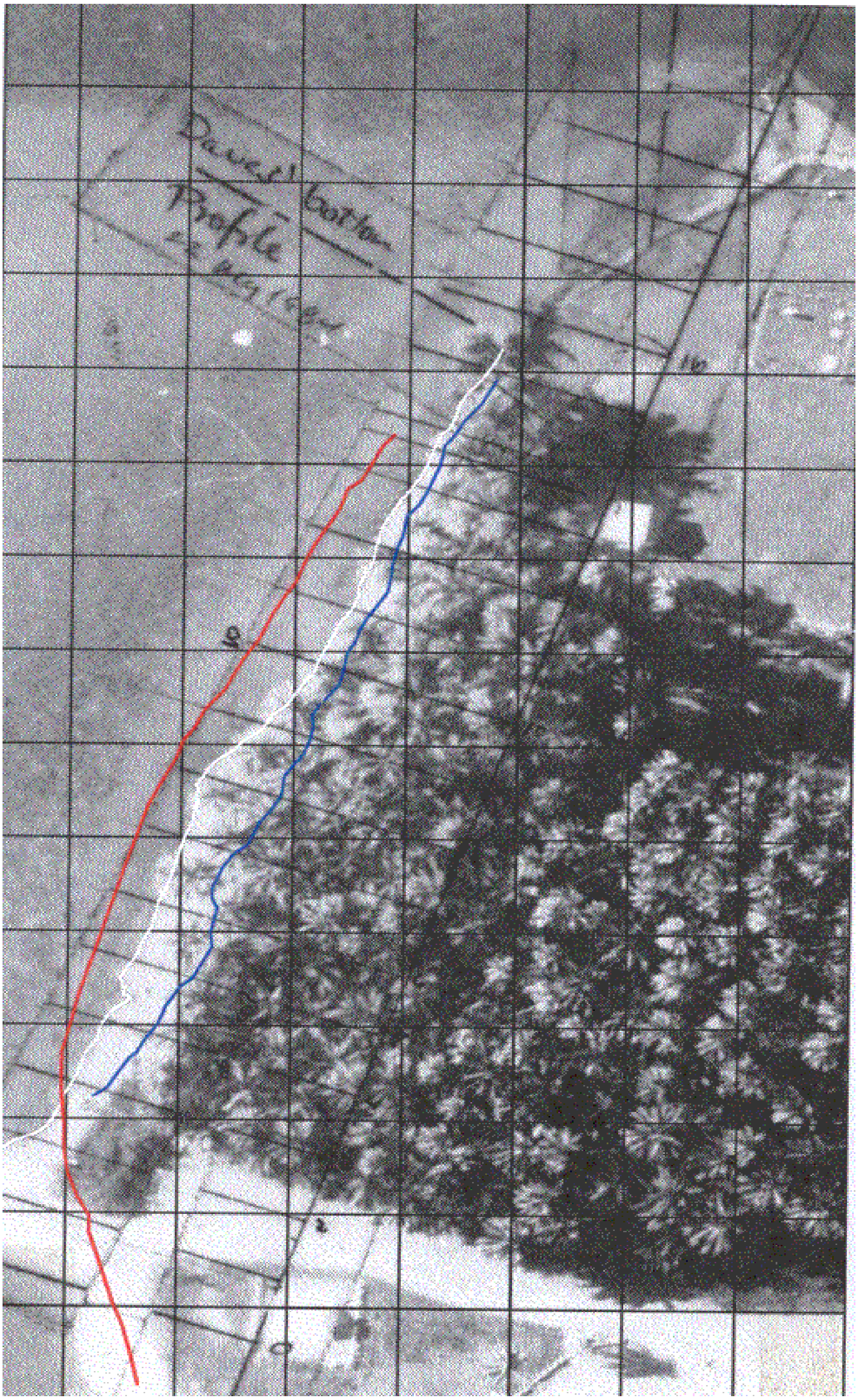

Figure 18. Shorelines defined by the waterline in 1970 (red), 1980 (white), and 1990 (blue) superimposed on a large scale air photo from 1980 with transect lines drawn by R. Carter and used for his measurements (Carter, 1991). Gridlines are 15 m apart.

