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Technical Report

SEAWALL PROTECTION FACILITY FOR MULINU'U POINT, WESTERN SAMOA

by

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DESIGN OF THE SEAWALL FOR MULINU'U PT APIA, WESTERN SAMOA

EXECUTIVE SUMMARY

The Mulinu'u Peninsula shoreline is being eroded along its seaward side. Once dredging of sand in Vaiusu Bay became significant severe erosion began on the western end of the peninsula. The present bottom topography will cause this loss of shoreline to continue on the west end until the former bottom depths are restored or until adequate shoreline protection is developed.

Reef configuration controls the wave pattern inside the lagoon causing a concentration of wave energy just west of the point. This condition precludes any extension of the point to the west. The narrow reaches of the peninsula could be breached during a severe storm, so the exposed seaward side of the peninsula should be considered for shore protection. The width of the peninsula should be increased in some areas. Land reclamation, 30 metres or more could be achieved along the seaward side of the peninsula by construction of a seawall and filling behind the wall parallel to the present roadway.

In particular protection should be provided to the west end of the peninsula. While it would be impractical to construct a seawall of sufficient height to prevent overtopping, a wall up to 1 metre above present ground level would provide a significant protection to the development on the peninsula, (Figure 9). The protection for the west end would be expected to cost on the order of six hundred thousand dollars.

The submerged sand in the nearshore area is stable on a 1:50 slope. As the dredge depth is on the order of 5.5 metres below mtl no dredging should be closer to Mulinu'u Pt than 275 or 300 metres.

A design life of 100 years is proposed for the shoreline protection at Mulinu'u Point. Technical information regarding the expected wind force, wave height, storm surge accompanying a 100 year storm is developed in this report.

GENERAL INFORMATION

This work was undertaken as a part of the CCOP/SOPAC Work Programme CCSP/WS.5 "Coastal Zone Management".

The reef flat area to the west of the Apia Observatory has been dredged for sand during the past 10 years or so. The water depth has been increased, and this increase in depth has altered the wave pattern over the reef flat so that the shoreline is now eroding rapidly. In order to prevent serious loss of land a seawall is now being considered for this section of shoreline. The following report presents the conditions and criteria for design of the seawall.

MULINU'U POINT

Mulinu'u Point, shown in Figure 1 is the site of several cultural and historical landmarks. Located on the west or Vaiusu Bay side of the point are the Tombs of Tuimaleali'ifanos and Tameseses. This is the area most threatened by erosion. The stone Tombs of Malietoa Tanumafili I and Malietoa Laupepa are on the East side of Mulinu'u Peninsula and would be threatened during only the largest storms. The tomb of Faalata Malietoa is located inland on the Point and it is well protected.

The Apia Observatory at the end of the peninsula began observations in 1902, and it is one of the worlds oldest observatories. It is an important tide and weather station and an active part of the world system of observations.

The Western Samoa Parliament House is located near the north central part of the narrow peninsula. The Lands and Title Court is also located there. Several hotel, historic sites, fales, radio and microwave facilities, clubs, and memorials are located on the peninsula (Figure 2).

Mulinu'u Point is the protecting headland for a large mangrove area that surrounds Vaiusu Bay on three sides (Figure 2). Also the developing industrial areas of Vaiusu, Vaigaga, and Vaitele are in the lee of Mulinu'u Point from hurricanes approaching from the north east.

Some sections of Mulinu'u Peninsula are no more than 30 meters in width during very high spring tides. The protecting seawall was not designed to withstand major storms, and the road could be lost during such a storm.

The peninsula appears to have been produced from the action of large storm waves. Photos taken prior to World War I during a German Flag ceremony show that a significant width of land existed seaward of the present shoreland. Sand found along the seaward side is transported to the west by the tradewind waves that are generated over the reef flat. This sand was accumulating in the lee of Mulinu'u Point until dredged recently. The erosion of land from the west end of the peninsula was due to dredging west of the point. The wave diffraction in that area was altered by changes in the depth of water in Vaiusu Bay. The loss of land and coconut trees along this shore (Figure 10) has prompt the current investigation.

STUDY OBJECTIVES

The objectives of this study was to develop baseline data and design a shoreline structure for Mulinu'u Point which would protect its western end and prevent further erosion. The design was selected to take full advantage of local materials and construction facilities.

PERSONNEL PARTICIPATING

Ralf Carter, Marine Scientist/Civil Engineer from the CCOP/SOPAC Staff in Fiji conducted the analysis. He had the support and assistance of the Staff at the Apia Observatory and the Department of Agriculture, Forests, and Fisheries. Jim Eade served as technical editor for this report. Individuals assisting and/or consulted included:

Dr. Kilifoti Eteuati, Foreign Office
Mr. Seve Iosa, Superintendent of Observatory
Mr. Ausetalia Titimaen, Hydrologist
Mr. Sapa Saifaleupolu, Meteorologist
Mr. Fa'atoia Malele, Hydrologist
Mr. Tuuse Lefi Taulralo, Public Works
Mr. Lealiifano J. T. Soon, Director of Lands
Mr. Alan A. C. Minson, SPDC
Mr. Sitivi Kamu
Mr. Ueta Faasili, Chief Fisheries Officer
Mr. Fuimaono Lantasi, PWD
Mr. Luatua Vrese, Fisheries
Mr. Gordon Dawson, Observatory

EQUIPMENT, FACILITIES, AND METHODS

Equipment and Facilities

The following equipment was provided by CCOP/SOPAC:

Echosounder
Compass
Charts, maps etc
Targets, tools etc

The following equipment was provided by the Western Samoan Government:

Survey boat and crew
Equipment storage
Land transport
Site crew
Office facilities

Study Method

Surveys of western shoreline were made from aerial photographs and onsite surveys to determine the rate of shoreline erosion. Rock samples were collected to determine the physical characteristics of the rock for construction materials. A bathymetric survey was made of the reef flat area bordering Mulinu'u Pt for making wave refraction diagrams. The major task of analysing the data, determine the design criteria and parameters, and design of seawall was an office exercise.

The results of these analysis are presented and discussed in detail below. As more design data is collected in the South Pacific, and as the performance of individual seawalls become known, it will be possible to design better structures.

TROPICAL CYCLONES

Data compiled by Kerr (1976) and Revell (1981) indicate that during the 40 year period, 1939 to 1979 the South Pacific Ocean averaged 9.1 tropical cyclones per season. The coefficient of variation for the average annual occurrence was 32 percent. The peak occurrence of storms is between January and February. Analysis of the 91 South Pacific cyclones reported between 1969 and 1979 show the geometric mean wind speed to be 54.5 +/- 1.3 knots and the average maximum wind speed for the 50 year recurrence interval to be 87.7 knots (Carter 1985). The wind speed for a given recurrence interval, R was found to fit the relationship:

$$S^{c} = A + B \log R \qquad (1$$

where c was determined to be 1.899061288, A was 1420.203803, B was 2046.050482 and S is in knots.

Tropical cyclonic circulations are classified as follows:

Beaufort scale description	Wind speed in knots
Below gale (up to force 7)	<34
Gale (force 8 or 9)	34-47
Storm (force 10 or 11)	48-63
Hurricane (force 12)	>63
Major hurricane	>90
Super hurricane	>120

The characteristics of four well known or recent South Pacific hurricanes that could occur in Western Samoa are:

Name	Year	Barometer	Storm surge	Wind	Speed
Bebe	1972	954.0 mb	4 m	97 k	7.5 k
Isaac	1982	976.4 mb	2-3 m*	95 k	12 k
Oscar	1983	952.5 mb	2-3 m	>69 k	7 k
Sally	1987	967.0 mb	1.9 m	58 k	11.3 k

* Undisturbed water level measured to be 2.65 metres above chart datum in Nuku'alofa (Netzeband, 1983).

With all of these cyclones there was a significant amount of storm surge. The forward speed was relatively slow so the storm wave could keep up with the storm. Three of the cyclones had relatively high maximum wind speeds for South Pacific cyclones. The 69 knot wind speed shown for Oscar was recorded at the Nadi airport and would not have been the maximum wind speed. The minimum barometric pressure that occurred during passage of these storms was lower than average for South Pacific cyclones.

