FMR

Department of Transport & Regional Services

Cocos (Keeling) Islands

Report On

Seawall Upgrade Design Concept

January 2000

GHD

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1. Introduction

A vertical seawall constructed on the western shoreline of West Island, Cocos (Keeling) Islands extends approximately 300m southward from House 1, Qantas Close providing protection to 7 properties including Government House. Wave reflections from the seawall result in a high level of wave energy in front of the wall and large waves have overtopped the seawall, with debris and green water reaching the adjacent houses. The most recent occasion this was reported to occur was in August 1999.

It is known that the wall has been overtopped at least 3 times in the past 20 years and on one occasion the extent of overtopping was sufficient to cause collapse of sections of the wall. In recent events wave overtopping has occurred at water levels lower than high tide. In the event that large wave conditions occur coincidently with high tide the volume of water overtopping the seawall will be greater and adjacent houses may be damaged. It is possible that future overtopping could occur more frequently and that a major storm event, say with a 1 in 20 year or 1 in 50 year return period, could cause a substantial breach and threaten the safety of the houses.

The seawall is currently in moderate condition with the majority of steel posts exhibiting heavy corrosion and a substantial length of the wall leaning seaward. In addition erosion of backfill material occurs at a number of sections of the wall.

GHD has been commissioned by the Department of Transport and Regional Services to undertake design investigations and prepare a concept design report for upgrading of the seawall to provide improved protection to adjacent properties.

This report provides a basis for future detailed design and construction of an upgraded seawall. Key elements of the design investigation include establishment of existing site conditions and design parameters such as:

- Design Wave Conditions;
- Design Water Levels;
- Local Bathymetry; and
- Local Reef Conditions.

A site visit was undertaken to obtain essential site data. This included a survey of water depths in front of the seawall and across the reef flat, investigation of foundation conditions at the toe of the seawall and measurement of currents across the reef flat.

Wave forces are the major design parameter for upgrade of the seawall and the key element in determining the structural requirements and long term risks of damage to the seawall was to obtain appropriate wave data for the site. For an external shore on a typical coral atoll this involves defining ocean wave conditions and examining the wave transformation processes on the reef.

Long term time series of hindcast wave data were obtained from the British Meteorology Office to derive a storm wave height exceedance curve. In recent years this hindcast data has been verified by checks against satellite measurements. Wave transformation across the reef is a complex process involving wave breaking on the reef edge, wave generation on top of the reef and refraction by reef top currents generated by wave set up as well as the effects of bottom friction.

Water levels also influence the height of waves at the toe of the wall, and high water levels coinciding with storm events can have a major effect on overtopping volumes. Knowledge of local bathymetry is critical in assessing design water levels and wave heights. Surveys of the reef flat and beach zones in the vicinity of the seawall wall were undertaken during the site visits.

Reef top and nearshore currents were investigated by releasing drogues and tracking their movement.

Test pits were also dug near the seawall toe and probing with a steel bar was carried out to identify foundation conditions.

Conceptual designs have been prepared for alternative seawall upgrade options and appropriate design parameters determined for detailed design. It is recommended that a sloping seawall be constructed over and in front of the existing vertical wall using the existing seawall as permanent form work and support. Given the isolated location of Cocos (Keeling) Islands it is recommended that the upgraded seawall be armoured using Seabee units. When properly installed these units provide the advantages of a durable, low maintenance revetment, that is also more aesthetic than a rock seawall. The comparatively smooth surface of a Seabee wall also means that it is less susceptible to trapping and accumulating water borne debris, which is a constant feature along the shoreline of Cocos (Keeling) Islands.

In order to minimise overtopping of the seawall a curved wave deflector should be located along the crest. This will enable larger waves to be turned back onto following waves and assist in reducing wave run-up and overtopping during storm events.

2. Background

A vertical seawall, constructed in 1975, extends approximately 300m southward from House 1, providing protection to 7 properties including Government House. The location and extent of the seawall is shown in Figure 1, following. The wall comprises concrete planks inserted between steel posts (at 5m spacing) and varies in height from approximately 1.1m at the southern end to 3m in the northern sections.

The concrete panels and steel posts are mostly in a moderate condition. A number of steel posts are heavily corroded and a substantial length of the wall is leaning seaward. Figures C1 to C6, Appendix C, show the condition of the seawall as it was in September and November 1999. In addition substantial erosion of backfill material was observed adjacent to House 1 and indications of repairs to similar problems were observed in front of House 2 and House 3. In these areas backfill at the top of the wall was comprised of coral sand and rubble.

House 1 and House 4 are set back less than 10m from the top of the seawall, while Houses 2, 3, 31, 32 and Government House are all set back between 15m and 26m. House 1 is located at the highest elevation and is approximately 0.8m higher than Government House. House 31 and House 32 are also located at a lower level and the seawall does not extend fully across the southernmost property. The proximity of these houses to the top of the seawall, as indicated in Table 1, means that they are susceptible to damage when overtopping occurs.

Table 1 Proximity of Housing to Seawall

Building	Floor Level	Approximate Ground Level	Approximate Setback Distance
House 1	+4.62m	+3.5m	5m
House 2	+4.67m	+3.3m	22m
House 3	+4.47m	+3.2m	15m
House 4	+4.22m	+3.1m	9m
Government House	+3.76m	+2.7m	22m
House 31	+3.91m	+2.8m	26m
House 32	+3.85m	+2.8m	21m

Note: All levels relative to mean sea level datum.

It is reported that large waves have overtopped the seawall in recent times, with debris and green water extending under all the adjacent houses. Anecdotally, these events have occurred during periods of large offshore swell, but have not necessarily coincided with high tides. In the event that large wave conditions occur coincidently with high tide the volume of water overtopping the seawall will be greater and these houses may be damaged.

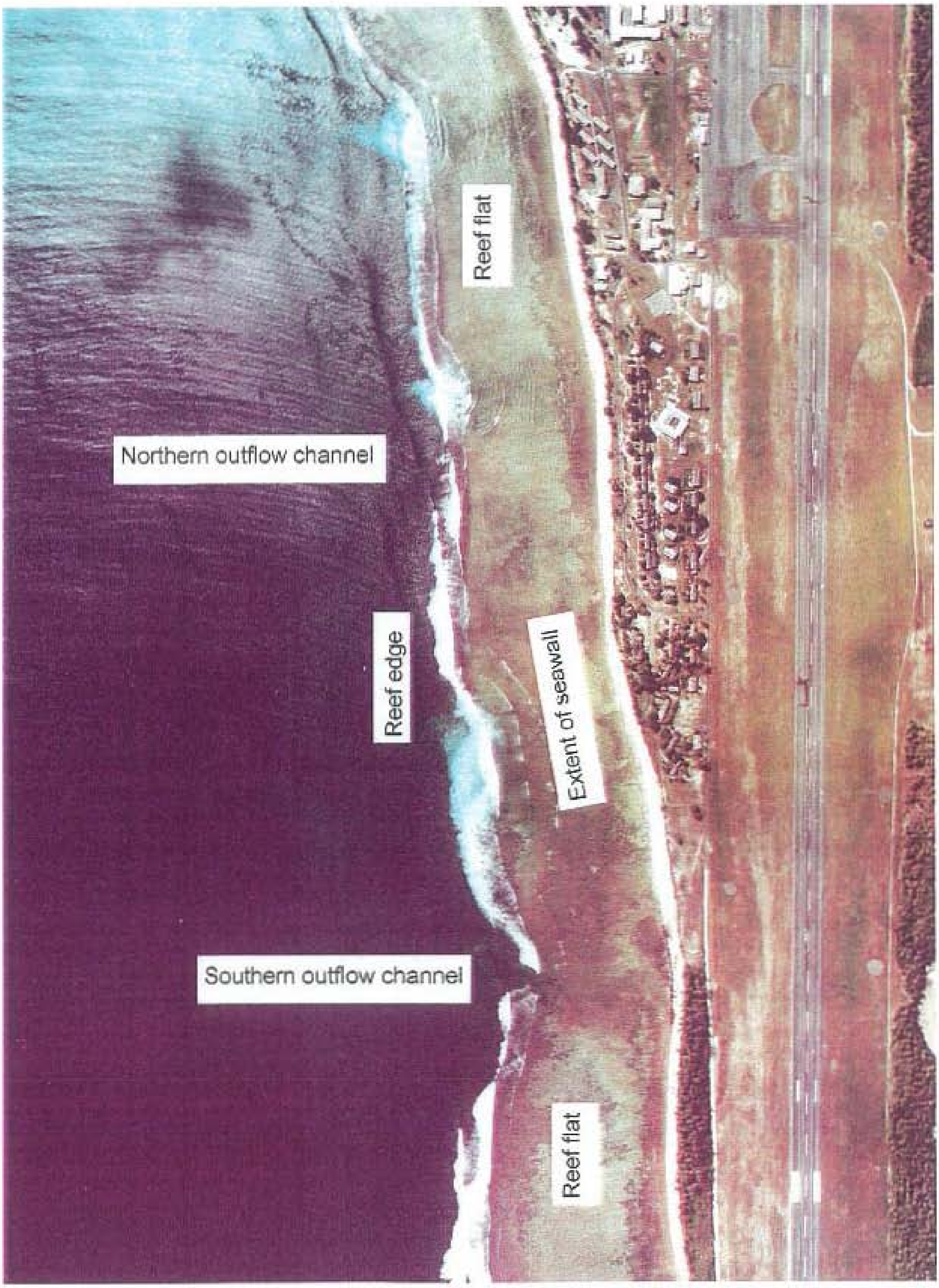
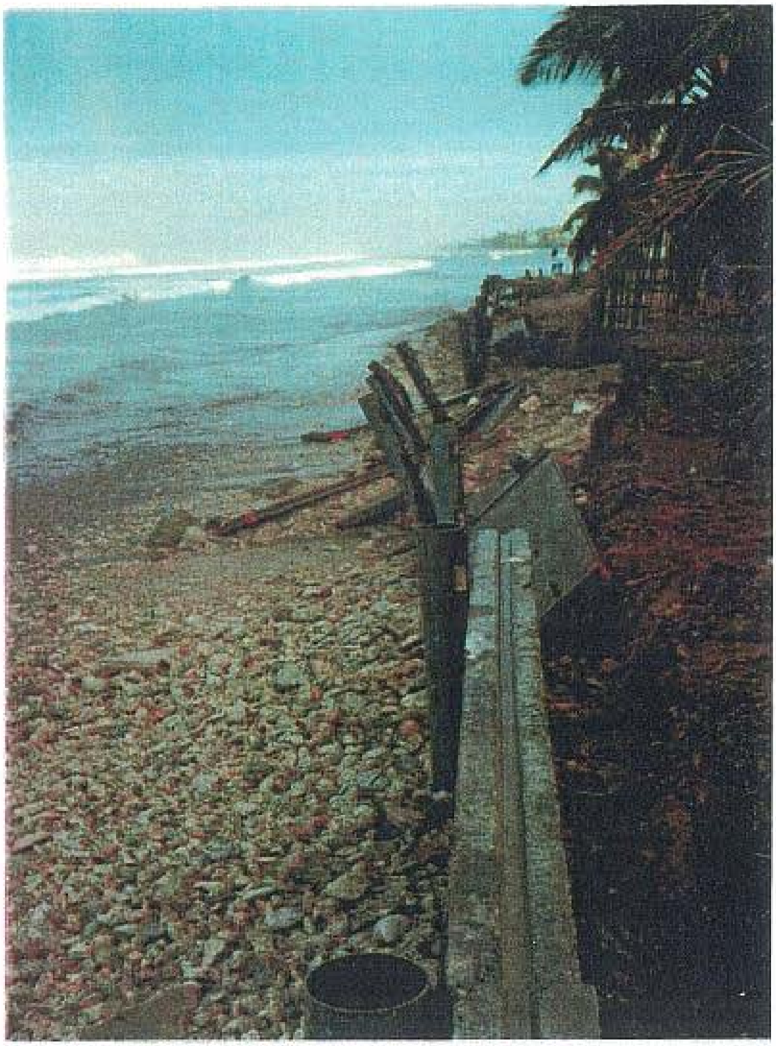


Figure 1: Western shoreline of West Island showing location of seawall.

Significant amounts of wave overtopping occurred in August 1980 and eroded the soil behind the seawall, resulting in collapse of the northern 70m of the wall, as illustrated in Figure 2. This section was subsequently reinstated.

Figure 2. Damage to northern end of seawall, 1980



Should similar heavy overtopping occur in the future resulting in the collapse of sections of the seawall the protection to the houses will be further compromised.

Wave reflections from the seawall result in a high level of wave energy in front of the wall and as a result sand does not accrete in this area. The beach immediately in front of the shoreline predominantly consists of coral rubble and concrete debris and slabs. Many of these have been dumped in an attempt to prevent undermining of the seawall. In the northern sections and beyond, large coral outcrops were observed and increasing volumes of sand.

3. Existing Environment

The Cocos (Keeling) Islands comprise a group of low-lying islands situated on a continuous reef flat and surrounded by deep ocean. The islands form an atoll made up of 27 coral sand land masses, of which only 2 are currently inhabited. A single uninhabited island, North Keeling, lies 24km to the north of the main atoll group.

The southern atoll, located at Latitude 12°12'S, Longitude 96°54'E, comprises 26 islands encircling a shallow lagoon. The islands have been created on the leeward side of the reef platform as a result of wave, wind and tide action under both natural and cyclonic conditions. They are geologically very recent, and are unstable and floodable structures. Land elevations are generally 2m to 3m above sea level, with the highest elevation being approximately 9m above sea level.

The environment in which the islands are located is highly dynamic and the islands are continually responding to changes in wind, wave and water level characteristics. Human activity has also affected the natural evolution of the islands through natural processes at various times, by means of groynes, seawalls, jetty construction and dredged channels. Historical coastal changes either natural or man made, have contributed to erosion and accretion problems experienced in some areas of West Island's foreshore.

Erosion and accretion of the island's shoreline is influenced by a variety of mechanisms. Wave action is the most important of these. Wind induced waves and swell approach the reef platform from various directions and break on its edge. Changes in wave conditions have the potential to alter shoreline alignments through increased erosion or accretion of sand. The ocean facing shoreline of the islands are particularly susceptible to changes in wave conditions and water levels and can respond rapidly to changes in this dynamic environment.

3.1 Physical Parameters

The physical parameters that impact on the performance of the seawall are:

- Wind conditions;
- Wave heights;
- Water levels;
- Current patterns; and
- Sedimentation.

3.1.1 Winds

The Bureau of Meteorology maintains a station at Cocos (Keeling) Islands. Analysis of historical wind data indicates that south easterly trade winds persist for more than 85% of the year. During the period April to October the wind climate is characterised by winds from the east to south east. These winds are generally strongest between July and September.

During the doldrums period from November to March wind speeds become more variable and wind directions tend more northerly. While average wind speeds are less during this period, the maximum recorded wind speeds typically occur between November and March.

Table 2 following indicates daily mean wind speeds and extreme wind speeds for each month.

Table 2 – Wind speed characteristics - Cocos (Keeling) Islands

Month	Daily mean wind speed (m/s)	Maximum recorded wind speed (m/s)
January	5.3	48.8
February	4.6	34.0
March	5.3	28.3
April	6.1	29.3
May	6.9	27.8
June	7.0	30.9
July	7.8	24.7
August	8.0	36.0
September	8.1	24.2
October	7.5	24.2
November	7.2	40.1
December	6.0	27.3

The islands are also infrequently subjected to cyclones. Major cyclones have been recorded in 1862, 1876, 1893, 1902, 1909 and 1968. In 1968 Cyclone Doreen passed directly over the islands. Between 1961 and 1992, 23 cyclones passed within 100km of Cocos (Keeling) Islands.

3.1.2 Waves

Waves at Cocos (Keeling) Islands are a combination of wind waves and swell waves. Waves generated and still under the influence of local winds are called wind waves. In ocean waters these waves are influenced by wind speed, duration and fetch, the distance over which the wind is blowing. Waves that have moved out of their area of generation are called swell waves. The predominant swell waves reaching Cocos (Keeling) Islands originate from low pressure systems in the southern Indian Ocean.

Offshore conditions derived from hindcasting waves at 6hr intervals from world synoptic records for the period 1993 to May 1999, sourced from the British Meteorology Office, indicate that 84% of wind waves occur from the south east quadrant and a further 9% occur from the north east quadrant. Less than 8% of wind waves occur from westerly directions.

Swell waves predominantly occur from the south west quadrant (74%), with only 24% of swell waves generated in the south east quadrant. Less than 4% of swell waves occur from northerly directions

More than 99% of combined offshore significant wave heights exceed 1.0m and more than 43% exceed 2.0m. The largest significant wave heights during this 6½ year period were estimated to be in the order of 4.5m. Corresponding maximum wave heights would be in the order of 8m.

Derived wave heights for the period 1993 to 1999 are shown in Figures A1 to A7, Appendix A. These indicate both wind and swell wave components and the combined wave height.