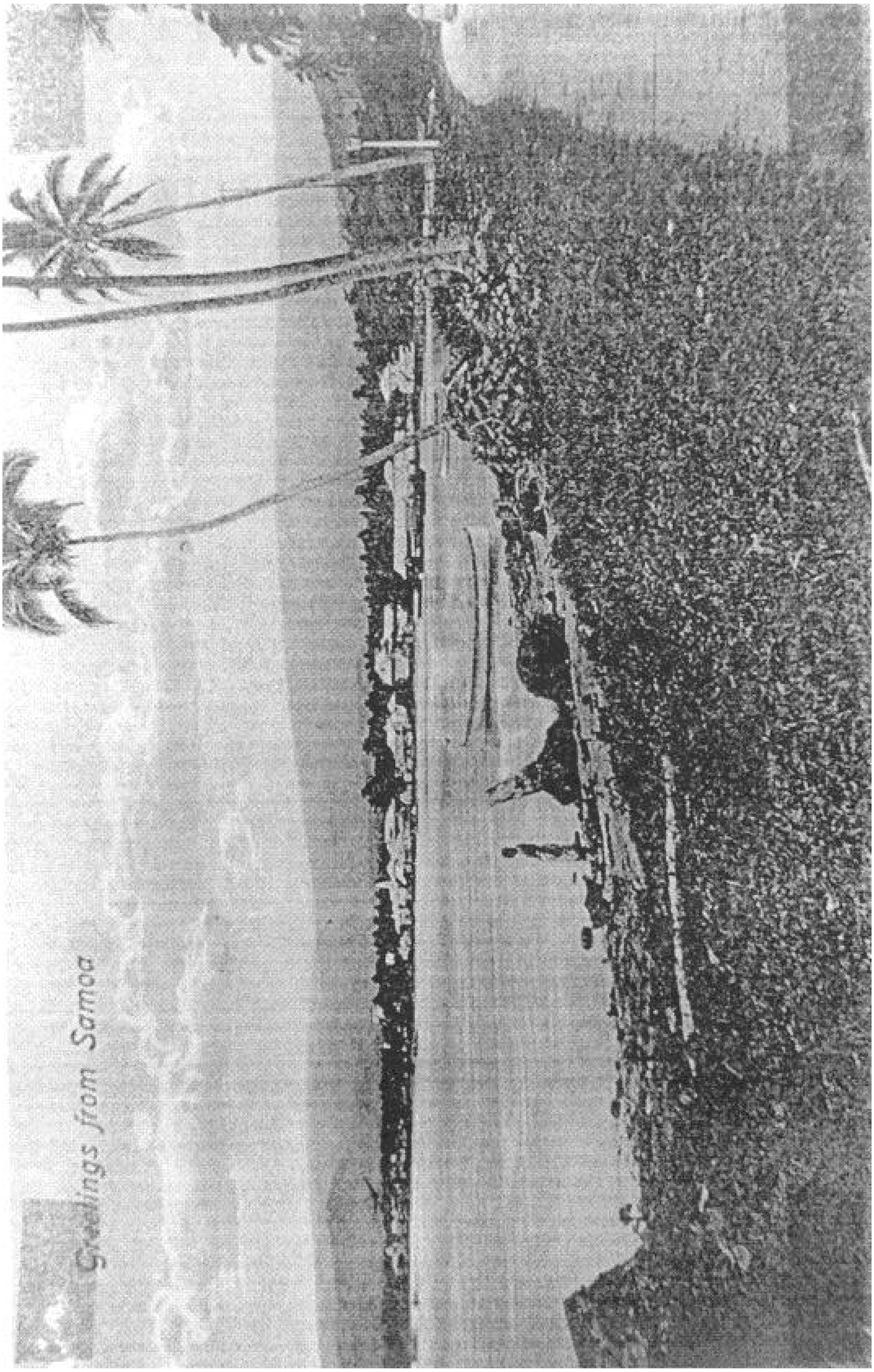

Figure 19. A scanned and enhanced postcard taken from somewhere along the Mulinu'u Peninsula looking back towards Apia around 1900. Note the eroded palms.

DISCUSSION

Sediment Transport, Erosion, and Reef Flat Circulation

The net longshore drift pattern in the vicinity of Mulinu'u Peninsula is indicated by the accumulation of sands on the east-facing (updrift sides) of groins, drift patterns from experiments by Hedgeland (1977) and Carter (1978), and the observations of westerly directed movement on wave ripples under fair weather conditions. Under these conditions, small (visual estimates of <0.5 m in height and about 3 second period) waves are formed by a combination of winds acting over limited fetch distances and swell waves diffracted through reef openings. These waves generate a net longshore current which moves a mixture of carbonate and volcanic sand northwestward along the east side of Mulinu'u Peninsula (Figure 12). The dominance of carbonate sand on the relatively accretional beaches in front of the BP tank farm suggests that the source of the sand is from the reef flat. The sand sheet which is visible on all of the air photos at the southeastern end of the Peninsula is the probable source for carbonate sands moving onto the beaches. The quantitative air photo analysis suggests that these beaches have been relatively more stable than those further north along the coast. The dominance of volcanic material on these northern beaches reflects the erosion of the volcanic Tafanamagu Sand which comprises the upper 3.5 m of the Mulinu'u Peninsula as indicated by drilling at the Apia Observatory. The observation that these beaches are erosional based on the dominance of volcanic debris is supported by the air photo analysis, however, the reason for this behaviour is not obvious.