Minimum barometric pressures of 980 mb and 990 mb are typical. During the passage of Cyclone Sally in Rarotonga the barometric pressure was 1009 mb three days prior and 1002 mb 24 hours before the minimum of 967 mb.

STORMS IN WESTERN SAMOA

Analysis of the tropical cyclones mentioned above show that the 5 degree square area that includes Western Samoa can expect about 5.87 tropical storms in 10 years or a tropical storm every 1.7 years. However a 5 degree square area is a rather large area and for such a storm to have a direct "hit" upon Apia would be much less frequent. The last major hurricane to pass through Apia was probably the one in 1889 or almost 100 years ago. However, there have been 22 tropical storms recorded for the 5 degree area this century up to 1979 (in the past not all storms in the 5 degree area were reported, by use of satelite observations reporting has now improved). The reported storms occurred on the following dates:

1903	February	1957	4 February
1915	January	1959	25 February
1926	January	1961	13 March
1936	January	1966	29 January
1939	January	1968	10 February
1941	16 February	1972	2 November
1941	1 March	1973	1 January
1941	25 December	1976	10 December
1946	25 December	1976	11 December
1950	30 January	1977	23 December
1950	31 December	1978	15 February

Track records indicate that approximately one-third (4.18 tracks 133 km wide are 5^{o} of latitude in width) of the tropical storms in the 5 degree area containing Western Samoa will hit land, or on the average a significant storm can be expected to pass through Western Samoa every 7.12 years.

These values were arrived at in the following manner. We assume that the chance of a cyclone crossing a given latitude is independent of its crossing a given longitude and conversely the chance for crossing a given longitude are independent of the latitude. The product of these probabilities is the probability for a crossing at a given latitude and a given longitude. We can derive these values from the above 916 satelite observed crossings that occurred between 1969 and 1979 in the South Pacific. Analysis of the 10 years of storm tracks show that the 10^{o}-15^{o}S latitude zone has a 0.14083 probability for a crossing and the 170^{o}-175^{o}W longitude zone has a 0.06987 probability for a crossing. Further we can assign a 0.6513 probability for a specific storm condition, such as the average cyclone which is expected to occur within a given 10 year period. If we consider only a 133 km wide area, the width of the average cyclone, we will reduce the chance of the storm by

4.18 for a specific location within the 5^{o} area. Combining these probabilities we get:

$$0.140873 \times 0.06987 \times 0.6513 \times 916 / 4.18 = 1.4 \quad (2$$

storms per 10 years or we will have an average storm about once in 7.12 years.

This value can be compared with observed data. The geometric mean wind speed for the South Pacific cyclone is 54.5 knots. The wind records developed at Mulinu'u Point since 1941 indicate that this wind speed has a recurrence period of about 8 years.

These data were derived from the hurricane tracks for the entire South Pacific where 916 crossings occurred in the 10 years considered (1969-1979). The 6 crossings in the 5^{o} area containing Western Samoa were analysed, and the recurrence frequency calculated for the various wind speeds is shown in Figure 3. However the values shown in this figure do not appear to agree well with the observed wind speeds in the 5 to 50 year recurrence period. The value for the 100 year cyclone gives better agreement with observed data. For design considerations it appears that the observed data, which is discussed in the following section, will be the more conservative, and only it will be used in this analysis.

WESTERN SAMOA WIND RECORDS

A review of the wind records held at Apia between 1941 and 1981 (Saifaleupolu 1982) show the 41 year event to be approximately 80 knots and the 100 year event to approach 95 knots. The records indicate that a value of 82 knots did occur in 1966, and it had a 0.98 probability or 41 year recurrence period for the 40 years of data recorded at Mulinu'u Point. These data are shown in Figure 4.

DESIGN WIND

A high storm surge would be particularly damaging to the Mulinu"u Point area. In order to include the combination of a slow moving hurricane that would have a minimum barometric pressure of 938 mb which would result in a high storm surge and not exceed the 100 year recurrence period, it is necessary to select a cyclone that has something less than the 100 year wind speed. Based upon the review of wind records the design wind for estimation of wave height was selected as the 85 year windspeed of 93 knots from Figure 4 rather than the 100 year wind speed which would be about 96 knots. This combination of variables should be the 100 year event with a high storm surge that could result in a significant damage to the area considered.

HURRICANE WAVE

The wave predicted from a hurricane moving at 11 knots, having a maximum wind speed of 93 knots at a radius of 25 nautical miles, and a barometric pressure drop of 2.37 inches would have a significant wave height of 12 metres, a period of 13.3 seconds, and a wave length of 277 metres. This wave was calculated for deep water. As the cyclone approaches the island, the effect of bottom friction increases due to a reduction in the depth of water, and the wave generated may be decreased in size due to both bottom effects and reduction in effective fetch. Other effects such as bottom topography may cause the wave height to increase. These combined effects were considered and the wave near the reef was calculated to have a wave height of 11.3 metres, a period of 13.6 seconds, and length of 288 metres.

WAVE SETUP ON A REEF

When waves break over a reef a rise in the water level behind the reef will occur (wave setup). Using a method for estimating this rise in water level that was developed by Seelig (1983), assuming a 2 meter water depth at the reef and an irregular wave height, the rise due to a 11.3 metre wave would be 1.11 meters. Recalculating this wave setup by a method described by in the Shore Protection Manual (US Corp Manual Vol I) gives a value of 1.4 metres. These values are of the same order of magnitude as those seen on the reef flat in Rarotonga during a hurricane.

The wave setup appears to be one of the more significant causes for the high water levels observed during a hurricane at smaller reef protected atolls or islands. Due to the presence of deep water seaward of the reef the wind setup should be relatively small.

STORM SURGE AT AN ISLAND

Storm surge is a storm related, temporary rise in the level of the sea water. There are two main factors causing storm surge. The first is the low atmospheric pressure found close to the center of a cyclone that may result in a water level rise of a half metre or so in the South Pacific (Krishna, 1984). A one centimeter rise in water level is expected for each mb depression of atmospheric pressure. The second factor relates to the piling up of water against the coast or reef by the strong winds of the cyclone. This wind effect is greatest on long flat coastlines and least for small islands that are surrounded by deep water.

The zone of significant storm surge typically is about 60 km in width when a cyclone passes. In the South Pacific the maximum storm surge is likely to occur between 10 and 25 km to the left of the cyclone track and have a duration of about 4 hours. Recent direct observations (Garcia, 1986) show that very rapid changes in sea water depth of more than a meter may occur over the time span of a few minutes during the passing of the center of the cyclone.

A storm surge of two to four metres are reported for both Nayau in Fiji (Krishna, 1984) and Funafuti in Tuvalu (Gabites, 1979). During the passing of a 20-25 year cyclone close to Rarotonga, 1967, a storm surge of 1.94 metre msl was recorded by water marks left in a building. The tide level was not greater than 0.5 metre and the barometric tide was estimated at 0.4 metre at the time of the maximum storm surge (Carter, 1985). Again in Rarotonga in 1987, a water level rise of 1.6 metres above predicted tide level was observed in Avarua Lagoon during a direct hit by Cyclone Sally (JICA Task Force, 1987).

The storm surge plus wave setup on islands that have significant reef flat area fronting deep water may include more wave setup during storm passage than would be estimated under non-storm conditions due the return of the water against the wind over shallow water.

The effect of a higher storm surge is to allow much larger waves to cross the reef flat without breaking before reaching the shoreline and in some cases breaking onto the land area itself. Serious damage may occur due to both flooding, wave, and reef rock impacts.

For the Mulinu'u Point site the storm surge was calculated over a 4.0 nautical mile (0.74 km) approach to the reef for a wind speed of 93 knots, a tide of 0.7 meters (0.2 metre msl), and a barometric tide of 0.7 meters. The wind setup was found to be 0.02 meters. Deep water near the reef precludes a significant wind setup. A rise in water level above the normal tide level will be due primarily from the barometric tide and wave setup at the reef. There will be some wind setup over the reef area. This is estimated to be on the order of 0.02 meters, so the total wind setup at the shoreline, wind setup at the reef plus wind setup over the reef flat, would be about 0.04 meters. Using wave setup of 1.4 metres the water level at the shore would be 2.34 meters msl. This value would indicate 1.5 metres flooding on land at the observatory.