3.1.3 Water Levels

Water levels in normal weather conditions are controlled by the astronomical tides. Tides at Cocos (Keeling) Islands are semi diurnal, meaning two high tides and two low tides occur each day. The mean tidal range is approximately 0.5m at neap tide and 0.7m at spring tide, with a maximum tide range in the order of 1.2m. Representative tidal planes for Cocos (Keeling) Islands obtained from the National Tidal Tables (1999) are shown in Table 3 relative to lowest astronomical tide (LAT) datum and mean sea level (MSL).

Table 3 - Tidal Planes - Cocos (Keeling) Islands)

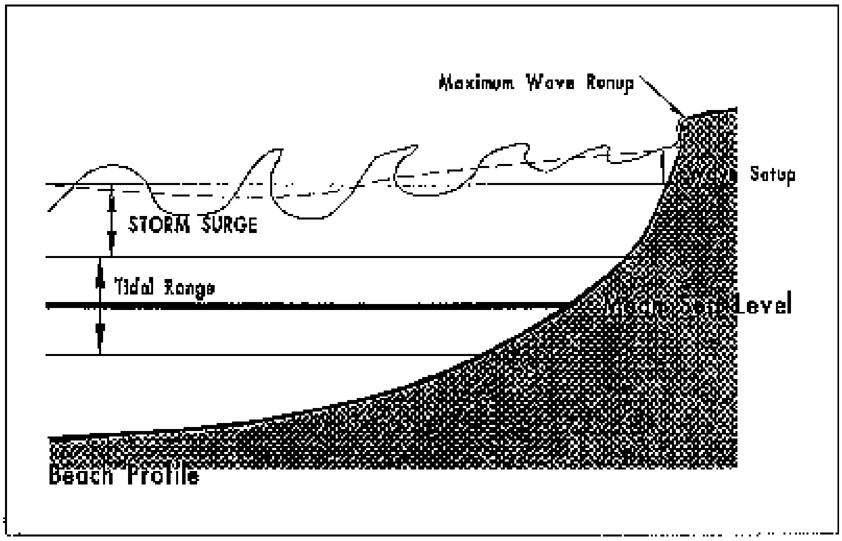
Tidal Plane	Level above LAT Datum	Level above MSL Datum
Highest Astronomical Tide	+1.4m	+0.8m
Mean High High Water	+1.2m	+0.6m
Mean Low High Water	+0.7m	+0.1m
Mean Sea Level	+0.6m	0.0m
Mean High Low Water	+0.6m	0.0m
Mean Low Low Water	+0.1m	-0.5m
Lowest Astronomical Tide	0.0m	-0.6m

Daily maximum and minimum water levels recorded at Cocos (Keeling) Islands since 1986 are shown in Figures B1 to B14, Appendix B. These levels are relative to LAT. The recording station is located at Home Island Wharf and the water levels would include astronomic tides and barometric effects. Wind and wave set-up effects would not be included.

The highest recorded water level during this 13 year period was +1.64m above LAT (recorded on 29/9/1999) and the lowest recorded water level was –0.17m below LAT (recorded on 17/3/1995). These values are equivalent to +1.04m above MSL and -0.77m below MSL.

During periods of high water level large waves can occur at the beach and toe of the West Island seawall, resulting in increased overtopping. Extreme coastal water levels result from combinations of tides, wave set up, storm surge and wave run up. When storm events, particularly cyclones, occur water level rises due to the effect of a low pressure system (inverse barometric effect) and strong winds piling up water against the shore (wind set up). Breaking waves in the nearshore zone can cause a further rise in water level (wave set up) and the extent of this is a function of wave height and wave direction. These factors are illustrated in Figure 3.

Figure 3. Factors affecting extreme water level



Deep ocean waters surround Cocos (Keeling) Islands and as a result the main influences on extreme water levels will be tides, wave set up across the reef flat and wave run up from waves breaking at the reef edge and propagating across the reef top.

3.1.4 *Currents*

Currents have been measured on the ocean side of West Island on two recent occasions. In September 1998 a series of drogues were released in deep water north of the Quarantine Station on rising and falling tides. In both situations the drogues moved offshore to the west and north west. Current speeds on the rising tide were observed to be greater than on the falling tide by a factor of approximately 2. At the same time dye was released which travelled towards the shore. It is therefore likely that the drogue movement was influenced to some degree by the south easterly winds (15-20 knots) which occurred at the time of deployment.

A series of drogues were also tracked across the reef flat in front of the seawall in November 1999. These were undertaken under the following tide conditions:

1. Outgoing tide immediately preceding low tide;
2. Outgoing tide at approximately mid tide;
3. Outgoing tide following high tide;
4. Incoming tide immediately preceding high tide;

On all occasions the drogues moved southward parallel to the shore and then veered offshore when reaching deeper water near the south end of the seawall. Measured current speeds were generally less than 0.1m/s.

3.1.5 Sedimentation

Currents, both tidal and wind driven combine with waves to drive sediments both alongshore and onshore-offshore. This movement is dependent on the wave height and wave direction and sediment characteristics. Sandy beaches tend to shape themselves parallel to the average wave crest alignment, although variations do occur from storm to storm. Cyclones can produce waves that reach Cocos (Keeling) Islands from a number of directions that can result in dramatic changes to the shoreline.

The shoreline adjacent to the north of the seawall comprises pockets of sand interspersed between coral outcrops. At the rear of the beach a near vertical embankment approximately 1.5m high exists. The top of the embankment is well vegetated, and numerous established and large trees and bushes are present. The shoreline to the south of the seawall is similar, although the embankment is lower, typically in the order 1m high and a wider, flatter expanse of sandy beach face exists.

Evidence of past erosion is indicated by dumped concrete and rubble at various locations along the shoreline and the presence of a groyne extending perpendicular to the shore adjacent to West Island Lodge.

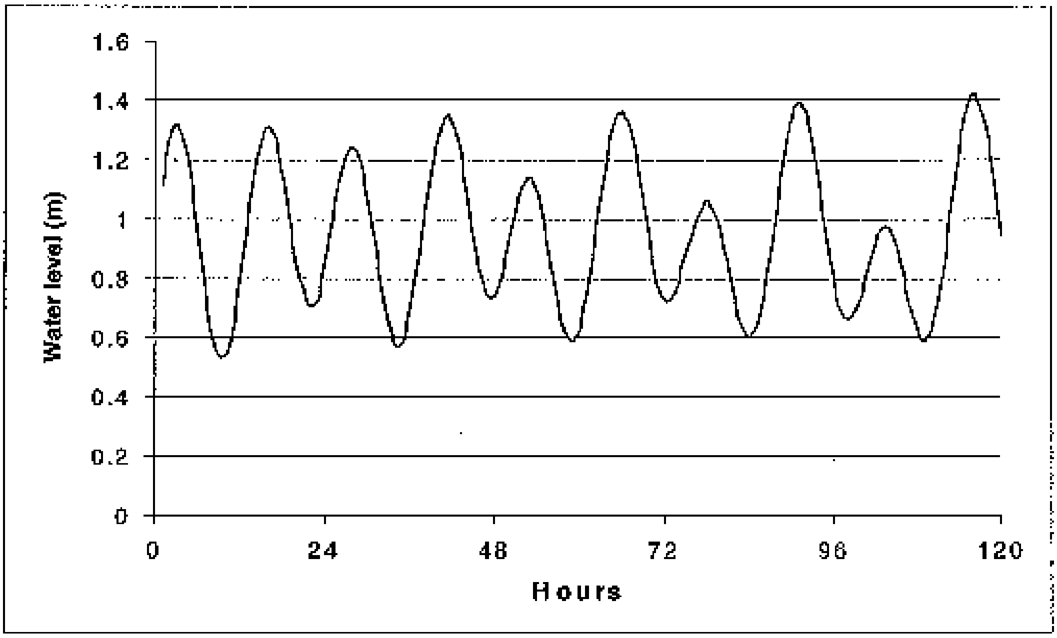
Five groynes, 100m apart, extending over approximately 400m of beach, north of the West Island seawall were constructed in 1975 in an attempt to control past beach erosion. These groynes proved ineffective in trapping sand and only one structure now remains. This ineffectiveness can be attributed to a large spacing to groyne length ratio and insufficient groyne length. The groyne heads were located above high water mark and extended to low water level, but did not protrude sufficiently into the zone of sediment transport. Sand has however built up on the southern side of the last remaining groyne, located in front of West Island Lodge, indicating a northerly movement of sediment.

3.2 Analysis of August 1999 Storm Event

It was reported that a large overtopping event occurred on 5 August 1999 at approximately 1.30am.

Water level records and hindcast wave heights for Cocos (Keeling) Islands were examined to see if the cause of this overtopping event could be isolated. Recorded water levels at the time indicated high water levels, with high tide levels in the order of 1.3m to 1.4m above LAT and low tides in the order of 0.5 to 0.7m above LAT. Figure 4 shows the recorded water levels (at Home Island Wharf) during the period 3 August to 7 August, 1999. At the same time a large storm was building to the south west of Cocos (Keeling) Islands which would have resulted in elevated water levels on the ocean side of West Island due to wind and wave set-up effects.

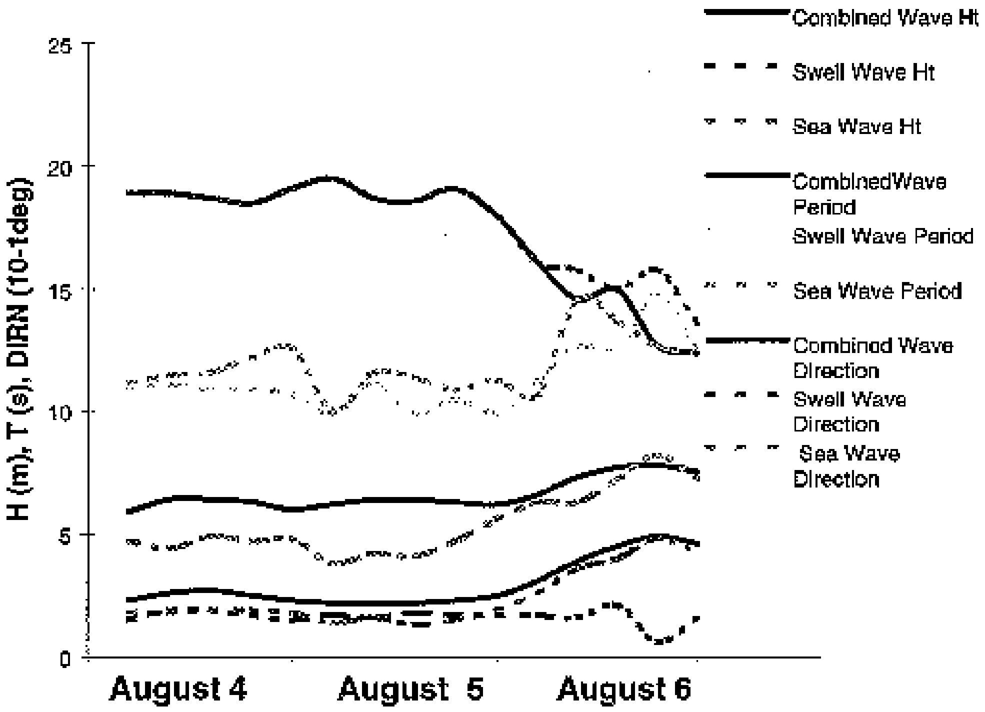
Figure 4. Recorded water levels August 3-7, 1999



At the time of the overtopping occurring, at approximately the 56 hour mark in the above Figure, the tide was falling, however wave heights were increasing. The storm to the south was building and waves were coming from the south-west to west. Much larger waves (up to 4.9m) occurred the following day, but by this time the storm centre had moved east and the wave direction was from the south-east. At the time of the reported event, reef flat water levels would still have been high and overtopping events possible if the correct combination of a wave group to temporarily increase water levels and a subsequent pair of large waves occurs. Figure 5 illustrates the build up of waves and change in direction of the storm over the period 4 August to 6 August 1999.

As the overtopping event did not occur at the peak of the storm it demonstrates the importance of the variability in reef flat water levels due to wave grouping effects.

Figure 5. August 1999 Storm Event



4. Design Parameters

A number of design parameters were adopted for preliminary design of the proposed seawall upgrade works to provide improved protection to adjacent properties, mainly:

- Seabed profile;
- Water level;
- Wave heights;
- Wave run-up; and
- Foundation conditions.

These have been defined from site investigations and through detailed numerical modelling and data analysis.

The proposed seawall upgrade will generally follow the alignment of the existing vertical wall. At the ends of the seawall the alignment will turn landward and extend past the foreshore embankment line to provide protection against erosion around the ends of the wall.

The proposed seawall will be designed to remain stable for the maximum wave that can occur with a water level associated with an Average Recurrence Interval (ARI) of 100 years. Minimal damage could be sustained to the wall during this event, however the overall integrity of the structure will not be affected. Additionally, the crest level of the seawall shall be selected to prevent overtopping by the maximum wave that can reach (break at) the structure, based on the nearshore seabed levels.

4.1 Offshore Wave Conditions

Offshore wave conditions for this study were obtained from the British Meteorology Office. This data comprised hindcasting waves at 6hr intervals from world synoptic records for the period 1993 to May 1999. This method has been found to be reliable in producing wave statistics and relatively accurate for producing individual event conditions. In recent years this hindcast data has been verified by checks against satellite measurements.

The data was filtered to include only waves from 180° to 270° the (south-west quadrant). All storms with significant wave heights greater than 3m were then selected (89 total) and a probability plot produced from the individual maximum waves from the storm. The wave height exceedance plot is shown in Figure 6. As the processes being examined are directly proportional to wave height only a log normal exceedance distribution was used to predict wave heights for longer return intervals. This approach produced a 1:100 year wave value of 5.55m.

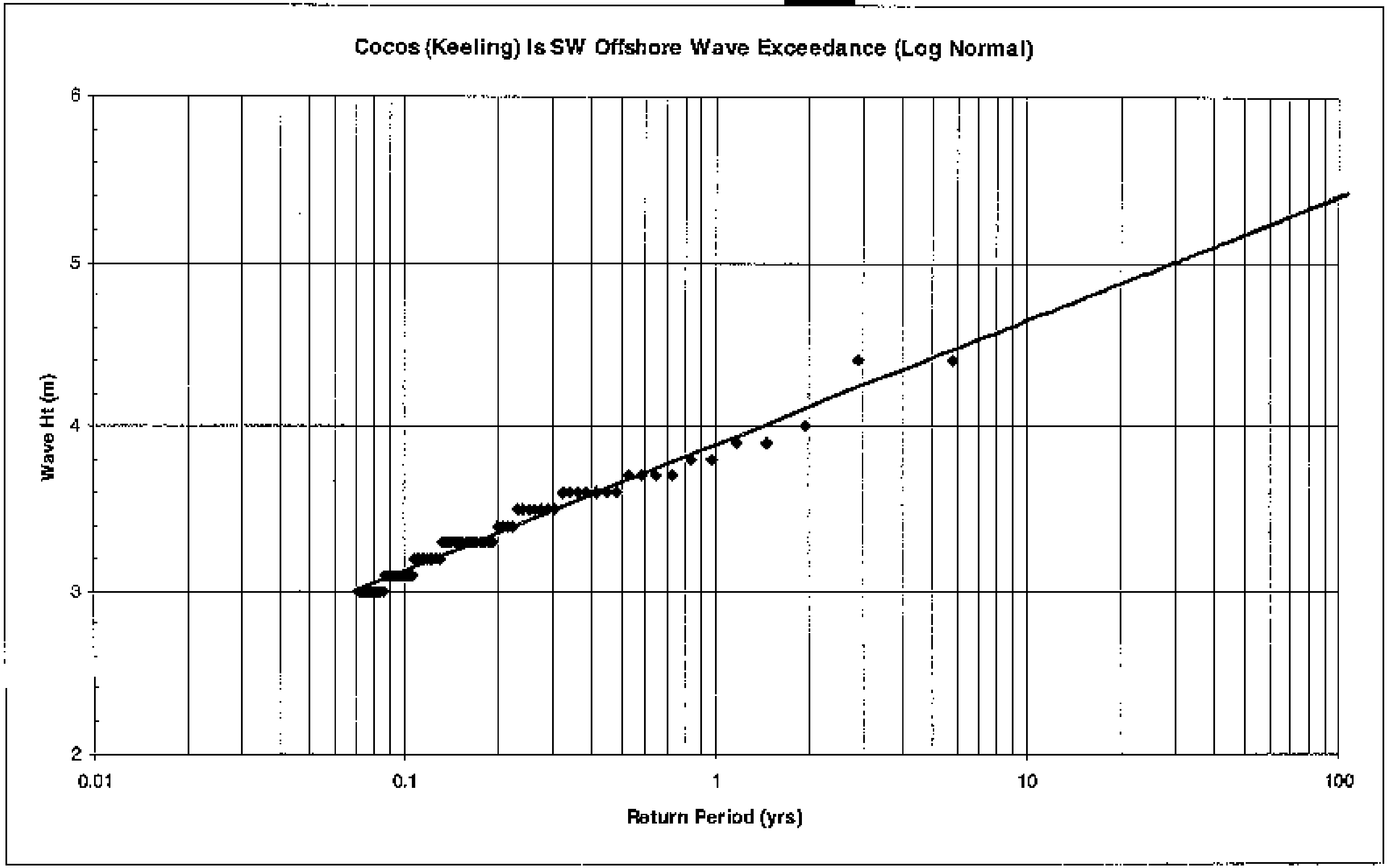
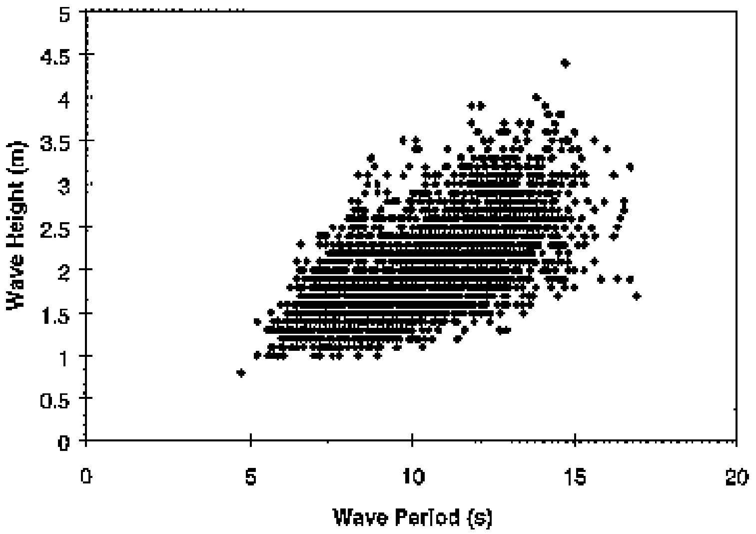


Figure 6. Wave Exceedance Plot (SW Waves 1993 - 1999)

A wave period/wave height scatter plot was used to examine any period dependency and is shown in Figure 7.