It is possible that the local circulation pattern over the reef flat is not conducive to movement beyond a certain point. The configuration of the seaward trending feature at Curry's Gap may represent a mechanism for deflecting sand away from the distal (northern) coast of the Mulinu'u Peninsula. Beach profiles (Figures 5 and 6) indicate that the moat observed on air photos is a negative feature, while the sand body has about 0.5 m of positive relief. It is hypothesised that there are south-easterly moving currents at the edge of the sand body which carry sand off of the reef flat through Curry's Gap. The currents are likely generated by a combination of ebb tides and wave/storm surge return currents. The information presently available does not permit a resolution of this question.

The time history of erosion along the Mulinu'u Peninsula is not detailed enough to permit an analysis of its relationship either to storms or human activities. Carter's (1991) study of erosion at the west end of the Peninsula is supported in a general sense by the quantitative analysis in this report, however, we could not duplicate his results exactly, either because of differences in methodology, or in the exact choice of the position of the waterline. Dredging appears to have influenced erosion immediately onshore from the dredge holes since there was significant retreat even during the relatively calm 1970-1980 period. Erosion at site B between 1980-1990 may be partly affected by dredging, but the influence of cyclone Ofa cannot be discounted. The presence of a dredge hole (presumably dredged pre-1985) within 100 m of the shoreline in the 1990 photo indicates that complete infilling had not yet occurred.

Aggregate Supply

The aggregate resource presently being mined by the Ulberg operation appears to be about 20-25 m thick based on seismic reflection data (Rubin, 1984). This estimate is based on the depth to a highly reflective layer at about 30 ms below the seabed. This material is likely basalt and such a depth is consistent with depth to basalt at the Central Bank building (John Bell, pers. comm., 1993) and the port facilities (JICA, 1988). Basalt exposed on the west side of Vaiusu Bay would require a slope of 1-2° to achieve that depth within the dredge zone; such a dip is consistent with nearshore lava slopes on Upolu and Savai'i (Keating, 1992). Estimates of volumes based on jet probing to depths of about 3 m (Mata'afa et al., 1988) are minimum values. Dredging is routinely performed to a depth of 15-16 feet (about 4.5-5 m). A borehole was drilled near the reef crest just opposite from Cape Ti'apepe (west coast of Vaiusu Bay) as part of a Japanese port development project (JICA, 1987). Drilled in less than 1 m of water, the borehole penetrated 18.5 m of unconsolidated material with a blow count of 0-3 blows per 30 cm (SPT-standard penetration test). The materials were described as coral sand with coral rubble in the upper 5 m and coarse coral sand with shell fragments below; the base was somewhat firmer than the top (9 blows per 30 cm). Unconsolidated deposits extend into Vaiusu Bay, but jet probing towards the head of Vaiusu Bay indicates that deposits get finer and muddier towards the river mouth. Further along the shore to the west information from a dredging operation (Apia Concrete Products) indicates that 1 m of fine material overlies the poorly sorted sand and gravel dredge material and that the dredged areas tend to be partially infilled after storms by westward flowing currents.

The fact that volcanic material is present in many of the jet probe samples described by Harper (unpublished notes, 1985) demonstrates that the origin of the resource is a combination of terrestrial and reef-derived material. The proportions of the two constituents and the age of the deposits are not known. It seems unlikely that coarse volcanic sand was supplied from the low gradient streams entering the protected waters of Vaiusu Bay, therefore the source was likely to be from erosion of the Mulinu'u Peninsula as well as from erosion and transport from other updrift sources such as the Mulivai and Vaisagano Rivers. With harbour development, updrift terrestrial sediment sources have gradually been cut-off either by seawalls or shore-normal structures (i.e.

wharves, land reclamation). The shore protection presently under construction completely eliminates all updrift sources so replenishment of the aggregate resource will depend entirely on reef-derived material. The rate of replenishment will depend on the health and productivity of the reef and reef flat as well as the circulation pattern and storm frequency. At the present time we have no data with which to estimate the replenishment rate.