This value appears to be excessive for use at Mulinu'u Pt. As water would spill over the land back into the mangrove and have a good sea return through the lagoon. Based on these uncertainties it appears that a water level rise of at least two metres above msl should be provided for in the design of a seawall at Mulinu'u Point.

ASTRONOMICAL TIDE

Mean tide level is 0.49 metres (Admiralty Tide Book, 1987). A survey conducted in 1970 (Lands and Surveys, 1970) indicated that the mean reading on the Apia tide staff between July 1965 and 1969 was 0.479 metres (msl 1970) and zero level was 1.582 metres below BM-1 located at the anemometer tower (this would be the old tide staff that is now lost). This msl datum is used as the local datum by the Department of Lands and Surveys in Apia. The value of 4.45 ft (1.356 m) above msl has been accepted as being the height amsl of the anemometer (the bolt on the SW corner of the SW block supporting the tower) for the primary msl reference datum (King, 1982). The BM-1 is 0.256 metres (0.84 ft) below the anemometer reference as shown on survey drawing 3137 dated 7/12/70.

A new tide staff has been installed and zero on the present tide staff was determined in 1985 to be 3.02 metres below BM-IV which is located on the SW corner of the tide gauge platform. The elevation of BM-IV was surveyed by Mr. David Ward in 1979-80 and found to be 2.323 metres above msl (1970). According to King (1982) the zero on the new tide gauge is 2.29 ft (0.698 m) below msl (1970) in 1981. These values agree within 3 mm.

The 100 year storm can be expected to impact the area for several hours. There would be a reasonable chance that the forward speed of the storm would be in the order of 10 to 12 knots, and it could have a diameter of 75 to 100 nautical miles (140 km to 185 km). The destructive part of the storm could impact an area some 4 or 5 hours; hence, there is a chance that high winds will occur during a high tide or at least 0.5 meters of tide. A maximum tide would be excessive as the event would then be one of >100 years recurrence. A tide of .7 meters is therefore assumed to exist during the time of highest wave impact.

HIGH WATER LEVEL

The 100 year water level at the shore would be the sum of the wave setup, storm surge (barometric tide and wind setup), and astronomical tide, ie: 1.4 + 0.7 + 0.2 = 2.3 metres msl within the lagoon.

The surface of the land at the shoreline was surveyed and found to be approximately 0.86 meters above msl (1970) in 1984. During the 100 year storm at least 1.4 meters of storm water would be expected to cover the land area near the shore at Mulinu'u Point.

As a comparison the 20 to 25 year hurricane that hit Cook Islands in 1967 was estimated to have produced about 1.54 metres rise in sea level in Avatiu, Rarotonga due to the combined effect of wind, wave, and barometric tide. The total rise in sea level was measured at 1.94 meters which included 0.4 metre rise of astronomical tide.

MAXIMUM WAVE HEIGHT

The maximum wave height is usually calculated using statistics developed by Longuet-Higgins (1952). This approach depends upon the number of waves being considered, ie:

$$Hm = Ho\ [\ 0.5\ \ln N\ ]^{0.5} \qquad (3$$

where Hm is the maximum wave height, Ho is the deep water wave, N is the number of waves being considered. A value of N = 1200 is assumed in this analysis which gives a maximum wave height of 21 metres outside the reef in deep water. This wave will break ahead of the reef face. A wave will reform from this breaking wave. The height of the secondary wave will depend upon both the height of the approaching wave and the depth of water at the reef. The significant wave height not the maximum wave height, is normally used for design of structures as the factors allow for the variation in wave size. The maximum breaker of about 24 metres in height would occur well ahead of the reef face at a water depth of about 27 metres. This wave can cause large amounts of the loose reef material which has accumulated ahead of the reef to be thrown onto the reef flat area. The first secondary wave would probably break at the reef and the next wave that formed would probably also break before reaching the shoreline. Generally some 60 percent of the wave energy can be lost during breaking.

The significant wave height will be employed for design. The smaller waves which reach the shoreline without breaking may break directly on the seawall structure. It is assumed that the 11 meter high wave will break at the reef and several solitary type secondary waves will form. Three secondary waves often form from one wave under these conditions. It is this secondary wave that will impact the seawall.

SECONDARY WAVE

In general the size of the secondary wave depends in part upon the slope of the reef face and the depth of water above the reef ridge. During major storms the reef may be modified significantly. In some instances material can be added to the reef. A ridge of rock can be deposited on top of the reef. In other cases the reef can be stripped of all material that is not massive and well cemented. In this design conditions it is estimated that the water depth over the reef ridge due to both astronomical tide and storm surge is 2.3 metres. The average water depth in the reef flat area during the 100 year storm condition was determined to be 3.2 metres from a bathymetric survey of the area in 1985 and the above tide and storm surge. A relationship developed by Dexter (1973), used by Homes (1979) in Tarawa, modified by Carter (1985) for use in Rarotonga, and further modified for hurricane waves in this analysis was used to estimate the secondary wave. The modified equation for d/Ho >0.325 is:

$$Hr = (Ho)^2 \times 3/4 \times 1/d \times [c/8(1-\exp-(d/Ho \times 1/c))]^{2/3} \qquad (4$$

where $c = 1.8446$, and d is the mean water depth at the reef crest, Hr is the height of the wave formed on the reef flat, and Ho is the height of the deep water wave. The equation for d/Ho <0.325 predicts that the secondary wave will increase in a linear relationship with the depth of water over the reef up to a maximum wave height. Thereafter it will decrease in height with the depth of water over the reef for a given height of deep water wave. The linear equation is:

$$Hr = 0.8215\ d. \qquad (5$$

Using the value of 11 meters for Ho and 2.3 metres for d the value of Hr is 1.9 metres. This wave height will be further modified over the reef flat due to refraction of the wave over the bottom contours of the reef, and combined with a wind wave generated over the 0.7 nautical mile (1.3 km) of fetch on the reef flat (Admirality, 1950 and 1963) before it reaches the shoreline. The secondary wave is a solitary wave.

SHOALING EFFECT

The wave height changes as a wave enters more shallow water. The water depth usually increases shoreward of the reef and then becomes less approaching the shoreline across the reef flat. Changes in wave height occur as the water depth changes. These changes can be described by the following relationship:

$$H/Hr = Kr\ Ks\ Kf \qquad (6$$

where Kr, Ks, and Kf are the refraction, shoaling, and friction coefficients respectively (Wiegel, 1964 and Gaythwaite, 1981). H and Hr are defined above. The refraction and shoaling coefficients are explained together and the friction coefficient is explained later.

The power transmitted by a train of waves between two orthogonals, lines drawn perpendicular to the wave crest at some spacing along the crest, is constant. The power is distributed over the wave crest between the two orthogonals as they diverge or converge due to bending of the wave crest as a change in water depth requires (Wiegel, 1964). The height of a wave is modified according to the following argument:

$$H = Hr[Co/C]^{0.5} \times [bo/b]^{0.5} \qquad (7$$

where H is the resulting wave height, Co is the wave velocity in deep water, and C is the wave velocity in shoal water. The wave velocity is a function of the water depth. The bo is the orthogonal spacing in deeper water and b is the spacing in shoal water. The analysis is generally performed graphically or by computer program. In this analysis Kr and Ks will be determined graphically on a bathymetric chart prepared for this purpose. Wave refraction diagrams for the pre-dredging condition and the post-dredging condition for two wave directions are shown in Figures 5, 6, and 7. Values of the product KrxKs varied from 1.1 to 2.0.

The friction coefficient is assumed to be 0.97 for the impervious reef flat area. The percolation within the coral rubble and sand bottom may be significant; however, in this analysis it is assumed to be included in the friction coefficient.