Figure 7. Wave height- Wave Period Scatter Diagram



(South West Waves, 1993 - 1999)

The wave model produces both sea (local wind waves) and swell wave predictions and can effectively represent the wave conditions as a bimodal spectrum. A slight correlation between wave period and height was found, therefore longer periods were assigned to the higher wave heights for calculation purposes.

Design wave conditions determined for the preliminary design of the seawall upgrade options are given in Table 6.

4.2 Reef Flat Conditions

4.2.1 *Physical Layout*

A coral reef platform is a living entity in that the conditions that control the growth rate of coral have a major effect on the shape and structure, as well as the response of the seabed materials to the physical forces from wave action and currents. Areas of high wave energy produce conditions suitable for the growth of coralline algae and low profile encrusting corals. This in turn causes a hard crown to grow on the seaward edge of the reef, which attracts more wave energy so that with time these areas become elevated above the adjacent reef edge areas. Height differences of the order of 0.2m to 1.0m were surveyed offshore of the seawall site.

The waves breaking on the high area locally elevate water levels so that reef top currents tend to flow away from the high crown and return to the sea in the lower sections. This current pattern is relatively stable for varying wave conditions and may affect the shape of the fringing beach behind the reef flat.

In front of the seawall a 300m long hard crown exists on the reef edge with deeper reef edges forming outflow areas to the south and north.

This provides some shelter to the beach behind the reef and has the tendency to form a salient area of low lateral transport. On the shoreline this shows up as the bend in the coastline and wall alignment. Figure C7 and Figure C8 in Appendix C illustrate the reef platform in front of the seawall.

The bathymetry of the reef flat determined from the survey results showing the crown area and outflow channels is given in Figure 8. The alignment of the existing seawall is on the righthand side of Figure 8.

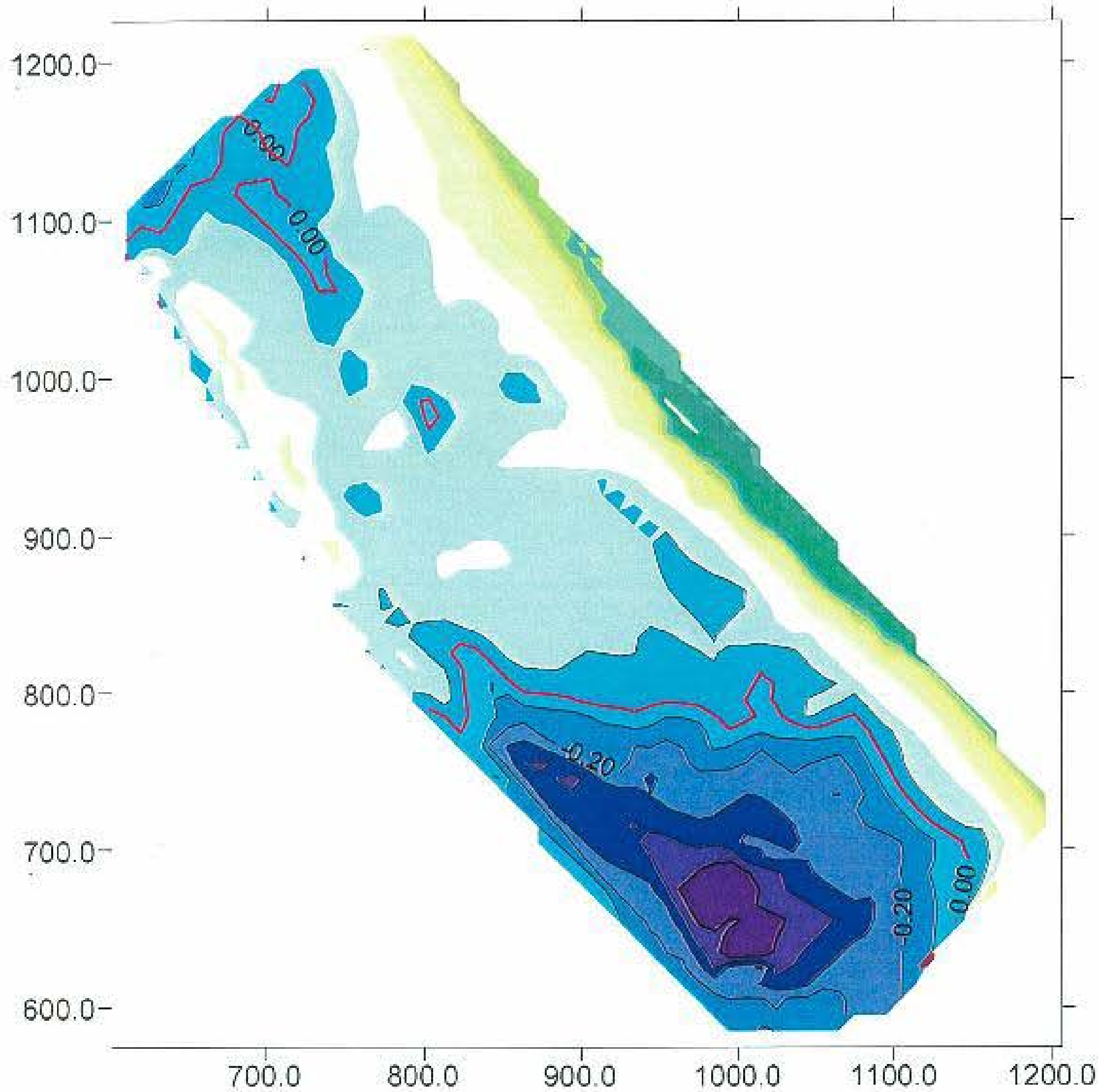
4.2.2 *Wave Propagation*

Work by Nelson (Reference 2) has demonstrated that $H_{max} = 0.55d$ for waves propagating across a horizontal surface. Therefore the depth of water on the reef flat will control the wave height at the toe of the seawall. The actual depth of water on the reef flat is subject to fluctuations due to the effects of wave groups and it is considered appropriate for the approximation of $H_{sig} = 0.55d$ to be adopted to account for any uncertainty in derivation of the reef top water level.

Waves moving across a reef flat often behave as a solitary wave where the velocity is proportional to the wave height, rather than the original wave period.

Design methods for revetment structures and overtopping are based on oscillatory waves and structure options need to be examined for sensitivity to attack from solitary or bore type wave attack.

Figure 8. Reef bathymetry adjacent to seawall



4.3 Wave Setup

For reef areas with a steep outer face and an almost horizontal upper surface, when the offshore water level is near the reef flat level, waves break across the reef edge depositing the water they are made up of on the reef flat. Under ideal conditions this wave setup can be of the order of half the incident wave height producing water levels at or above normal high tide levels for large storm waves. The effect is reduced with increasing depth of water over the reef flat. This often creates a relatively constant high water level on the reef flat during storms with the resulting water level being due to wave setup at low to mid tide and natural tidal levels at high tide. The relatively constant water level allows wave attack of the shoreline at all stages of the tide during storms.

It should be noted that fluctuations above this relatively constant water level will occur due to the effect of wave groups. These fluctuations are reduced for shelf widths in excess of 300m.

For this study, wave conditions for 4 and 5 August 1999 were transformed into the break point at the reef edge and used to calculate wave setup levels in accordance with methods outlined by Gourlay (1993). A *k* factor of 0.6 was chosen since the waves do not approach normal to the reef edge and the two drainage paths exist to the north and south of the site. This produced maximum reef top water levels of the order of 1.7m above lowest astronomical tide (LAT). Therefore the overtopping event would most likely be due to a group of large waves causing a short term rise in the water level. A similar analysis was carried out to determine wave heights across the reef top. This indicated peak significant wave heights in the order of 0.5m. The corresponding maximum wave heights during these conditions would be in the order of 1.0m.

The same methodology was used with wave heights derived for various return periods and water level matching reef flat level to get an approximation of the various return periods of extreme water level on the reef flat.

This approach is considered reasonable as the storm wave conditions are likely to last for the 6 - 12 hours necessary for the water level to occur and the resultant water level will be relatively insensitive to actual tide or atmospheric pressure conditions. The approximate return periods for extreme water levels, including wave set-up and storm surge, and calculated conditions for the 4 August 1999 storm are shown in Table 4 and Table 5 respectively.

Table 4. Predicted extreme water levels over reef flat

Return Period	Predicted water level
1 Year	RL +1.73m MSL
2 Years	RL +2.12m MSL
10 Years	RL +2.23m MSL
50 Years	RL +2.26m MSL
100 Years	RL +2.48m MSL

Table 5. Calculated Conditions for August 1999 Storm

Date / Time	Calculated Reef Top Water Level (m) above MSL	Reef Top Wave Height H_{sig} (m)
4/8/99: 0630	0.81	0.33
4/8/99: 0830	0.88	0.38
4/8/99: 1030	1.10	0.49
4/8/99: 1230	1.00	0.44
4/8/99: 1430	0.74	0.30
4/8/99: 1630	0.73	0.29
4/8/99: 1830	1.00	0.44
4/8/99: 1930	1.07	0.48
4/8/99: 2030	1.13	0.51
4/8/99: 2130	1.17	0.54
4/8/99: 2230	1.16	0.47
4/8/99: 2330	1.04	0.46
5/8/99: 0030	0.99	0.43
5/8/99: 0130	0.93	0.40
5/8/99: 0230	0.84	0.35
5/8/99: 0330	0.77	0.31
5/8/99: 0430	1.33	0.29
5/8/99: 0530	0.80	0.33
5/8/99: 0630	0.89	0.33

Design wave conditions based on the site investigations, numerical modelling and data analysis detailed above for the design of the seawall upgrade options are given in Table 6.

Table 6. Seawall Design Parameters

Parameter	Value
Wave Height	H = 1.25m
Wave Period	T = 13 sec
Still water level	z = +2.48m MSL

4.4 Foundation Conditions

Limited geotechnical investigations undertaken in the vicinity of the seawall indicate relatively uniform subsurface conditions.

Three test pits were dug in the beach to determine if a cemented layer existed at reef flat level. No cemented layer was detected in any of the holes indicating that in the past, beach erosion probably has not exposed this area long enough for the carbonate deposition processes at the point of freshwater outflow in the beach to form the cemented layer.

Subsurface conditions were found to consist of sand and coral rubble to depths of approximately 2m. The sand was found to be composed of coral fragments in medium to coarse grain sizes. Typical conditions encountered comprised a surface layer of sand in the order of 300mm thick overlying a thin band of coral rubble varying in size from 50mm diameter to 300mm diameter. A deep sand stratum was then encountered, with small amounts of further coral rubble encountered between 1m and 2 m below the surface.

Typical photographs of the test pits are shown in Figures C9 to C15, Appendix C.

For the design of the seawall upgrade works it has been assumed that the beach is scoured and the toe of the wall will be located on an extreme erosion depth. The toe of the revetment structure will require normal design for scour and structural support, however toe levels are unlikely to drop below RL0.0m LAT (0.4m below reef flat level) due to the presence of the harder reef flat seaward of the toe of the wall.

5. Seawall Upgrade Options

5.1 General

The mains concerns with the existing seawall are:

1. The proximity of House 1 to the top of the seawall;
2. Erosion of backfill material;
3. Overtopping of the seawall by waves; and
4. The deteriorating condition of the seawall.

The general condition of the seawall is such that upgrading works should be undertaken as soon as possible to ensure ongoing protection to the adjacent housing. Options to improve the function of the seawall and/or provide ongoing protection to the adjacent properties include:

Option 1	Relocate existing housing;
Option 2	Repair/raise/extend the existing seawall; or
Option 3	Construct an upgraded seawall to replace the existing seawall.

The primary purpose of the existing seawall is to provide protection to the adjacent housing. In the event the housing was relocated away from the shore there would no longer be a need for the seawall. However, if the seawall were to be removed the shoreline would revert to a similar alignment and profile as exists at either end of the wall and some land area would be lost. A dynamic beach profile would establish over time, but the area may be subject to long term erosion similar to the shorelines further north and south.

The decision to retain, and hence protect these buildings, or relocate the buildings would involve consideration of numerous factors of which cost would be but one. It would also be necessary to consider occupier and community attitudes and availability of suitable alternative sites.

Of the remaining options, i.e Option 2 repair the existing seawall or Option 3 construct an upgraded wall, it is recommended that Option 3 is adopted with sloping seawall to replace the existing vertical seawall. Vertical walls are non-energy absorbing and as a result they produce high wave reflection and incur high wave run-up that require increased crest levels. In addition high reflection of wave energy increases scour of the beaches in front of the wall. Vertical walls also restrict access to the beach, reducing user amenity. The upgraded seawall would be designed to reduce wave run-up and overtopping, and improve user amenity to the adjacent foreshore. It is proposed that the upgraded seawall be constructed along the same alignment as the existing seawall, using the existing seawall as permanent formwork and support.

Alternative forms of seawalls could be implemented which absorb wave energy, thus reducing the crest height and, to a lesser extent, scour at the toe of the wall. Typically this would involve a sloping seawall with a porous face. Sloping revetments with increased roughness are preferred because of the energy they remove from the wave bore as it impacts the wall and the reduced wave reflection which can contribute to local increases in reef top water levels. A sloping seawall would reduce the incidence of overtopping under normal conditions, however some overtopping would still occur in a major storm event and during cyclones.

5.2 Alternative Revetments

Vertical seawalls tend to exacerbate loss of beach in front of them and increase the levels at which significant overtopping occurs. Sloping seawalls absorb energy as the wave breaks on the wall rather than impacts the wall.

Options for sloping walls include:

- Rock revetment structures
- Concrete armour block structures
- Linked block revetments

However, only rock revetment and concrete armour block structures are considered appropriate for further investigation.

5.2.1 Rock Revetment

A rock revetment would comprise an outer layer of armour rock overlying a secondary filter layer, which in turn would be placed on a robust geotextile fabric.

Rock revetments provide a rough surface with a high ratio of voids. As such wave energy is dissipated as it travels across the revetment, resulting in reduced wave run up levels.

It has been calculated, using the preliminary design parameters discussed previously, that the weight of the rock armour would need to be in the order of M_{50} = 400 kg to 750 kg on a 1V:1.5H revetment slope. This would require armour rock weights ranging from approximately 100 kg to 2 tonne in weight.

Alternatively, should a moderate level of damage be allowed to the revetment resulting from the design storm event, the armour weight range could be reduced nominally to M_{50} = 300 kg to 600 kg.

These armour weights typically relate to individual rocks having diameters in the order of 0.5m to 0.7m and the required armour layer thickness would be approximately 1.0m to 1.3m. The minimum thickness of the underlying filter layer would be in the order of 0.8m to 1.0m.

For a 300m long wall, with a vertical height of 4m and a slope of 1in 1.5, the estimated volume of rock required would be 5,300 tonne. In addition a further 3,400 tonne of rock with a nominal weight of 75kg would be required as a filter layer. Given that both the size and quantity of rock would not be available on Cocos (Keeling) Islands armour rock would need to sourced off island and transported to site.

Rock revetments are generally durable but require a moderate level of maintenance, particularly after storm events, to maintain their profile and integrity. It is also common for rock revetments to require additional placement of material after several years to accommodate settlement and dislodgment of fine material and smaller units.

The rough surface and high ratio of voids also enables debris to be trapped and accumulate in the rock face, causing an untidy appearance.

5.2.2 Concrete Armour Block Structures

Due to the lack of availability of suitable armour rock on the islands and relatively small wave heights, a pattern placed concrete armour unit structure is considered an appropriate alternative. A suitable armour type would be the Seabee unit, which is a hexagonal block with a hollow core.