The dredging operation currently involved in reclaiming land in front of the Tusitala Hotel is mining the sand body discussed above. The available data suggests that this material has been a source of sand to the accretionary beaches along the proximal end of the Mulinu'u Peninsula. Even under ordinary circumstances, it would be difficult to rationalise taking this material out of the coastal system, however, the new shore protection project requirements need to be addressed as well. The report describing the design specifications of the shore protection was not available during the course of this study. If the design specifications included the establishment of a natural beach at this site, removal of the source material for the beach may jeopardise the long-term stability of the seawall. Alternatively, we do not know what proportion of the material moves onto the shore or off of the reef flat and into the harbour, so it is difficult to estimate the impacts of the sand dredging operation. Removal of a substantial amount of sand would permit larger waves to enter the reef flat area from the harbour and impact the shoreline.

Sand has been identified in the entrance to Apia Harbour (Rubin 1984) and sediment thicknesses of 20 m were noted. A survey performed in 1987 (JICA, 1987) indicated an accretion rate of more than 7 cm/a in 7 to 13 m of water. In these water depths it is unlikely that these materials would be returned to the coastal system, they therefore represent a potential sand and aggregate source. In general, the reef openings and terraces fronting the reefs may hold potential for sand mining, although increased costs over the current techniques are likely.

Cyclone Banks

The role of cyclone banks in supplying material to the reef flats and lagoons has been studied in several regions. Baines et al. (1974) and Maragos et al. (1973) describe the development of a cyclone bank on Funafuti and its possible role in island building. In the case of Western Samoa there has been no evidence of shoreward migration of the banks, however, their presence is surely moderating the effects of swell and subsequent storms which would allow the shoreline of the Mulinu'u Peninsula to stabilize or accrete. Movement of the material on the banks under the generally benign conditions on the reef flat requires considerable comminution of the originally deposited materials. The rate of material degradation to sand sizes represents a major control on the role of the cyclone bank material in supplying coral sand to the coast. It is possible that much of the material present in the banks may be returned to the fore-reef by a combination of wave erosion on their seaward side and storm surge return currents on their landward side.

Origin of the Mulinu'u Peninsula

The Mulinu'u Peninsula has been described as a barrier spit (Richmond, 1991) which is probably partially relict from a previous Holocene shoreline configuration. The dominance of volcanic material in the upper 3.5 m at the Apia Observatory suggests that this interpretation is correct and the source of the spit is a combination of Holocene alluvium eroded from the harbour area downdrift and sediment supplied by the Mulivai and Vaisagano Rivers. The orientation of the feature is approximately parallel to the reef trend (northwest/southeast), which is curious given the dominance of the east winds and the sheltering effects of winds from the south. It would be expected that such a configuration would result in a spit with a predominantly east-west trend.

One explanation for this orientation is a structural control of the peninsula. Drilling at the Apia Observatory and evidence of more than 20 m of unconsolidated and unlithified material both offshore in Vaiusu Bay and at the proximal end of the spit (Central Bank Building) suggests that this is not the case. It is therefore likely that the orientation of the Mulinu'u Peninsula is controlled by both the locally generated wind wave field and perhaps more importantly by the reef-transformed offshore swell waves. This has been alluded to by Carter (1990, 1991) in his suggestions that coastal erosion problems are governed in part by the morphology of the reef and the attendant effects on wave heights and periods. Wave diffraction patterns at reef openings like Curry's Gap and the Apia Harbour mouth demonstrate the radical changes in direction experienced by wave crests as they enter the reef flat area. A feature morphologically similar to Mulinu'u was described earlier near Moata'a. This is a lagoon-backed barrier oriented northwest/southeast and updrift of a large river fed reef opening. There has been no systematic study of these features and their relationship to reef morphology, rivers, or the presence of onshore alluvial deposits.

HYPOTHESES AND RECOMMENDATIONS

An understanding of the Mulinu'u Peninsula/Apia Harbour/Vaiusu Bay sediment transport regime is necessary in order to develop a plan for managing the aggregate resources present in the area. In addition, a better understanding of one such system will enable a better approach to the assessment and management of other aggregate resources in similar systems. Our present level of understanding leads to the following hypotheses:

(1) Sediment in the Ulberg dredging area has been supplied by a combination of reef-flat carbonate sand and terrestrially derived volcanic material. Mulinu'u Peninsula and the Apia Harbour area has been the source of the volcanic component. With harbour development over the past century and recent construction of shore protection, replenishment of the aggregate resource will depend entirely on reef-flat material.