The combined K coefficient used in the wave analysis was therefore 1.0 and this value was used to modify the wave height employed for the estimated weight of the armor rock needed to cover the seawall.

DESIGN WAVE

The wave developed at the reef is found to be 1.9 metres in height. These waves are translating and act similar to solitary waves. However, as three or so waves will develop from each 13.6 second wave that reaches the reef they will occur every 3.5 second on the average. The distance between the reef and the shoreling was estimated to be 1296 meters, and the average depth was estimated at 3.2 metres. With a wind speed of 93 knots a wind wave of 1.2 metres height would be generated over the reef flat. Combining the solitary and the wind wave on an energy basis gives a solitary wave equivalent to 2.0 meters in height at the shoreline. This wave appears to be the largest wave that would break upon a seawall located at the shoreline. A larger wave could break upon the reef flat ahead of the seawall. This 2.0 meter wave is taken as the design wave for the seawall armor rock. As a comparison waves were estimated to be 2 metres in height in the Avarua Lagoon and 0.7 metres inside Avarua Harbour during Hurricane Sally on the 2nd of January this year. The waves outside the reef were estimated to be 7.8 metres at 10 seconds with the maximum waves at about 12 metres.

POSSIBLE SEAWALL DESIGN

A multiple layer rubble mound seawall is suggested for protection of Mulinu'u Point and its western shore. Local rock is available for this type of construction. A gravel filter and graded layers of cover rock protected by two layers of armor rock are part of this type of design. All of the material is to be obtained locally. The armor rock is rounded in shape and more or less smooth. It was found to have a specific weight of 2.69 MT/CUM (168 lbs/cf). The following Hudson equation (US Corp of Engineers, 1977) was employed to estimate the appropriate weight of the armor rock:

$$W = \frac{s\,H^3}{K\,(S - 1)\,\cot a} \qquad (8$$

where W is weight of armor, s is the specific weight of the rock, H is the wave height, S is the specific gravity of the rock, and cot(a) is the armor unit layer slope. K is a dimensionless, experimentally evaluated, coefficient (Bruun, 1976) that depends primarily on armor unit shape and method of placement, wave breaking condition, location along the structure, and allowable damage. Values for W are given in Tables I, II, III, and IV for the conditions indicated. The largest units are placed at the head of the structure where breaking waves are encountered. The trunk of the structure can utilize smaller rock. The thickness of the different grade layers of rock are indicated in the tables along with the sizes of the grades. A plan view of the seawall is given in Figure 8, and the arrangement of the layers of rock are shown in the profile view in Figure 9.

When large waves come from a northern direction, wave energy is concentrated along the entire west end of Mulinu'u Pt (Figure 6). This condition will exist as long as the present bottom topography remains. The seawall profile (Figure 9, Table I) is the minimum safe design for the entire west end of the Peninsula. Once sand returns to the dredged area the wave energy would be less at the seawall. The lighter rock shown in Tables II through IV would be adequate for the wave sizes and conditions given in those tables. The shoreline in section 4 will receive somewhat smaller waves, so the rock sizes given in Table II should be safe for this section.

COST CONSIDERATIONS

A preliminary sketch of a suggested seawall scheme was given to Mr. Alan Minson of SPDC (Special Projects Development Corporation) in 1985 for making a cost estimate. The general plan used for the estimate is shown in Figure 8. The first stage of construction includes 198 metres of shoreline shown as Stage I in Figure 8 and the second stage includes 181 metres of shoreline protection. Since Mr. Minson's estimate, the size of the armor rock has been increased as well as the elevation of the top of the seawall. The cost estimate was made for 3650 pound armor rock, and the top of the seawall was just above ground level. The costs as given by SPDC's Chief Estimator, Mr McGarva are as follows:

Mulinu'u Protection: Stage I (198.1 m)

1.	Establishment	$ 4,000
	-Setting Out	1,500
	-Supervision	3,200
2.	Clearing Site	1,000
3.	Leveling & Cutting to Profile	12,600
4.	Cartage Cost	15,030
5.	Material Cost - Crusher feed	20,190
	- Crushed sizes	41,830
6.	Placing Material	14,000
7.	Overheads & Profit, 25%	28,410
8.	Contingencies, say 10%	14,200
	Total	$156,000

Mulinu'u Protection Stage II (180.9 m) Total $143,000

The estimate was received 17 December 1985, and the costs do not allow for changed in the rate of exchange and local costs as well as some additional material and placement costs for increased volume of material required for the revised design. The revised design calls for armor weighing 4,400 lbs (2 metric ton) and a height of one meter above ground level. These revisions are assumed to approximately double the overall cost of the structure. The total weight of armor rock was estimated to be 2614 tonnes for both stages of protection costed above. The revised design requires a total of 10,945 tonnes of armor rock. This would indicate a unit cost of about $1,579 per metre for 380 metres of breakwater.

The 2330 metres of breakwater constructed on Nuku'alofa in 1983 had an overall cost of 358.39 Tala per metre. This included quarry, transport, dredging, backfill, 10 culverts for drainage, and construction costs including spare parts.

RECOMMENDATIONS AND CONCLUSIONS

The following recommendations and conclusions are based upon the findings of this study and other data from Western Samoa and elsewhere in the South Pacific Islands. Reliable tropical cyclone data from the last ten years was used. Additional supporting data was also used from about the last 100 years. However, this data was considered less reliable than the more recently collected information. A much more reliable evaluation should be possible when 20 years of observations using modern methods become available. The extreme wave, storm surge, and wave setup are expected to be close to the estimates given here, and no conservative margin of safety is built into the calculations.

1. It is recommended that a multiple layer rubble mound seawall be built along the west end and around the north point of Mulinu'u Pt to stabilize this area at its present position. Further consideration should be given to the construction of a seawall along the seaward or northeast side of the peninsula. This seawall could be located 30 metres or so out on the reef flat and reclaim some land that has been lost to the sea.

2. Absolute protection of Mulinu'u Point against extreme high waters and wave attack which have to be expected during the 100 year cyclone is not considered because of the enormous cost. The protection is designed to cause the reef wave to break before reaching the land proper. It is also designed to provide erosion protection for the land located near the west end of the peninsula where the dredging of sand has altered the wave pattern.

3. Tropical cyclones with winds of at least gale force (whole gale 48-55 k, knots) can be expected over Mulinu'u Pt on the average of one in three years, storm force winds (56-63 k) can be expected each decade, hurricane force winds (64-71 k) average one in 16 years, and a major hurricane (>93 k) can be expected once in 85 years.

4. There are sufficient landmarks and important facilities located at the west end of Mulinu'u Pt. to warrant adequate protection from erosion by the sea. There are numerous important structures located along the trunk of the peninsula that will justify the rebuilding of an adequate breakwater along the entire western side. Only the western end was considered in detail in this study.

5. The design water level of 2.3 metres above msl could occur during the 100 year storm. Recent slow speed hurricanes under conditions that are comparable to that at the project site have resulted in storm surges on the order of 2 to 3 meters. The value of 2.3 metres was derived theoretically.

6. While the proposed seawall for the west end of Mulinu'u Pt would not be effected by the dredging of sand much closer than 300 meters distance, it is recommended that dredging be prohibited within 300 metres of the seawall in order for the sand to accumulate in that zone and establish bottom topography that is similar to the pre-dredging condition.

7. Some surface drainage immediately shoreward of the seawall should be provided to prevent flooding during heavy rainfall. At least three storm catchment basins should be considered for the west end. They could be connected directly to the reef flat area as no significant pollution would be anticipated in this area.

8. Local rock either from a quarry which would tend to be rough and angular. Rock from the field areas tend to be smooth and rounded. Either should be adequate for a seawall. The field rock tested had an apparent weight of 168 pounds per cubic foot. Tests to establish the strength, hardness, chemical stability, and specific weight should be made before using any quarry rock.

9. One layer of armor stone is recommended to protect the toe of the seawall. The main front surface of the seawall should have two layers of stone and the top should have at least three stones in width. The back two courses of cap

armor can be one ton rock, but the front cover should be two ton rock as is shown in Figure 9. The individual armor rock should be weighed and/or measured to confirm their size. The blocks must be carefully placed under the supervision of the site engineer.