The amount of wave run-up on Seabee units is influenced by the surface roughness of the wall face, the amount of water which penetrates the underlayer and the turbulence generated by the release of trapped air within the voids of the Seabee unit.

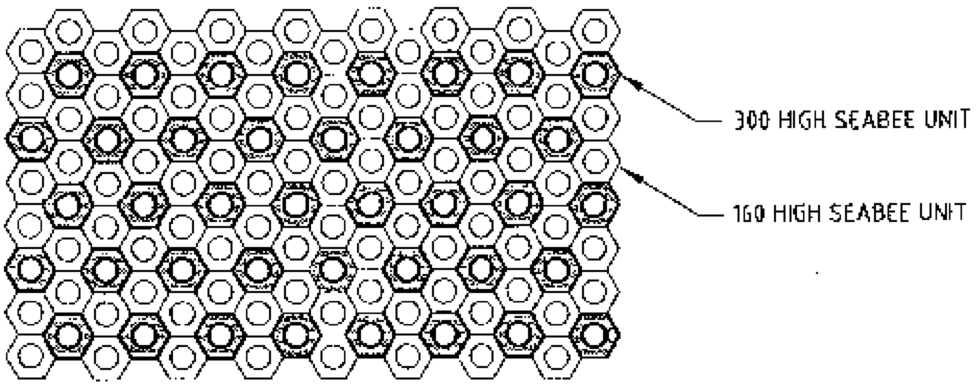
To maximise energy absorption a mixture of block heights is proposed to increase surface roughness and decrease wave runup. A curved concrete wave deflector would be included at the crest of the wall to counter overtopping effects.

A typical cross section through a Seabee wall is shown in Figure 9. A photograph of a similar type of wall constructed at Green Island, a coral atoll in the Great Barrier Reef, is shown in Figure 10.

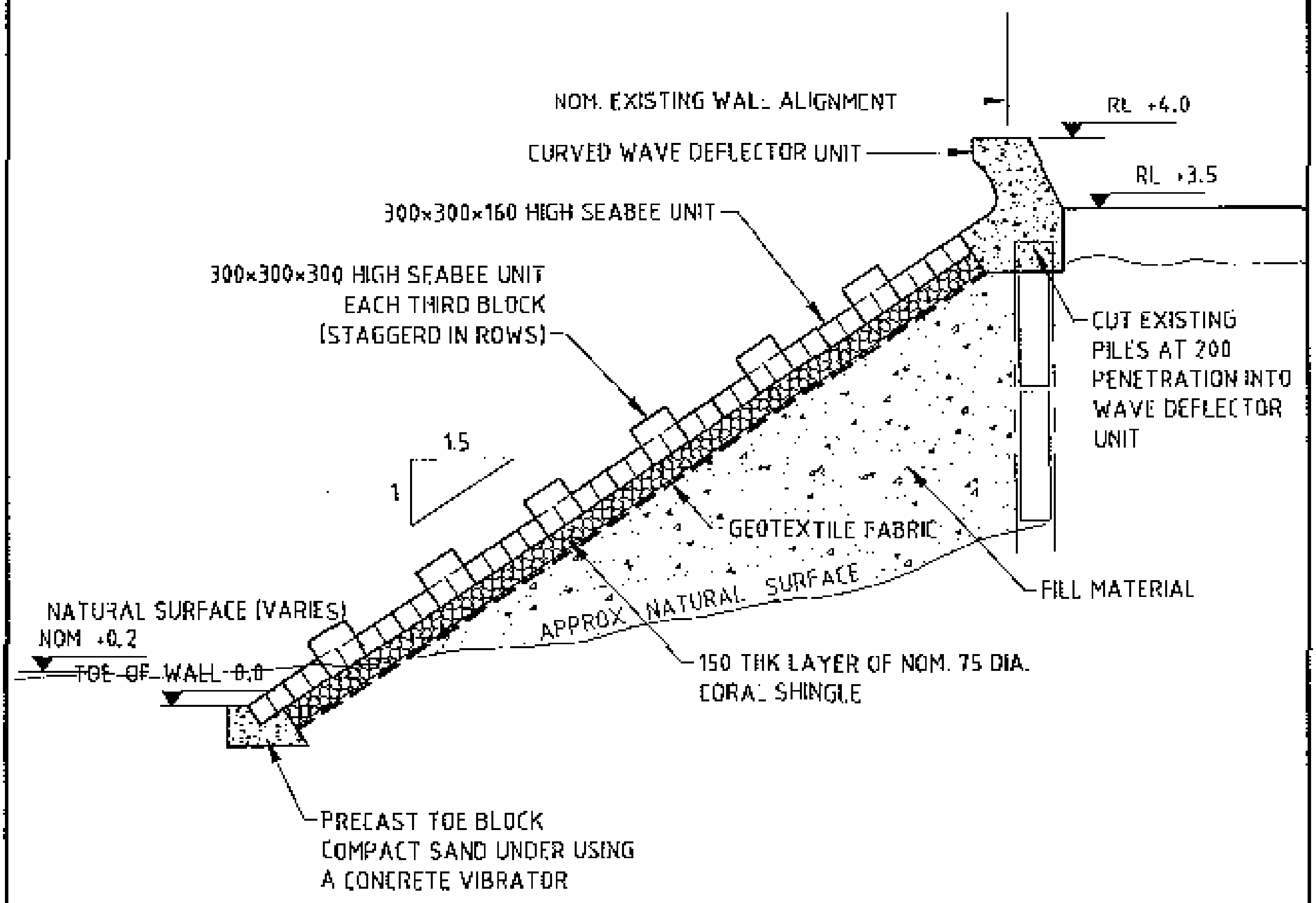
The patterned finish will reduce the likelihood of debris being trapped and accumulating on the revetment and will improve the amenity of the adjacent foreshore. This could be further enhanced by providing access stairs at two or more locations along the wall.

The crest height of the seawall will be designed to prevent over-topping in extreme storm events, but not under cyclone conditions, and as such will be determined by the water depth (tide level, storm surge and wave set-up) and extent of wave run-up during storm events.

For structural design it is prudent that a design water level and wave condition with a 1:50 or 1:100 year return period is chosen. However, for the West Island seawall, it is considered appropriate to use a 1:100 year return period for structural design.



VIEW ON FACE OF WALL



CROSS SECTION THROUGH WALL

COCOS (KEELING) ISLAND
SEAWALL UPGRADE
CONCEPT ARRANGEMENT

FIGURE 9

Island seawall, it is considered appropriate to use a 1:100 year return period for structural design.

For overtopping design it is necessary to examine the frequency at which overtopping events can be tolerated to minimise the height and affect on functionality of the wall. A return period of 1:20 years is considered appropriate for overtopping to the degree that it would cause the onset of scouring the backfill from behind the wall. A 1:10 year event is considered appropriate for overtopping to the extent that it would make it unsafe for a fit adult to stand behind the wall.

The various overtopping rates are tabulated in Table 7. It should be noted that these rates are long term averages and individual overtopping waves may be significantly larger.

Figure 10. Seabee Seawall, Green Island, Qld

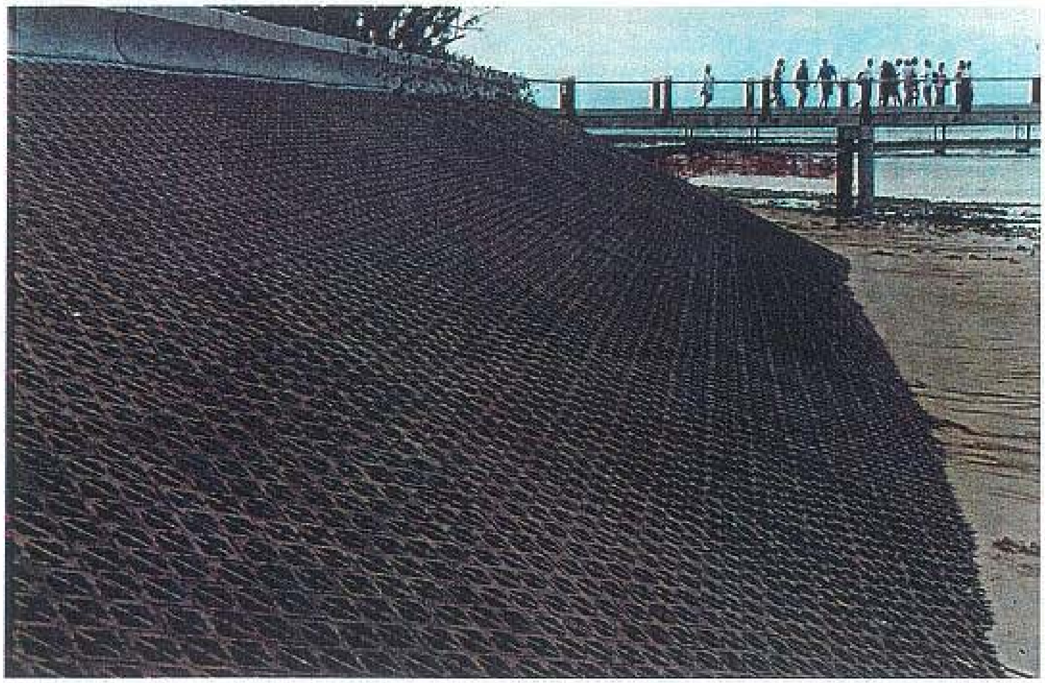
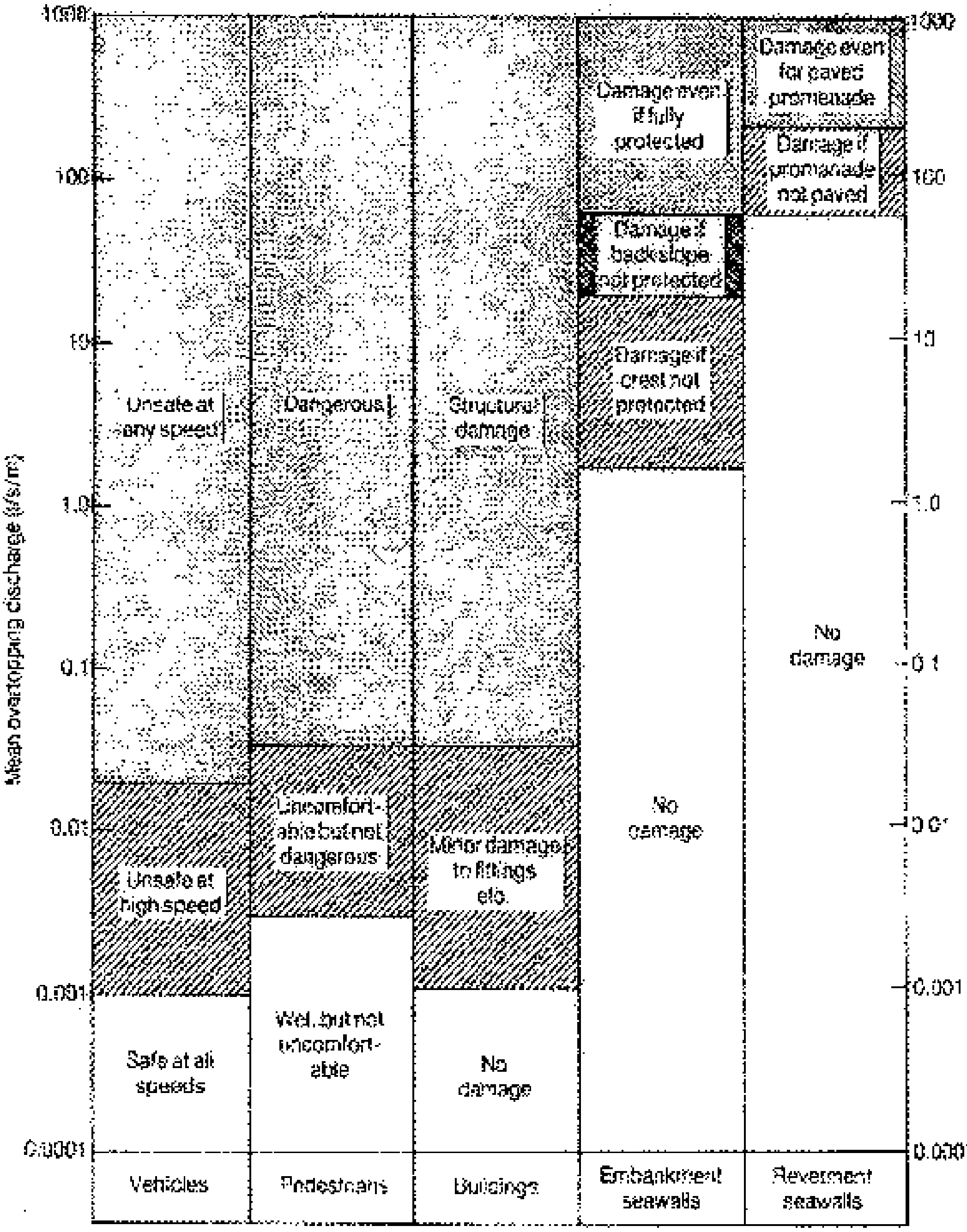


Table 7.Critical overtopping criteria

(Source: van der Meer, et al. 1998)

Limiting values of Q for different design cases have been suggested, and are summarised in Figure 152. This incorporates recommended limiting values of the mean discharge for the stability of crest and rear armour to types of seawalls and/or the safety of vehicles and people.



5.3 Impact of Seawall Upgrade Works

The relative impact of the proposed sloping seawall on coastal processes compared to the effect of the existing vertical seawall is expected to be reduced erosion of the beach.

The sediment transport has two main components: longshore transport along the beach; and onshore-offshore transport up and down the beach profile. Because the upgraded seawall is proposed to be built along the existing seawall alignment, the longshore sediment transport condition is expected to remain unchanged when the proposed seawall is built. Onshore-offshore sediment transport is expected to reduce with the construction of the proposed seawall.

The vertical impervious surface of the existing seawall results in high reflection of wave energy, generally responsible for erosion of sand near the toe of the wall. The proposed upgraded seawall will present a sloping face to the waves, which will reduce wave run up on the wall. The rough surface of a rock revetment or perforated nature of the Seabee units will also help dissipate wave energy and therefore contribute to reduced overtopping and beach erosion as compared to the existing seawall.

The proposed seawall will extend landwards at both ends to prevent localised erosion that frequently occurs at the seawall ends and is particularly evident at the southern end of the existing seawall.

5.3.1 Water Quality During Construction

The likely effect on water quality during construction is expected to be small. The limited geotechnical information available indicates that the sediments comprise sand and loose coral. The apparent lack of silt in the sediments suggests that turbidity plumes will not be significant during construction.

To further mitigate adverse impacts during construction, the following measures are recommended:

- All topsoil material located at the crest of the existing seawall will be removed landwards prior to demolition.
- Excavated materials at the toe be used to form a sand berm seawards of the construction zone to act as a natural barrier to prevent fines from moving offshore during high tide periods.
- Machinery and loose material such as Seabee units be removed from the beach and stored during high tide to avoid localised erosion occurring.

5.4 Indicative Cost Estimates

Indicative cost estimates for the alternative seawall types considered above are shown in Table 8 and Table 9 and have been prepared for comparative purposes. The estimates have been prepared on the basis of site information currently available, which includes 3 test pits adjacent to the existing seawall and base surveys showing the surface levels in the vicinity of the seawall. These indicative costs do not include costs for temporary works and construction of access ramps.

Indicative cost estimates have been compiled from the extension of calculated quantities with tendered rates and prices from recent works at Cocos (Keeling) Islands. Variations from the indicated rates and prices may result from market forces at the time of tendering, changes in freight rates or actual site characteristics. Nevertheless the rates and prices that have been adopted are considered a reasonable representation of the tender prices that could be expected.

The indicative cost estimates are current at December 1999 prices.

Table 8. Rock Armoured Seawall (300m Length)

Item	Description	Qty	Unit	Rate	Amount
1	Preliminaries, mobilisation, demobilisation	Item			$280,000
2	Supply, place and trim fill material	m^3	1500	$70	$105,000
3	Supply and place geotextile material	m^2	2000	$10	$20,000
4	Supply, place and trim to profile secondary armour rock (Range 5kg to 75kg)	m^3	2000	$28	$56,000
5	Supply, place and trim to profile primary armour rock (Range 100 kg to 2000 kg)	m^3	3200	$38	$121,600
6	Transport rock to site	m^3	5200	$300	$1,560,000
7	Contingencies (@ 20%)	Item			$429,000
	TOTAL				$2,571,600

SAY **$2,575,000**

Table 9. Seabee wall (300m Length)

Item	Description	Qty	Unit	Rate	Amount
1	Preliminaries, mobilisation, demobilisation	Item			$225,000
2	Manufacture and supply to site Seabee Units	tonne	670	$1,300	$871,000
3	Manufacture and supply to site precast toe units	tonne	160	$1300	$208,000
4	Supply, place and trim fill material	m^3	1500	$70	$105,000
5	Excavate toe and place foundation units	m	300	$50	$15,000
6	Supply and place geotextile material	m^2	2000	$10	$20,000
7	Supply, place and trim to profile 75mm dia. rock	m^3	300	$300	$90,000
8	Place Seabee units to lines and levels	m^2	2000	$25	$50,000
9	Remove excess concrete planks and cut existing pile heads to level	Item			$30,000
10	Construct curved concrete wave deflector at Crest of wall	m	300	$240	$72,000
11	Install 2 sets beach access stairs	Item			$20,000
12	Contingencies (@ 20%)	Item			$340,000
	TOTAL				**$2,046,000**

SAY **$2,050,000**

6. Recommendation

It is recommended that a sloping seawall be constructed over and in front of the existing vertical wall. Given the isolated location of Cocos (Keeling) Islands it is further recommended that the upgraded seawall be armoured using Seabee units. When properly installed these units provide the advantages of a durable, low maintenance revetment, that is also more aesthetic than a rock seawall. The comparatively smooth surface of a Seabee wall also means that it is less susceptible to trapping and accumulating water borne debris, which is a constant issue along the shoreline of Cocos (Keeling) Islands.