(2) Based on the history of erosion since 1954, there has been a persistent erosional trend at the most exposed west end of the peninsula which was present prior to dredging. While nearshore dredging in this location probably exacerbated the problem there is little evidence for it being a major problem, provided that sufficient distance from the shoreline is maintained.

(3) The sand body offshore from the Mobil tank farm is the source for sands moving onto the shore at BP beach and south. Dredging of this sand body will decrease the material available to replenish the coastal system. This may shorten the useful life time of the newly installed protection.

(4) Sand is removed from the reef flat system through openings in the reef such as the harbour mouth and Curry's Gap. Sand deposits at the base of these openings represent significant potential reserves of aggregate which are now lost to the coastal system and may become useful resources if technology can be found to exploit them cost-effectively.

(5) The cyclone banks reduce the wave energy propagating over the reef into the coastal areas and may also reduce the offshore currents induced by wave set-up in the reef flat area. Their role in nourishing the coastline in not known.

In order to test these hypotheses, the following recommendations are made:

(1) Study of reef-flat sediment transport and circulation. Perform a systematic study of waves and currents over the reef flats combined with a survey of surficial and nearsurface (to 1-2 m below the seabed) sediments and sedimentary structures. The purpose of the study will be to investigate the present and (using the sediments) recent past hydrodynamic regimes in order to develop a model for circulation over the reef flats and into the aggregate resource areas. Sediment texture and composition can be used to infer transport directions and current strengths.

(2) Maintain and expand the beach profiling network. The beach profile data collected during the recent in-country workshop (Howorth and Woodward, 1993) provides an invaluable benchmark for monitoring the performance of the recently installed shore protection. Every effort should be expended to maintain and expand the network of sites to other parts of the islands where erosion and/or sand mining is a problem.

(3) Survey the quantity and quality of aggregates in reef openings. A high-resolution seismic and sidescan survey should be performed at several areas which are potential sources of aggregate to assess the size of the resource. If possible jet probing or vibracoring should be performed in order to groundtruth the geophysics. It would also be advisable to investigate the dredging systems and costs involved in exploitation of these types of resources.

(4) Refine the estimates of the Vaiusu Bay resource. Dredging on the reef flats on the exposed side of the Mulinu'u Peninsula is removing material which is moving onshore to supply beaches at its proximal end. It would be preferable to mine material which is lost to the coastal system such as the reef openings and in Vaiusu Bay and other lagoons. Preliminary jet probing in Vaiusu Bay outlined reserves of about 1 million m^3 (Mata'afa, 1988) as of 1987. A jet probing survey over a denser grid with a probe length of 5-6 m would provide a more complete estimate of reserves. Vibracores would assist in characterising the quality of the resource as well as provide an opportunity to understand the mechanism for its formation. It would be desirable to combine this with recommendation 1.

(5) Undertake or support further efforts to refine the sea level history of Western Samoa. Medium to long term (50-100 years) development plans should be made based on historical erosion patterns and predictions of future patterns. Understanding the response of the coast to Holocene sea level change is an important part of planning for future coastal development. Predictions of increased submergence due to sea level rise could have dire consequences if it is superimposed on an already submerging coast. It is less important if the coastline can presently be demonstrated to be emerging.

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APPENDIX A

Retreat in Metres along each Transect

Transect #	1954-70	1970-80	1980-90	1954-80	1954-90
1	-7	2	6	-4	2
2	-8	-2	7	-9	-2
3	NA	NA	NA	NA	NA
4	NA	NA	NA	NA	NA
5	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA
8	-1	-2	-4	-3	-7
9	-1	1	-6	0	-6
10	0	-2	-7	-2	-9
11	-3	3	1	0	1
12	-8	4	-2	-5	-7
13	-11	5	-13	-6	-19
14	-18	-6	0	-24	-24
15	-19	4	-4	-15	-19
16	-12	1	-14	-11	-25
17	-7	4	2	-3	-2
18	-3	NA	NA	NA	-5
19	-5	NA	NA	NA	-3
20	-6	NA	NA	NA	0
21	-4	NA	NA	NA	-8
22	5	-2	2	3	5
23	-4	1	-3	-3	-5
24	-4	-2	-1	-5	-6
25	-3	4	2	1	3
26	-3	5	0	2	1
27	-2	4	-1	1	0
28	1	4	1	4	5
29	-6	8	-4	2	-1
30	-6	6	0	0	0
31	7	5	-1	12	11
32	-1	6	-5	4	0
33	6	8	-7	13	6
34	1	5	-4	6	2
Mean	-4	2	-1	-2	-4
Standard Deviation	6	4	5	7	8