10. Any existing holes or presence of poor foundation material in the supporting layers are to be excavated and carefully filled with sound material.

11. The filter layers (Figure 9) are an essential functional feature of the seawall structure, and particular attention should be given to rock size of the layers as well as the elevation, grade, and thickness of the layers. They are a foundation for the armor stone, a protection for the fine material in the soil material, and serve as a seawater return.

12. In the event of a major cyclone people should be evacuated from the peninsula as the waves could cut away the roadway and isolate the western end. Storm surge could then be a serious hazard.

13. No tests of the bearing strength were made on the foundation material for the seawall location. Neither was the site explored for soft or peat deposits that are known to exist nearby. Some foundation evaluation will be required.

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TABLE I

SEAWALL DESIGN VALUES

Remarks : Head with Breaking Waves   Kd = 1.7
Wave H = 6.6 ft   Wave P = 4.1 sec   Wave L = 91
Wt Rock = 168 #/cf   Slope 1 : 2   N = 2

Material	Weight Rock Lbs.	Diam. Ft	Thickness Ft	Remarks
ARMOUR ROCK	8394	4.6	8.5	Smooth and Rounded
W/10	839	2.1	2.1	Angular
W/200	42.0	0.8	1.0	Angular
W/4000	2.10	0.3	1.0	Mill Run

Total Thickness = 12.6

TABLE II

SEAWALL DESIGN VALUES

Remarks : Head Non-Breaking Waves   Kd = 1.9
Wave H = 6.6 ft   Wave P = 4.1 sec   Wave L = 91 ft
Wt Rock = 168 #/c   Slope 1 : 2   N = 2

Material	Weight Rock Lbs	Diam. Ft	Thickness Ft	Remarks
ARMOUR ROCK	7511	4.4	8.2	Smooth and Rounded
W/10	751	2.0	2.0	Angular
W/200	37.6	0.8	1.0	Angular
W/4000	1.88	0.3	1.0	Mill Run

Total Thickness = 12.3

TABLE III

SEAWALL DESIGN VALUES

Remarks : Non-Breaking Trunk		Kd = 2.4
Wave H = 6 ft	Wave P = 4.1 sec	Wave L = 91 ft
Wt Rock = 168 #/cf	Slope 1 : 2	N = 2

Material	Weight Rock Lbs	Diam. Ft	Thickness Ft	Remarks
ARMOUR ROCK	4467	3.7	6.9	Smooth and Rounded
W/10	447	1.7	1.7	Angular
W/200	22.3	0.6	1.0	Angular
W/4000	1.12	0.2	1.0	Mill Run

Total Thickness = 10.6

TABLE IV

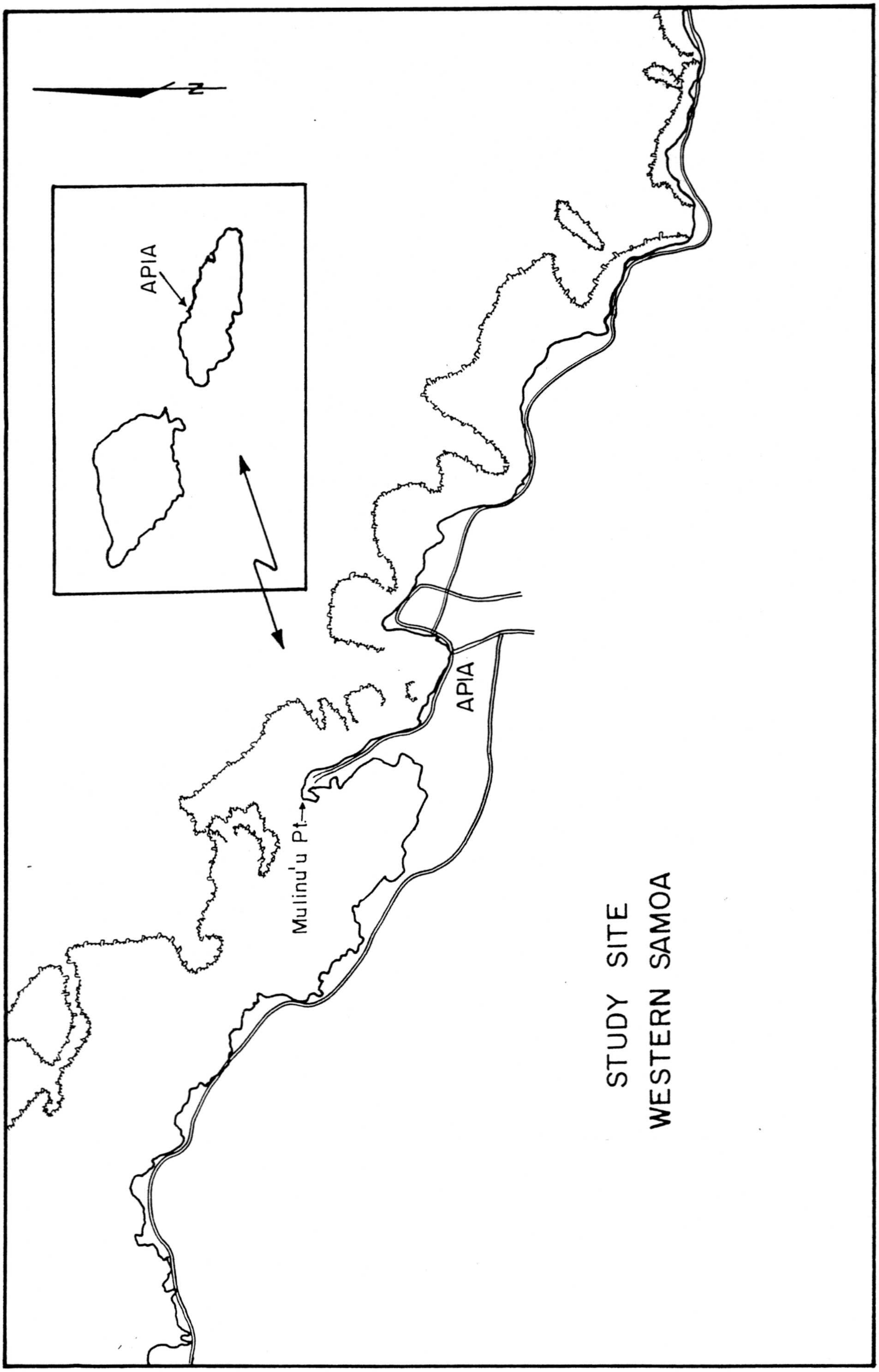
SEAWALL DESIGN VALUES

Remarks : Non-Breaking Trunk		Kd = 2.4
Wave H = 5 ft	Wave P = 4.1 sec	Wave L = 91 ft
Wt Rock = 168 #/cf	Slope 1 : 2	N = 2

Material	Weight Rock Lbs	Diam. Ft	Thickness Ft	Remarks
ARMOUR ROCK	2585	3.1	5.8	Smooth and Rounded
W/10	259	1.4	1.4	Angular
W/200	12.9	0.5	1.0	Angular
W/4000	0.65	0.2	1.0	Mill Run

Total Thickness = 9.2

Figure 1.