In order to minimise overtopping of the seawall a curved wave deflector should be located along the crest. This will enable larger waves to be turned back onto following waves and assist in reducing wave run-up and overtopping during storm events.

The indicative cost estimate for the construction of a new sloping seawall using Seabee units is $2,050,000 exclusive of professional fees as detailed in Table 9.

7. References

- Wave Transformation on a Coral Reef, M R Gourlay, Coastal Engineering 23 (1994) 17-42
- Depth Limited Design Wave Heights In A Very Flat Region, R C Nelson, Coastal Engineering 23 (1994) 43-59
- Wave Setup on Coral Reefs - Setup and Wave Generated Flow on Two Dimensional Horizontal Reefs, M R Gourlay, February 1993
- A code for dyke height design and examination, J W Van der Meer, P Tonjes, J P de Waal. Coastlines, Structures and Breakwaters (1998).

Appendix A

Offshore Wave Conditions 1993 -1999

COCOS (KEELING) ISLAND

Source: The Meteorological Office, UK

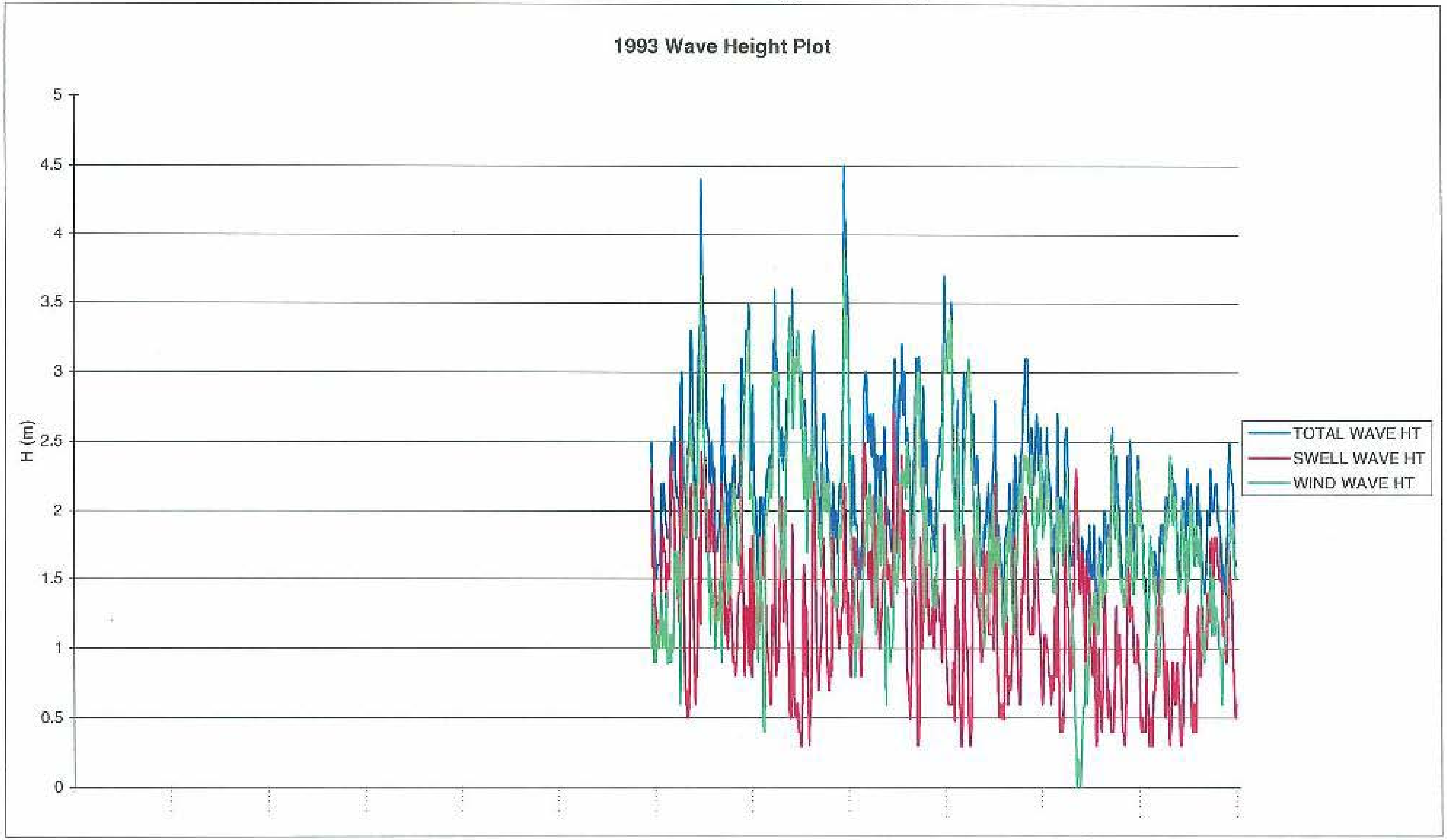


FIGURE A.1

COCOS (KEELING) ISLAND

Source: The Meteorological Office, UK

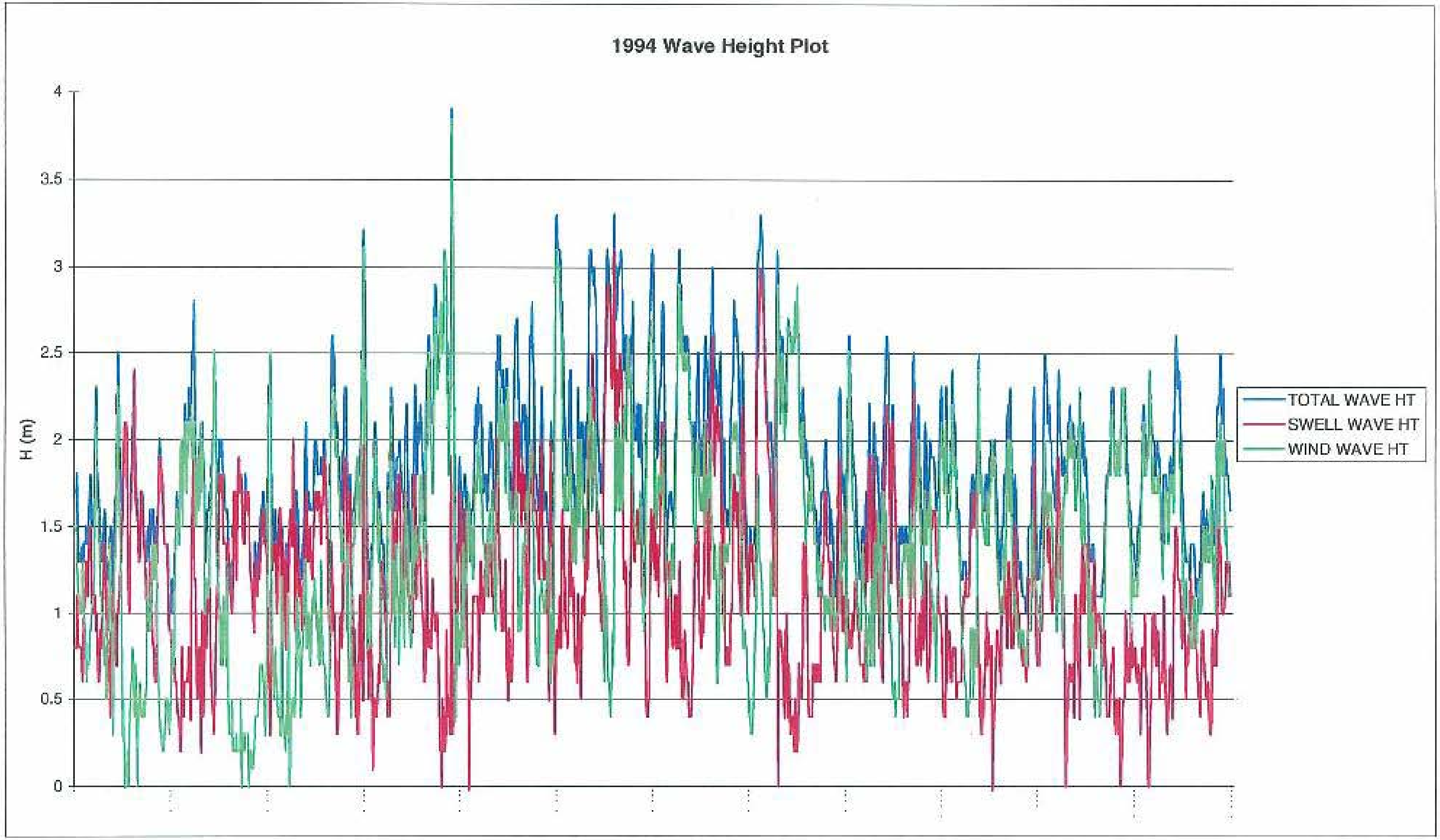


FIGURE A.2

COCOS (KEELING) ISLAND

Source: The Meteorological Office, UK

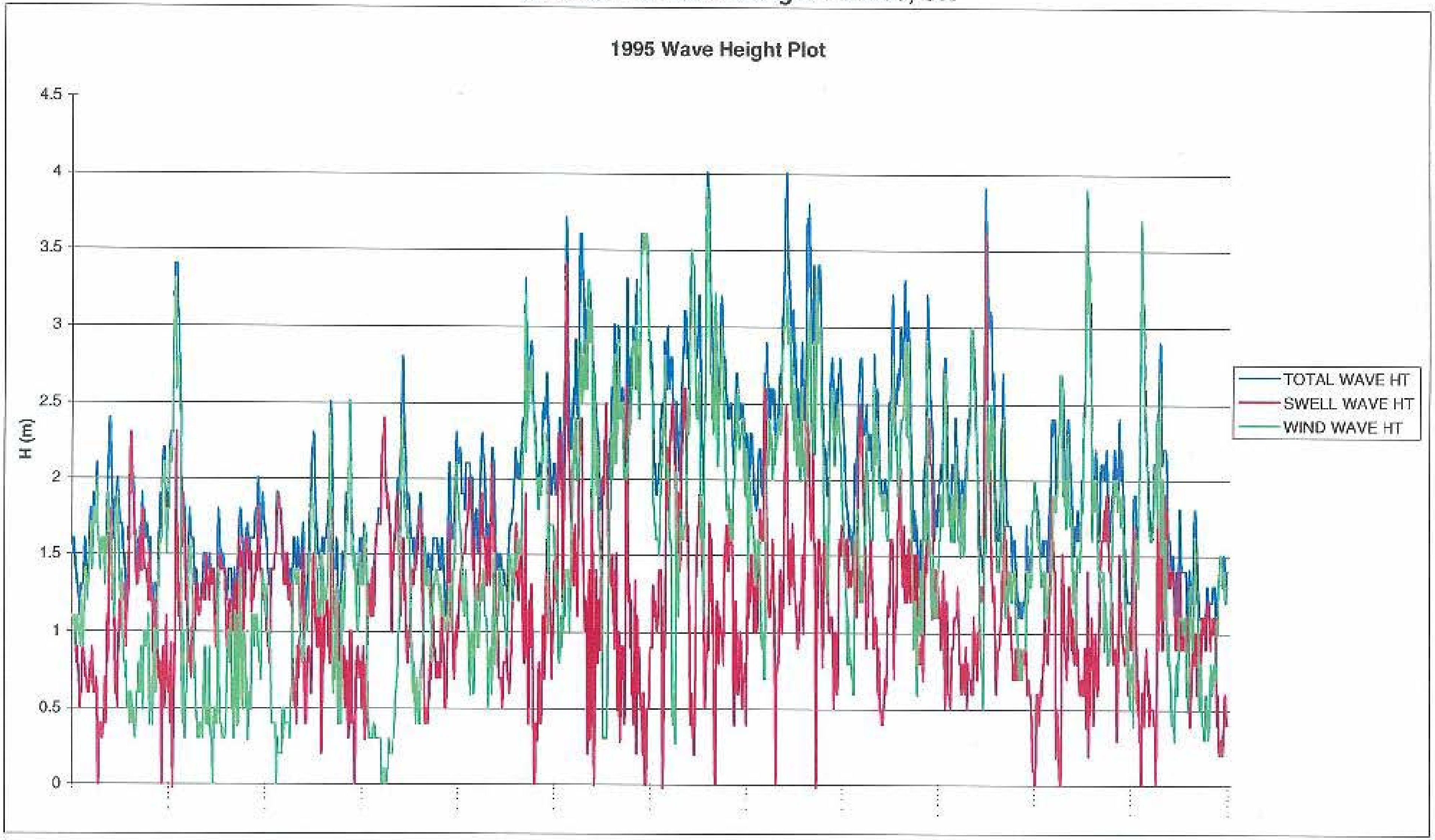


FIGURE A.3

COCOS (KEELING) ISLAND

Source: The Meteorological Office, UK

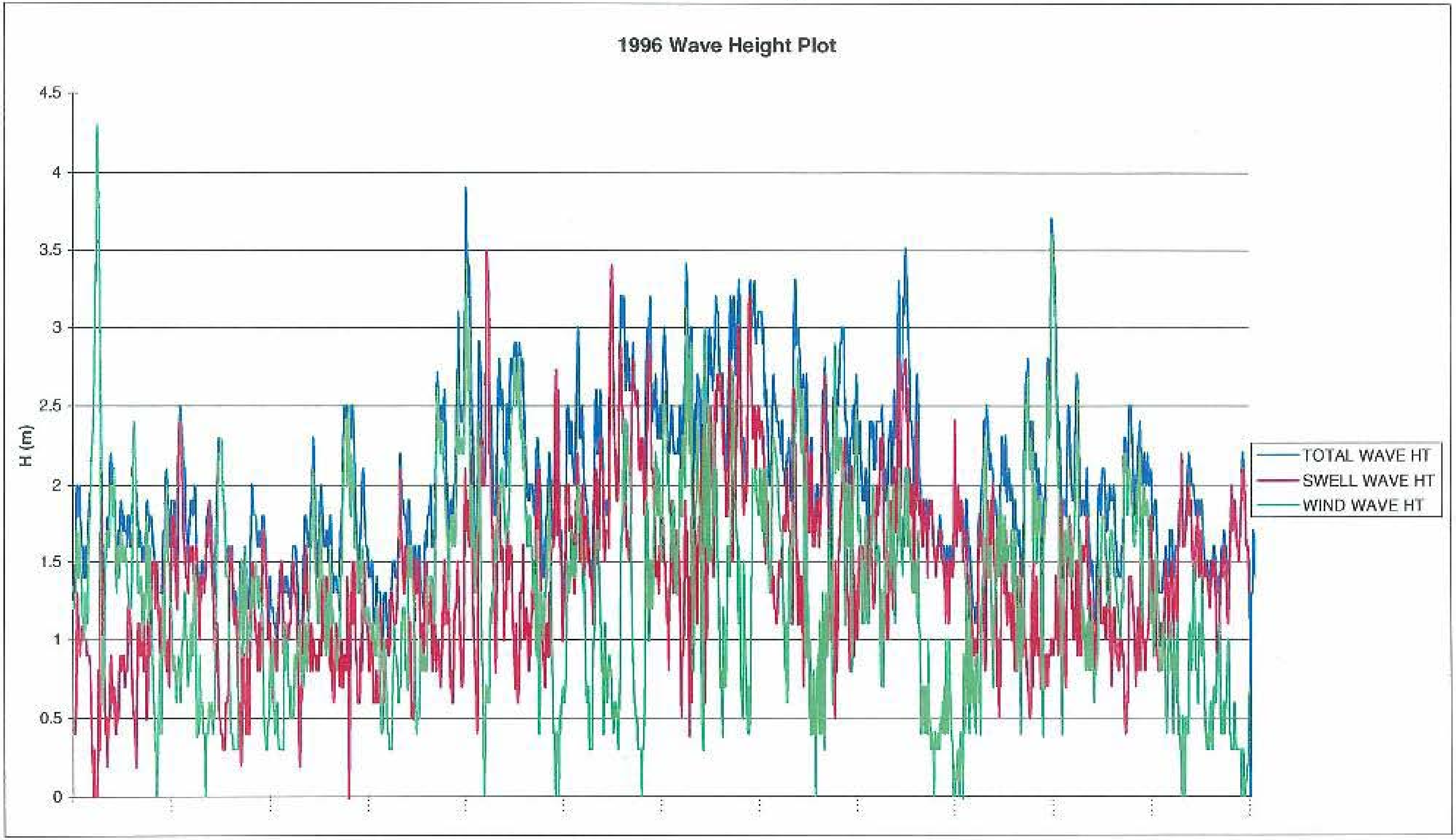


FIGURE A.4

COCOS (KEELING) ISLAND

Source: The Meteorological Office, UK

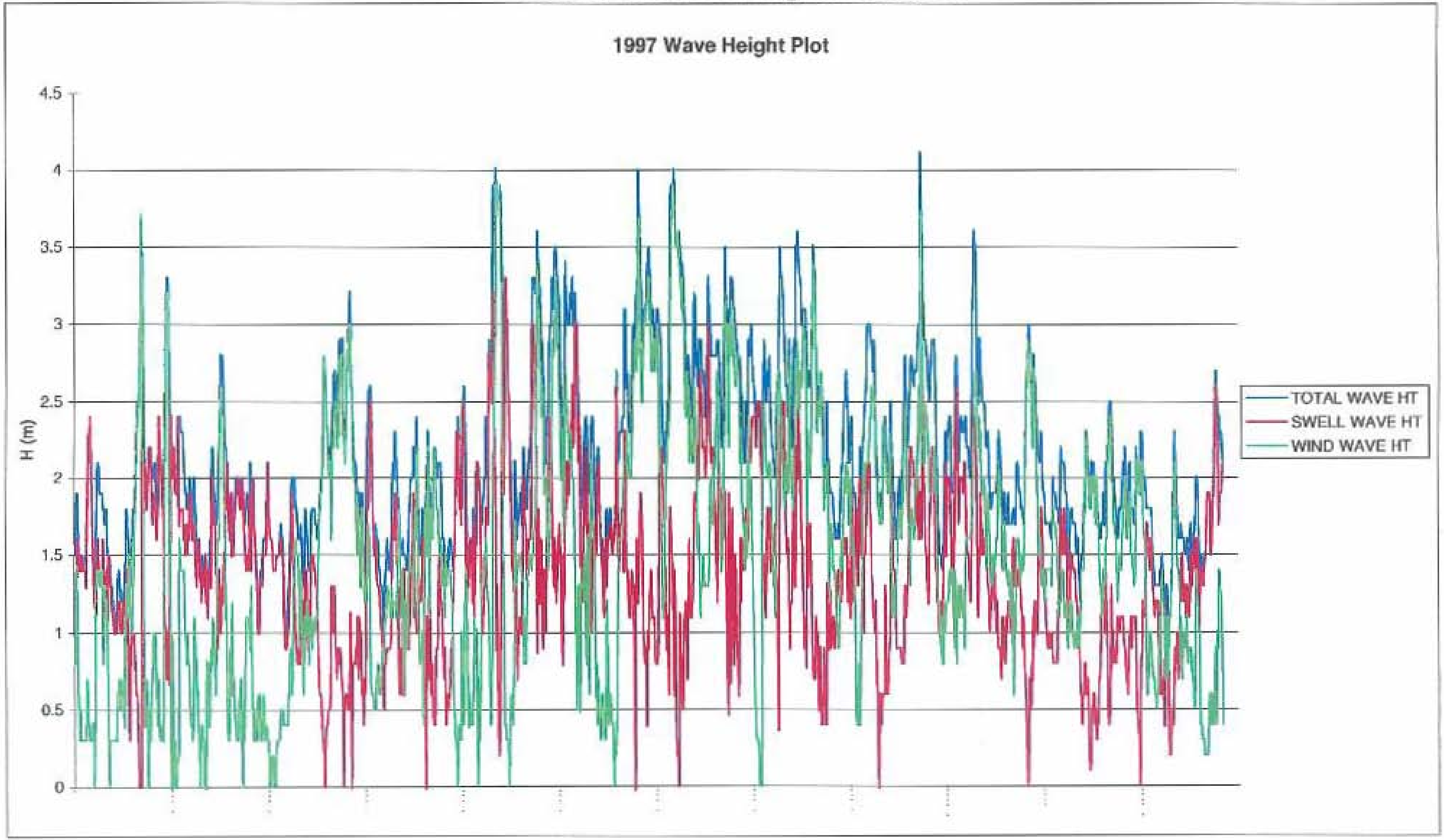


FIGURE A.5

COCOS (KEELING) ISLAND

Source: The Meteorological Office, UK

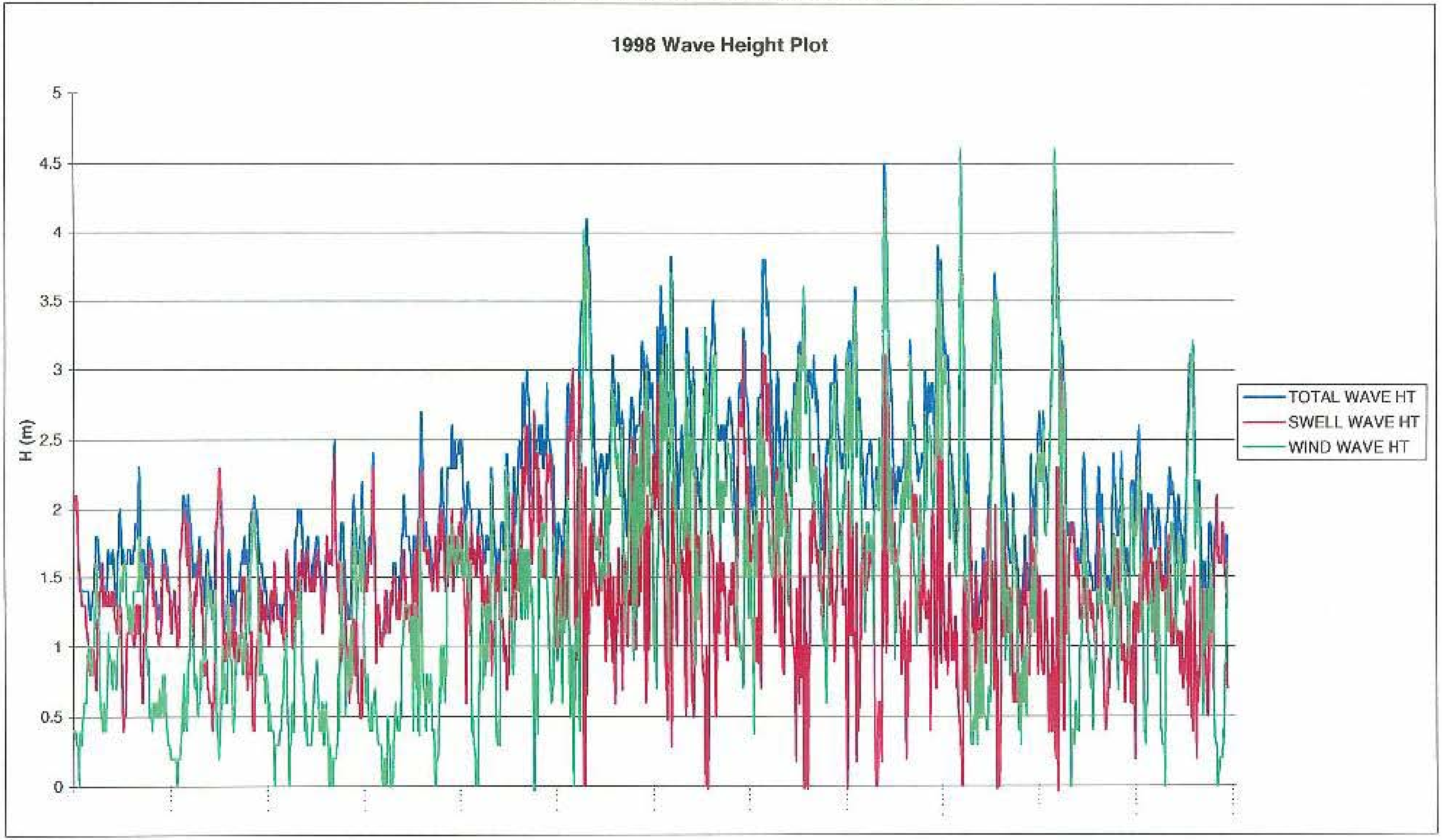


FIGURE A.6

COCOS (KEELING) ISLAND

Source: The Meteorological Office, UK

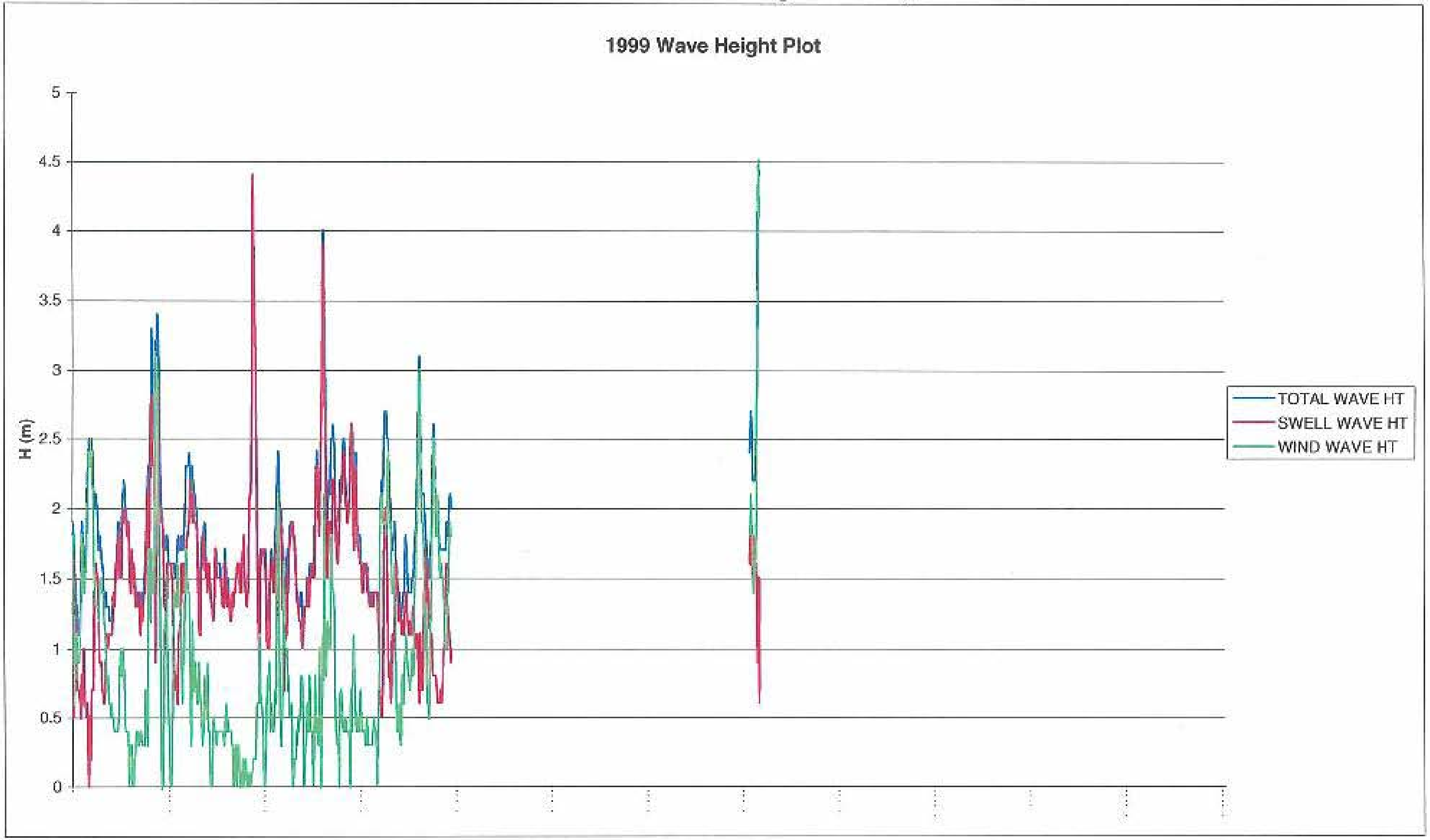


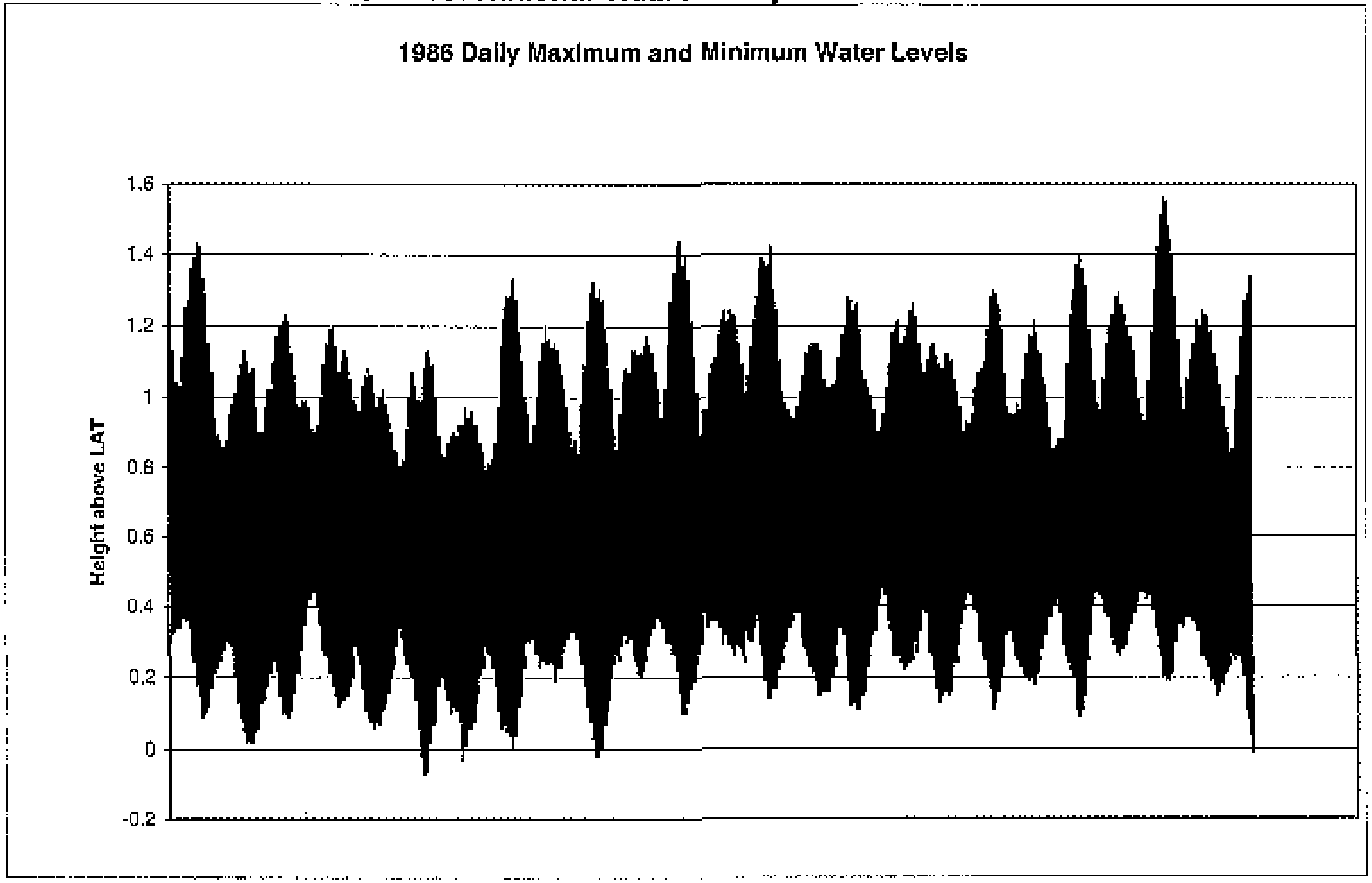
FIGURE A.7

Appendix B

Water Levels 1986 - 1999