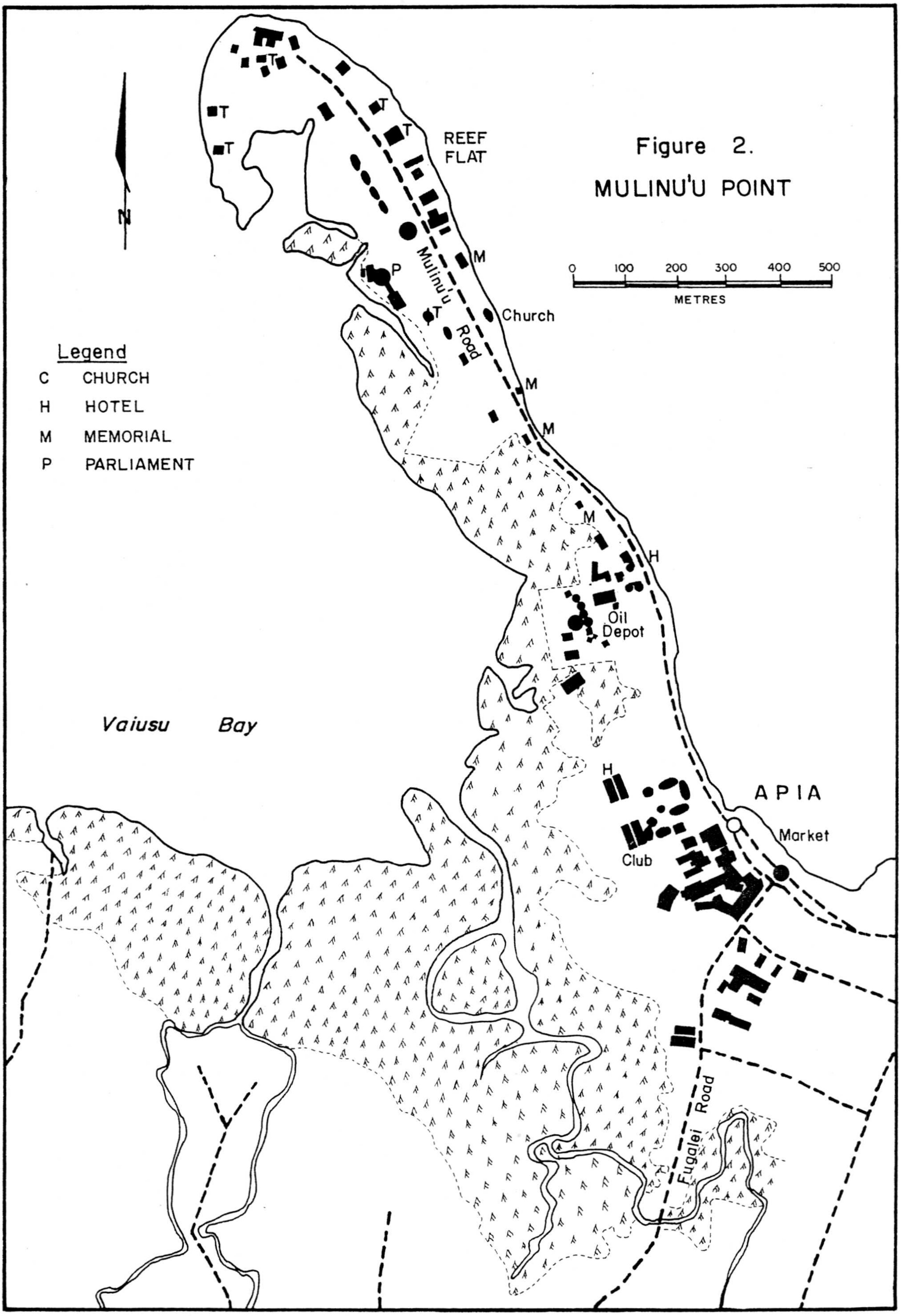


Figure 2.
MULINU'U POINT
0 100 200 300 400 500
METRES
N
REEF FLAT
Mulinu'u Road
Church
P
T
M
H
Oil Depot
Club
APIA
Market
Fugalei Road
Vaiusu Bay
Legend
C CHURCH
H HOTEL
M MEMORIAL
P PARLIAMENT

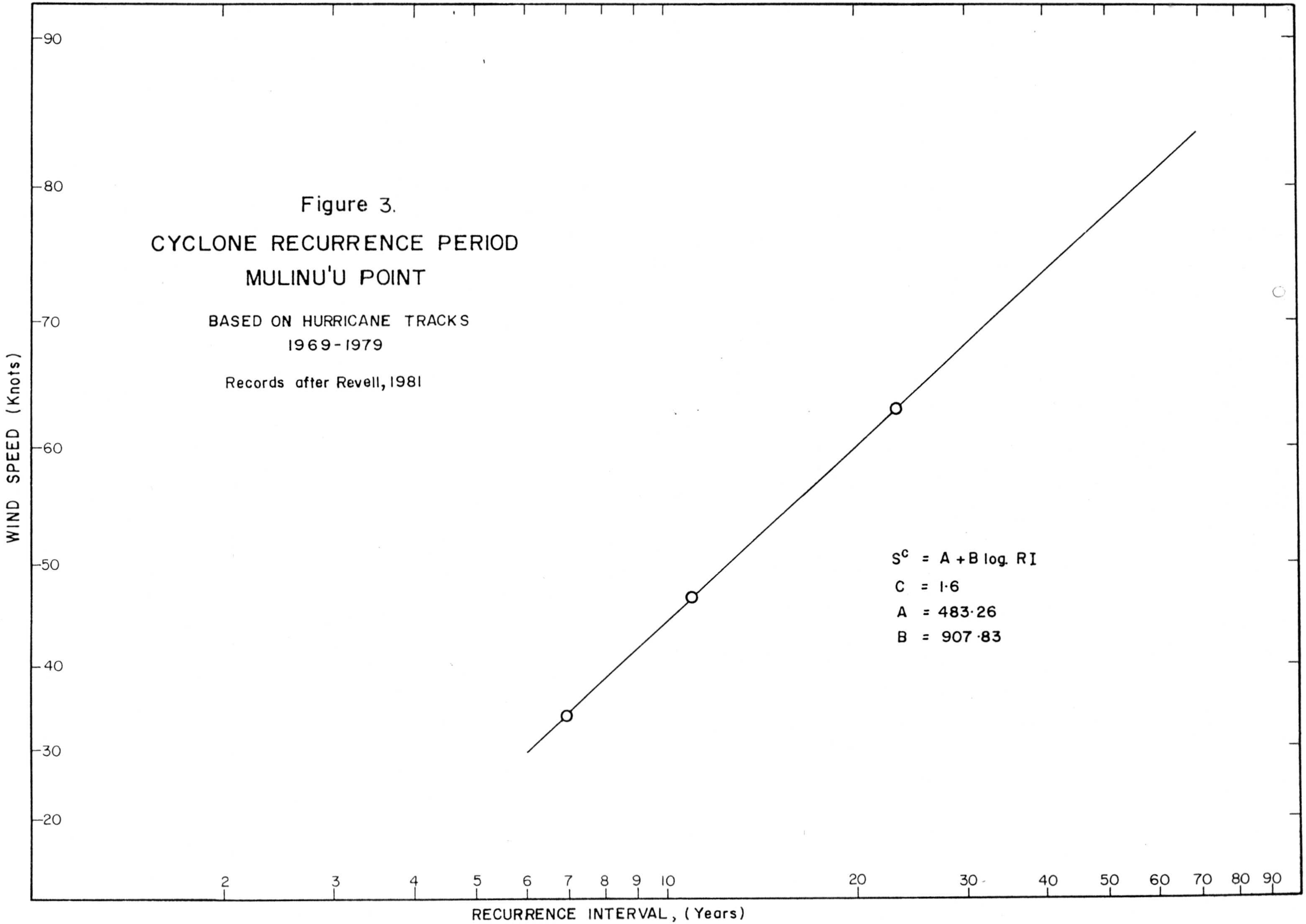


Figure 3.
CYCLONE RECURRENCE PERIOD
MULINU'U POINT
BASED ON HURRICANE TRACKS
1969-1979
Records after Revell, 1981
S^C = A + B log. RI
C = 1·6
A = 483·26
B = 907·83
WIND SPEED (Knots)
90
80
70
60
50
40
30
20
RECURRENCE INTERVAL, (Years)
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90

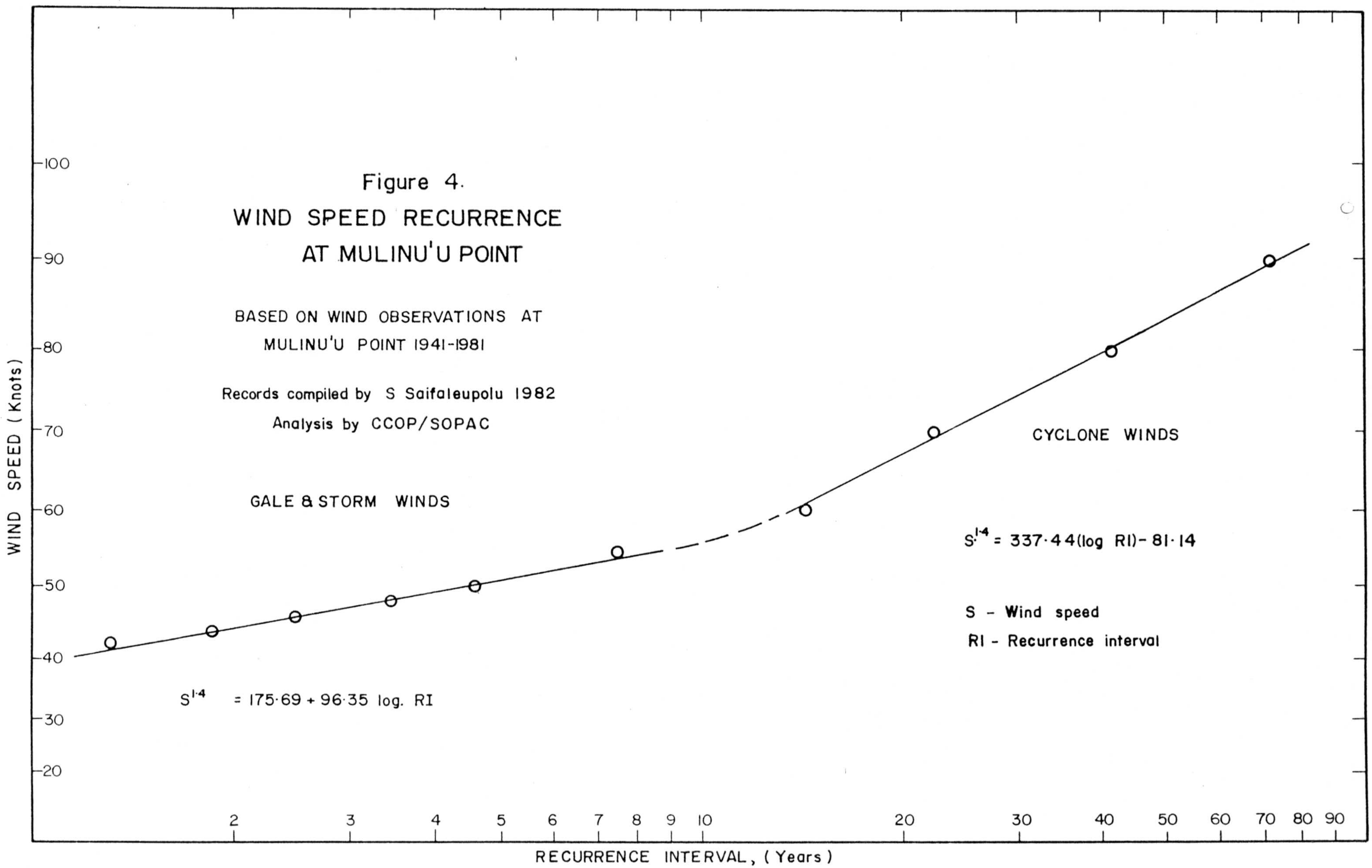
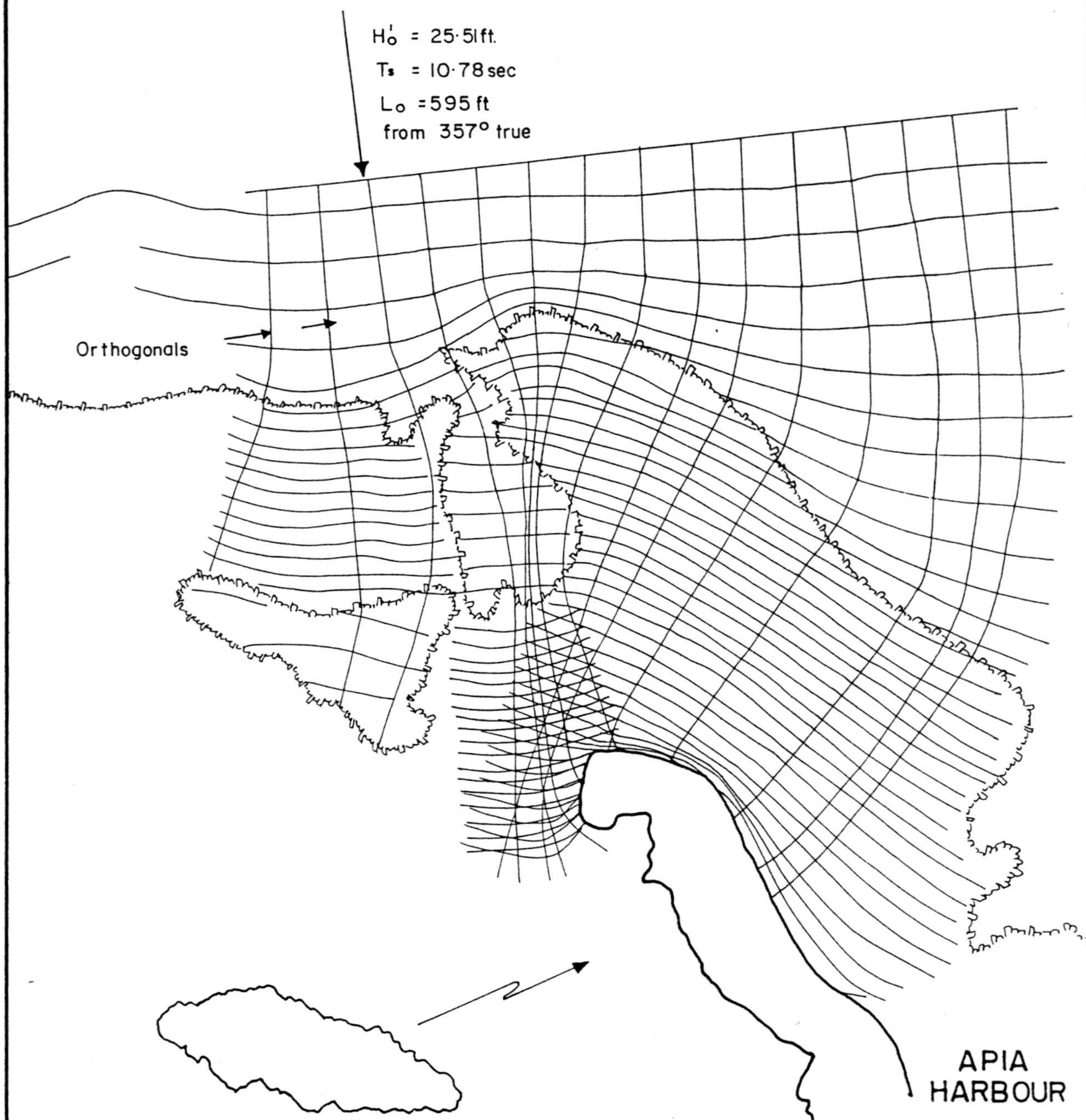