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



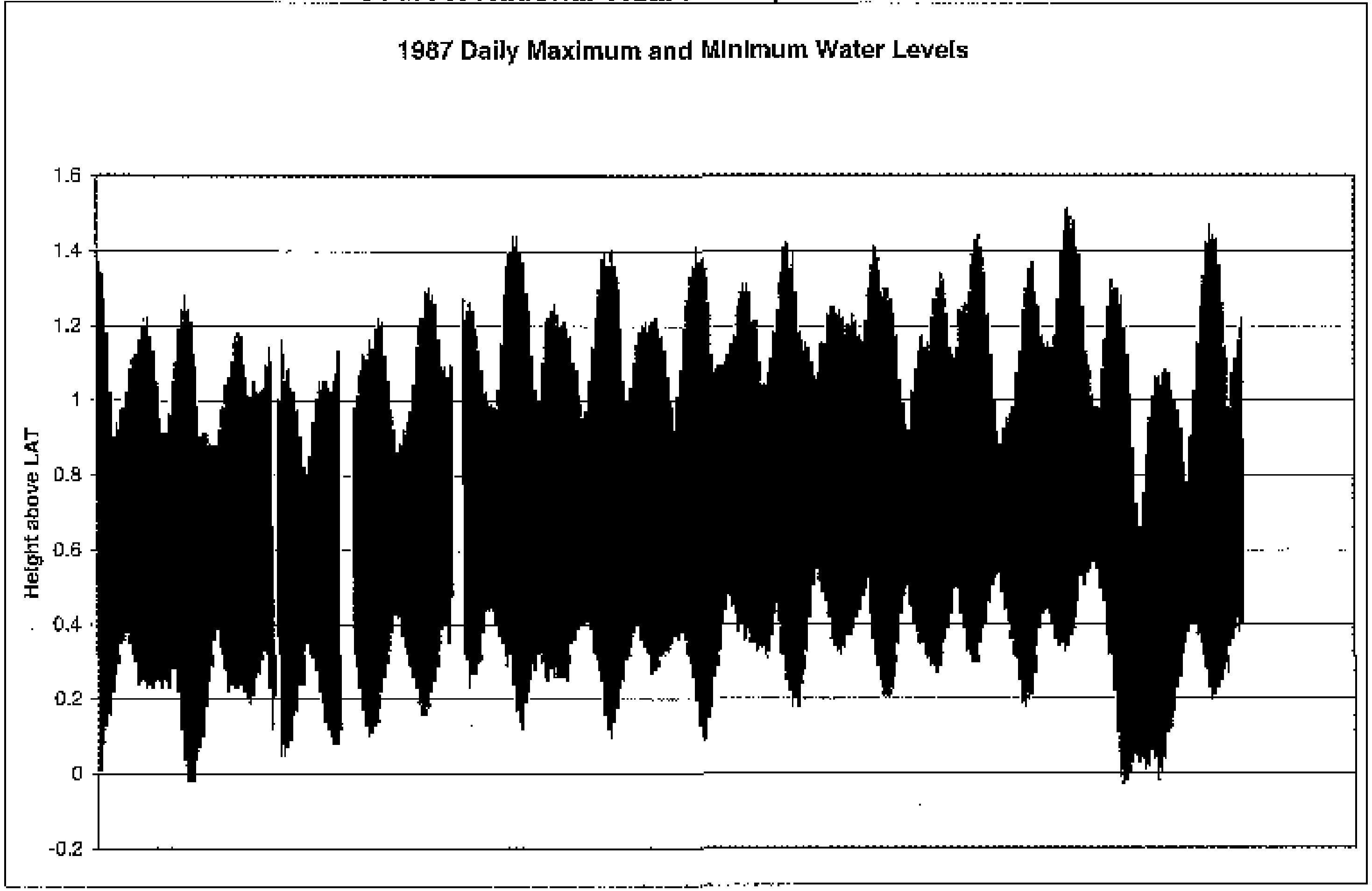
Maximum recorded level
1.56 m above LAT

Minimum recorded water level
-0.07 m below LAT

FIGURE B.1

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



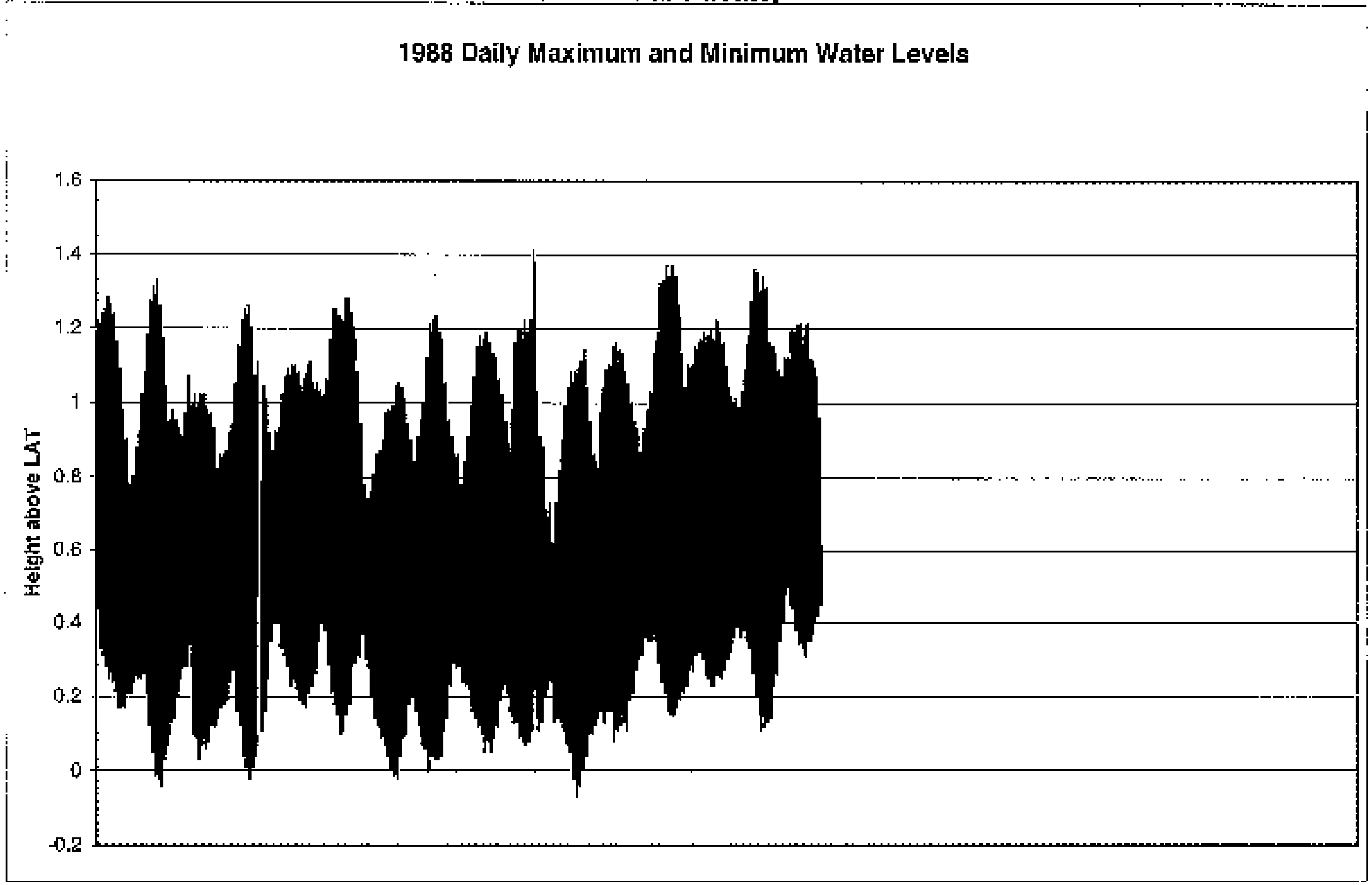
Maximum recorded level
1.51 m above LAT

Minimum recorded water level
-0.03 m below LAT

FIGURE B.2

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



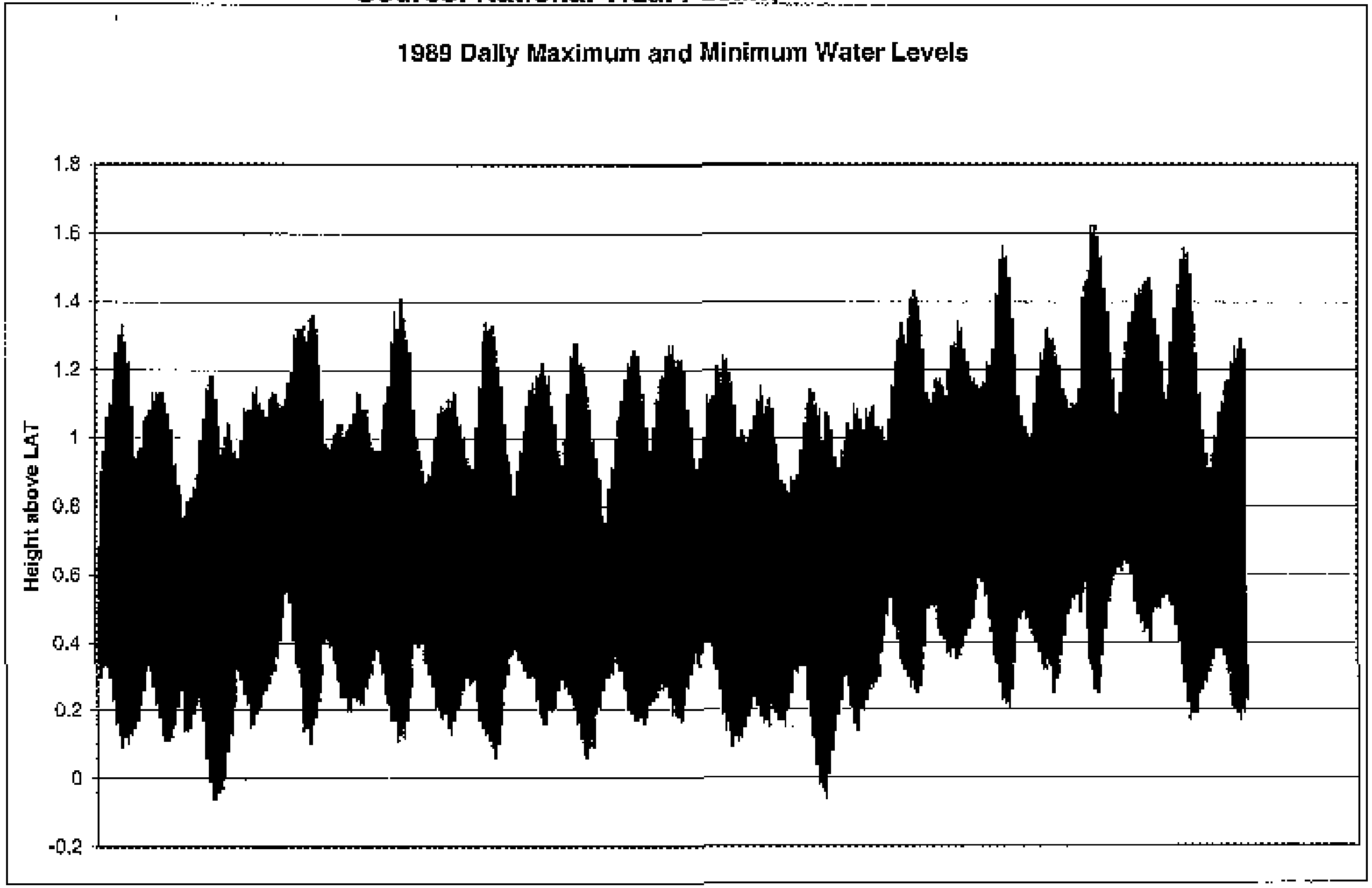
Maximum recorded level 1.41 m above LAT

Minimum recorded water level -0.07 m below LAT

FIGURE B.3

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



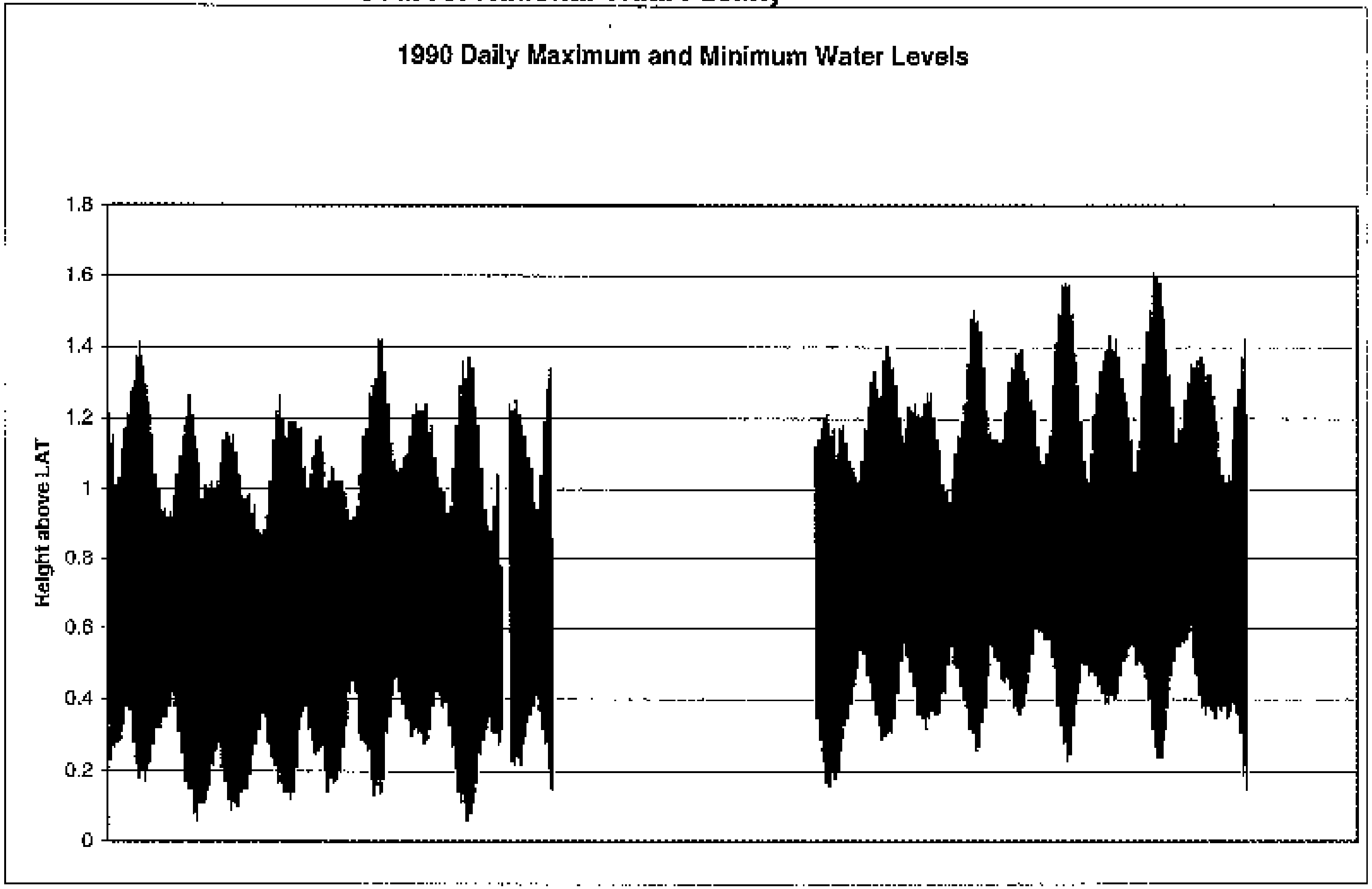
Maximum recorded level
1.62 m above LAT

Minimum recorded water level
-0.06 m below LAT

FIGURE B.4

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



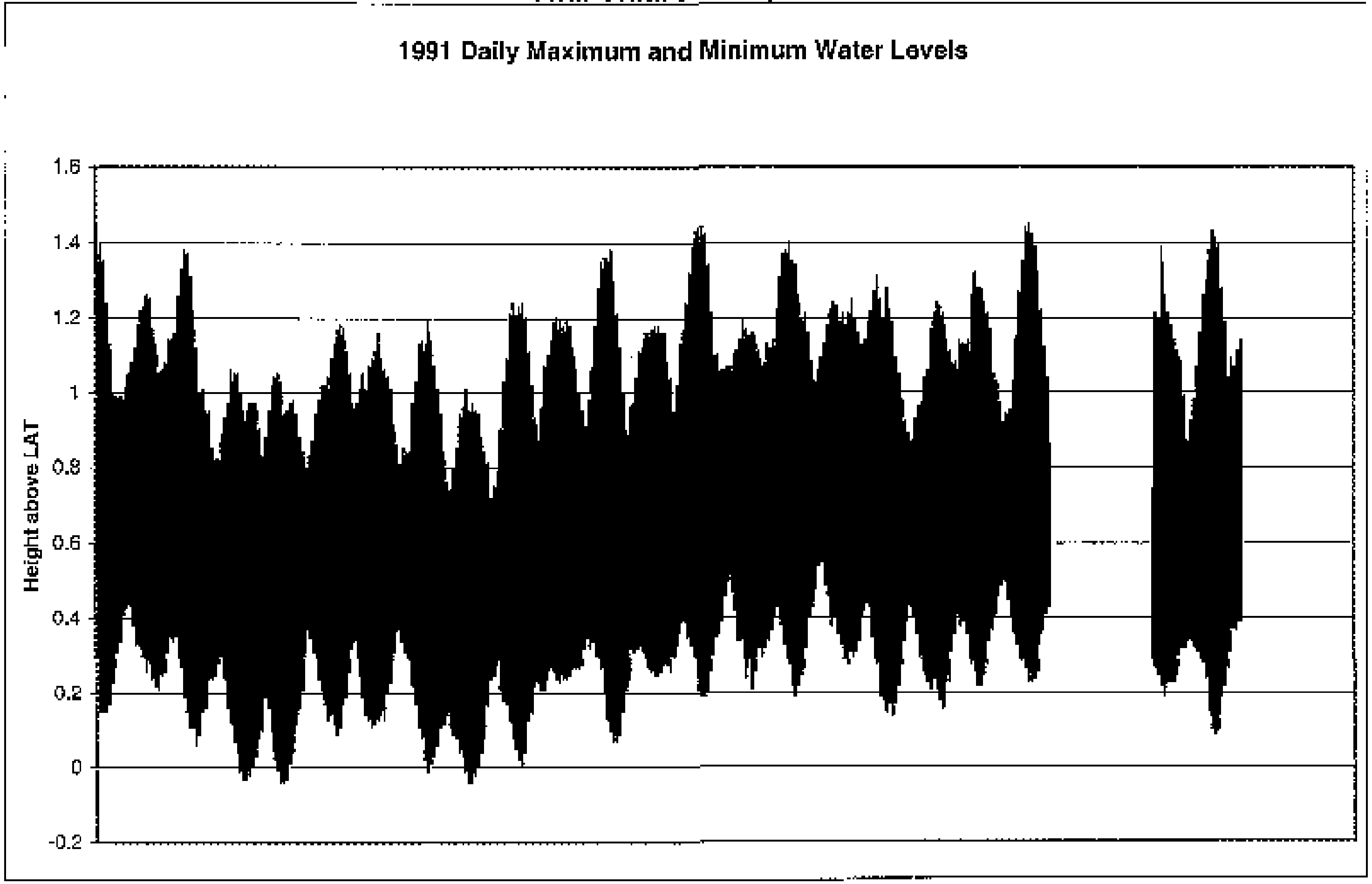
Maximum recorded level
1.61 m above LAT