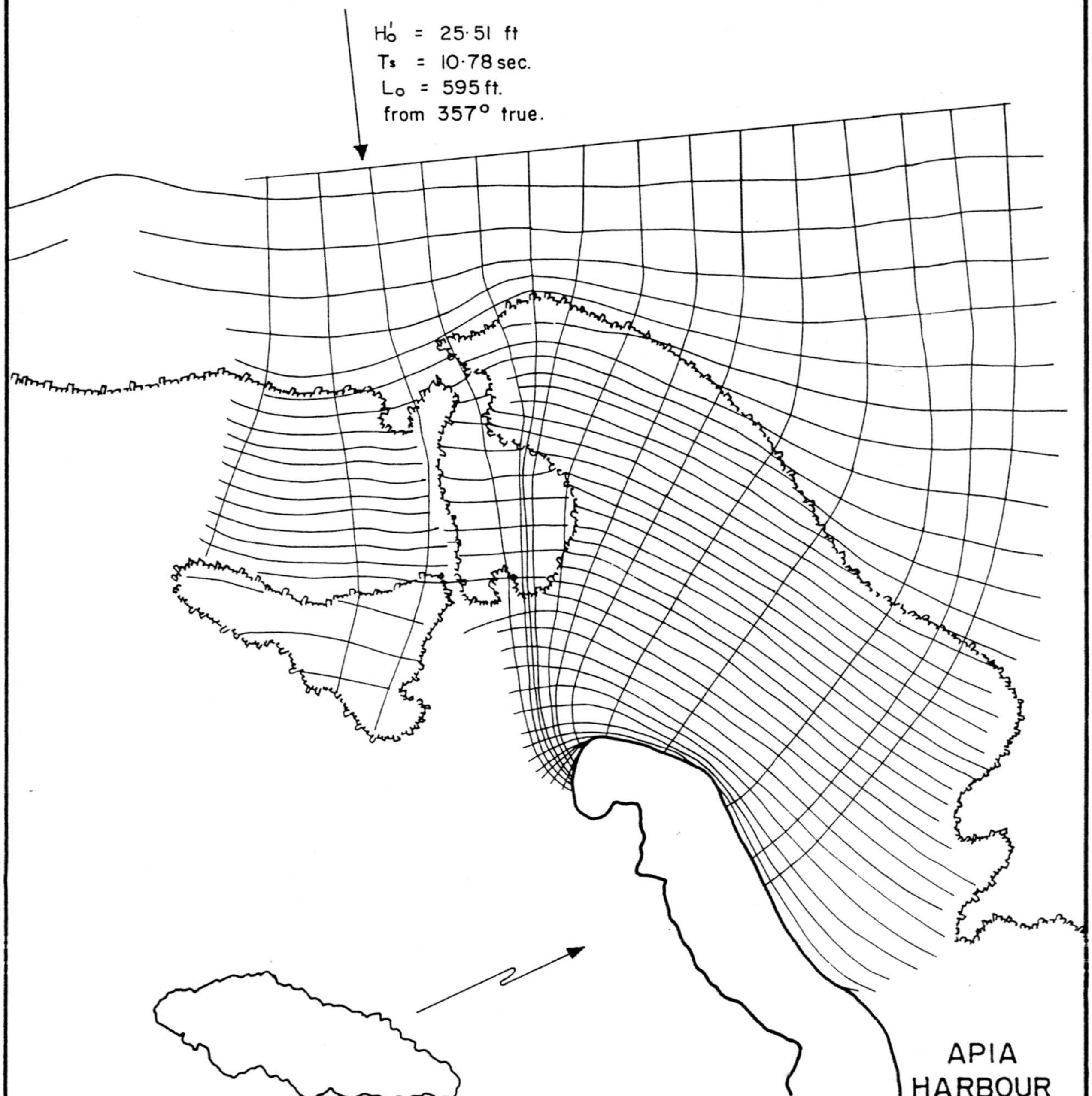
Figure 4.
WIND SPEED RECURRENCE
AT MULINU'U POINT
BASED ON WIND OBSERVATIONS AT
MULINU'U POINT 1941-1981
Records compiled by S Saifaleupolu 1982
Analysis by CCOP/SOPAC
GALE & STORM WINDS
$S^{1.4} = 175.69 + 96.35 \log. RI$
CYCLONE WINDS
$S^{1.4} = 337.44(\log RI) - 81.14$
S - Wind speed
RI - Recurrence interval
WIND SPEED (Knots)
100
90
80
70
60
50
40
30
20
RECURRENCE INTERVAL, (Years)
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90

FIGURE 5



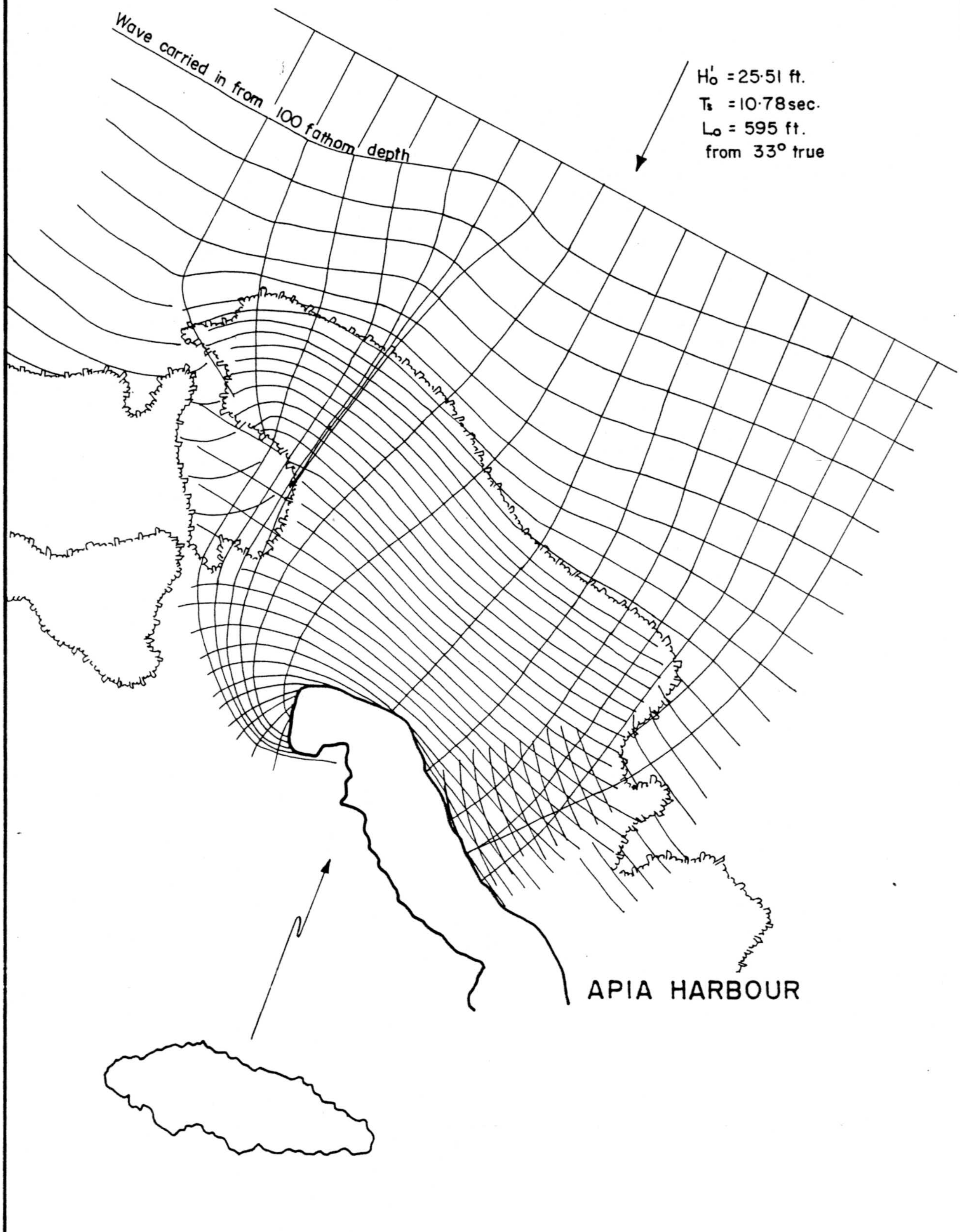
Wave defraction of a north wave for the pre-dredging condition on Mulinu'u Pt. Note moderate concentration of wave energy upon the point with a significant number of orthogonals passing to the west of the land area into Vaiusu Bay

FIGURE 6



Wave defraction of a north wave for the Post Sand dredging condition at Mulinu'u Pt. Note the in-force focusing of wave energy upon the beach at the east side of the Point.

FIGURE 7



Wave defraction of a north east wave for the Post Sand dredging condition at Mulinu u Pt. Note the high concentration of orthogonals being focussed upon the beach towards the southern end of the Point.