Minimum recorded water level
0.06 m above LAT

FIGURE B.5

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



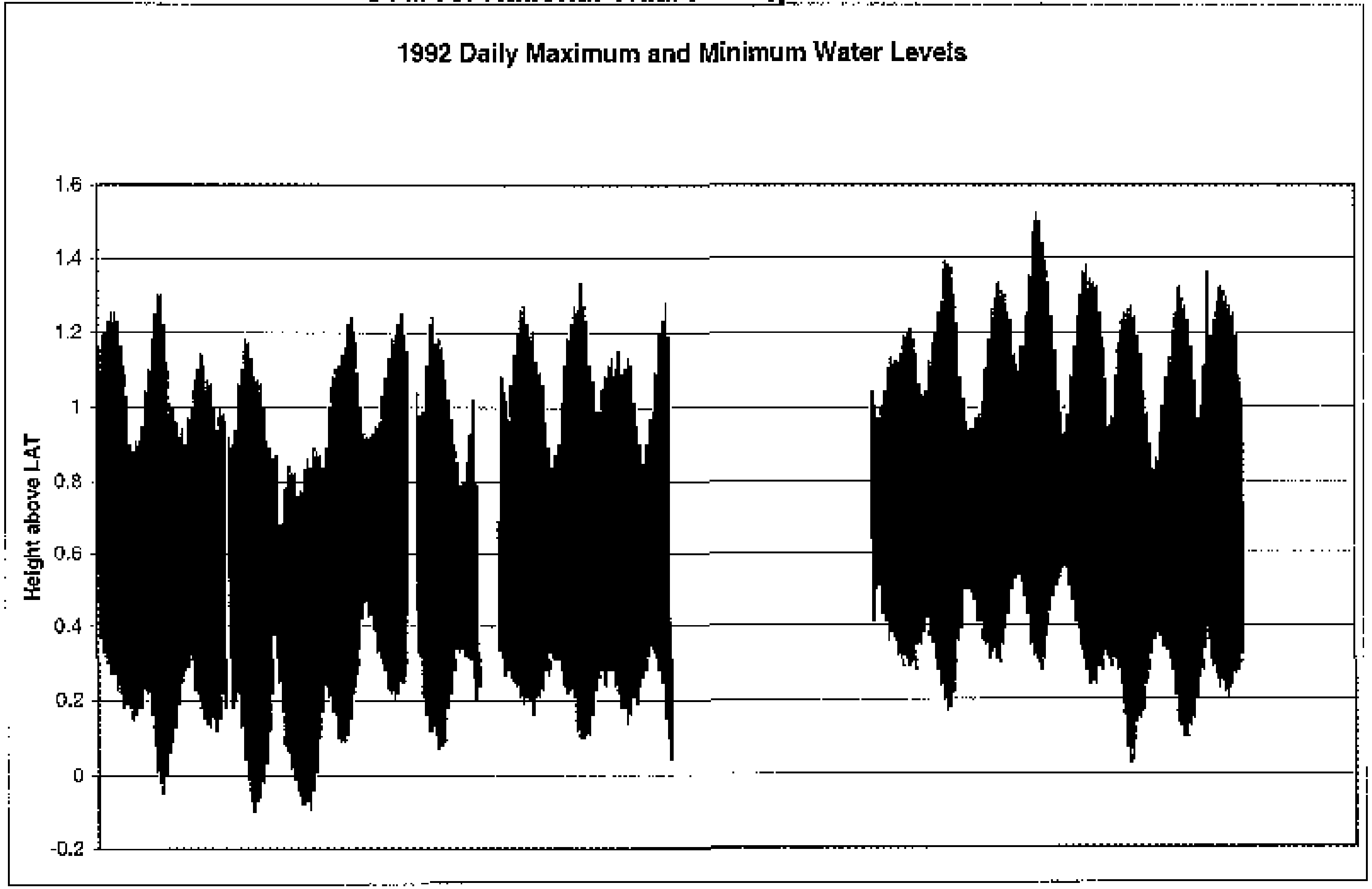
Maximum recorded level
1.45 m above LAT

Minimum recorded water level
-0.04 m below LAT

FIGURE B.6

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



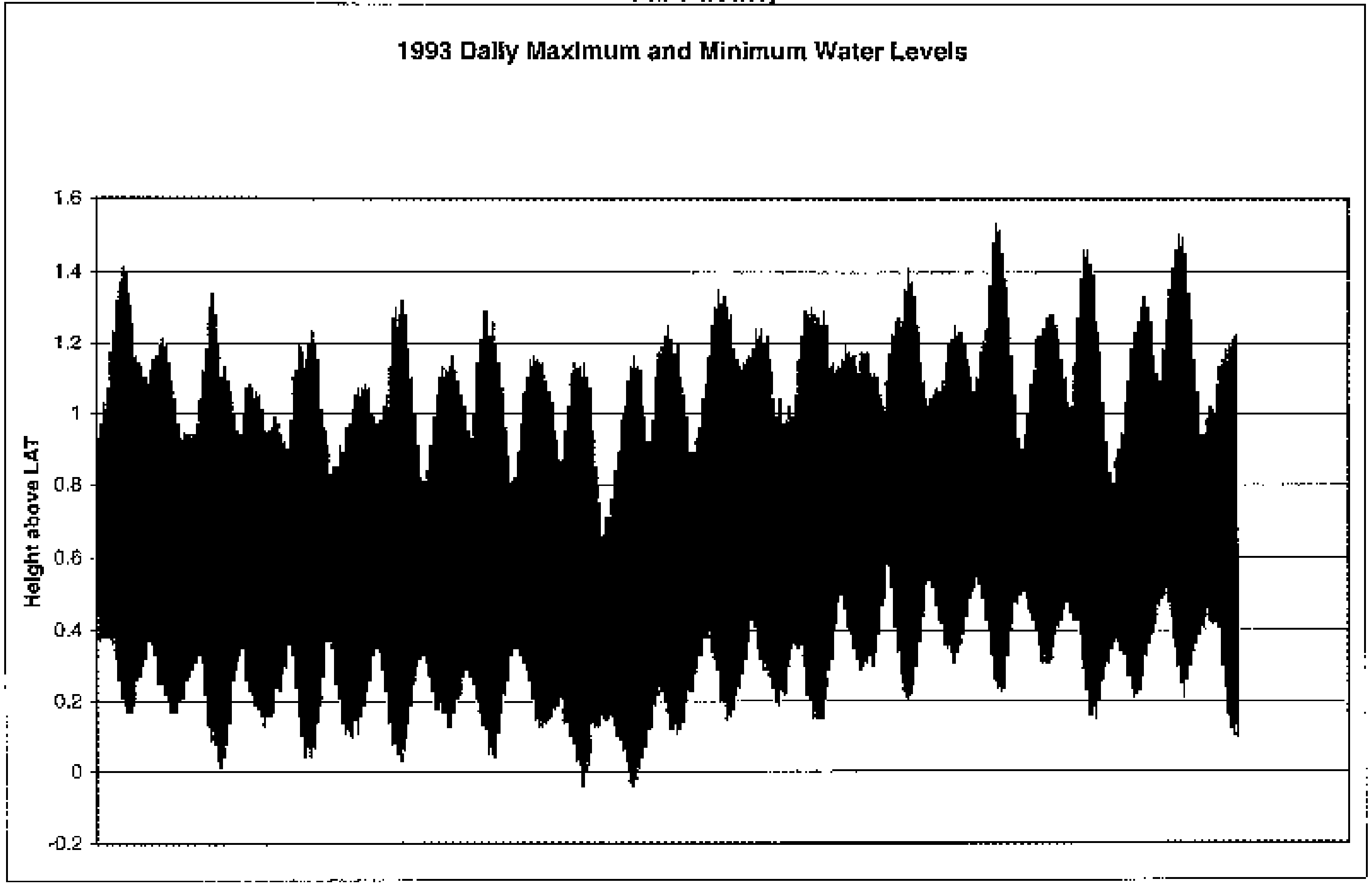
Maximum recorded level
1.52 m above LAT

Minimum recorded water level
-0.10 m below LAT

FIGURE B.7

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



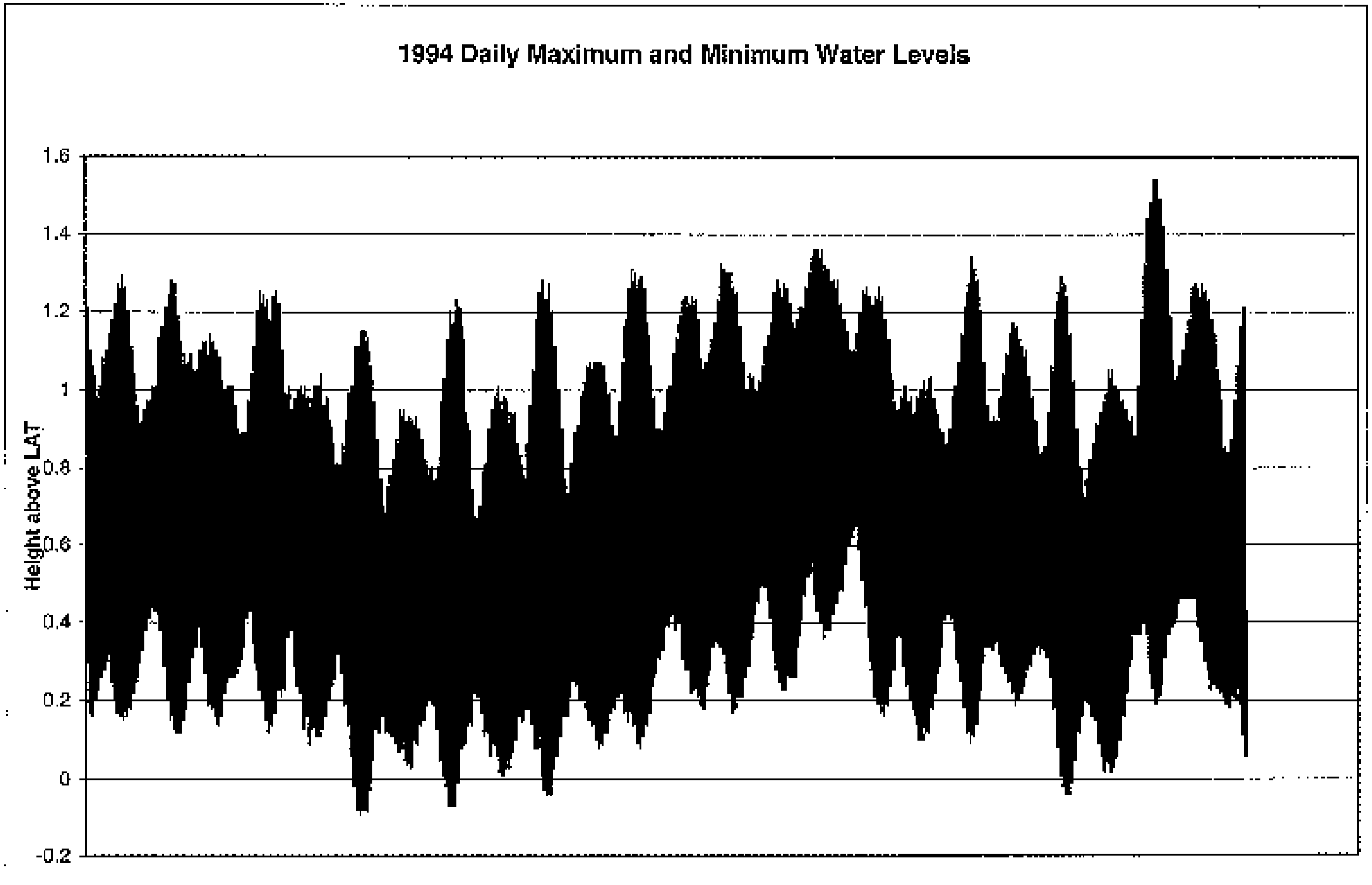
Maximum recorded level
1.53 m above LAT

Minimum recorded water level
-0.04 m below LAT

FIGURE B. 8

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



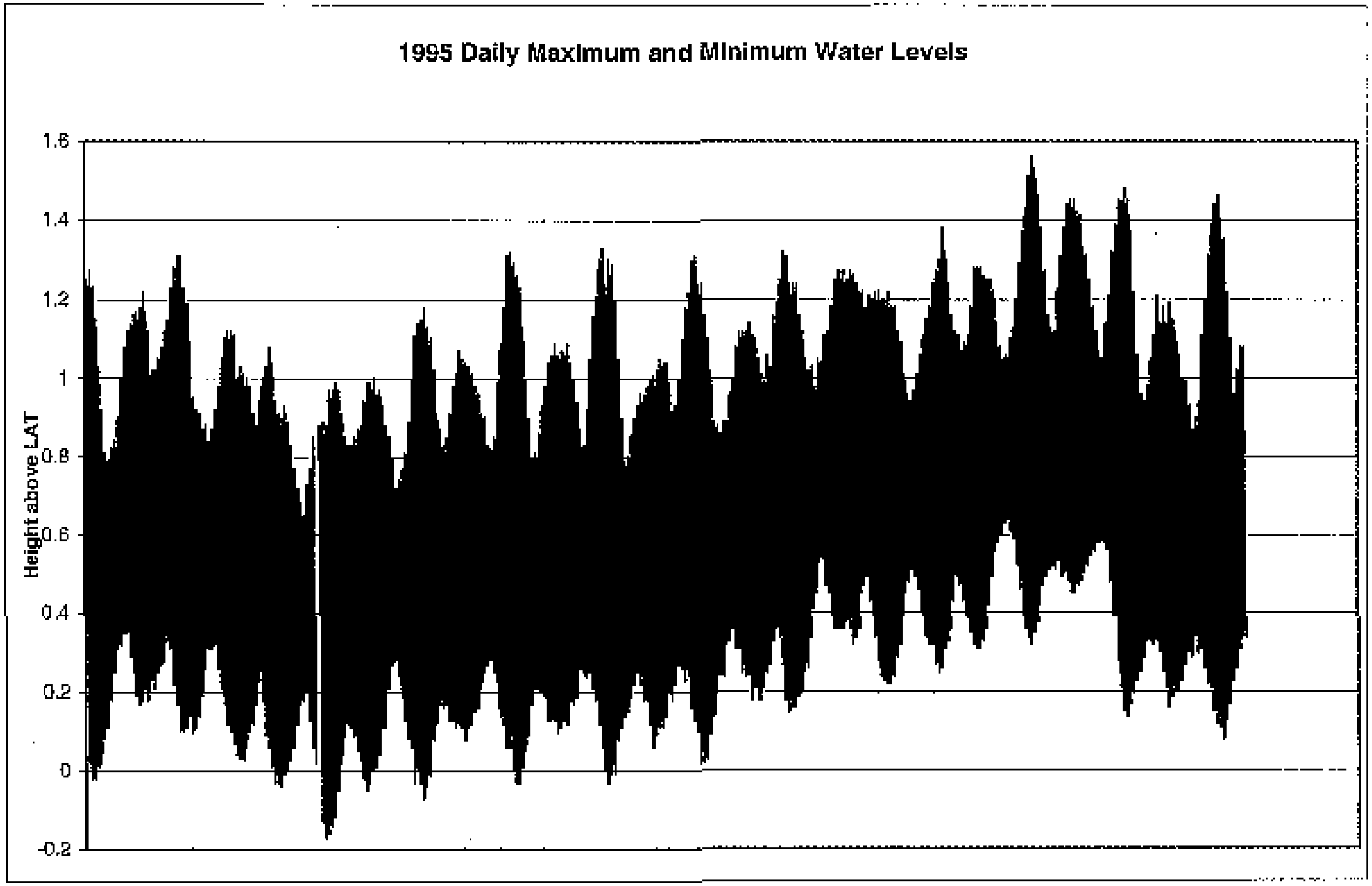
Maximum recorded level
1.54 m above LAT

Minimum recorded water level
-0.09 m below LAT

FIGURE B. 9

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



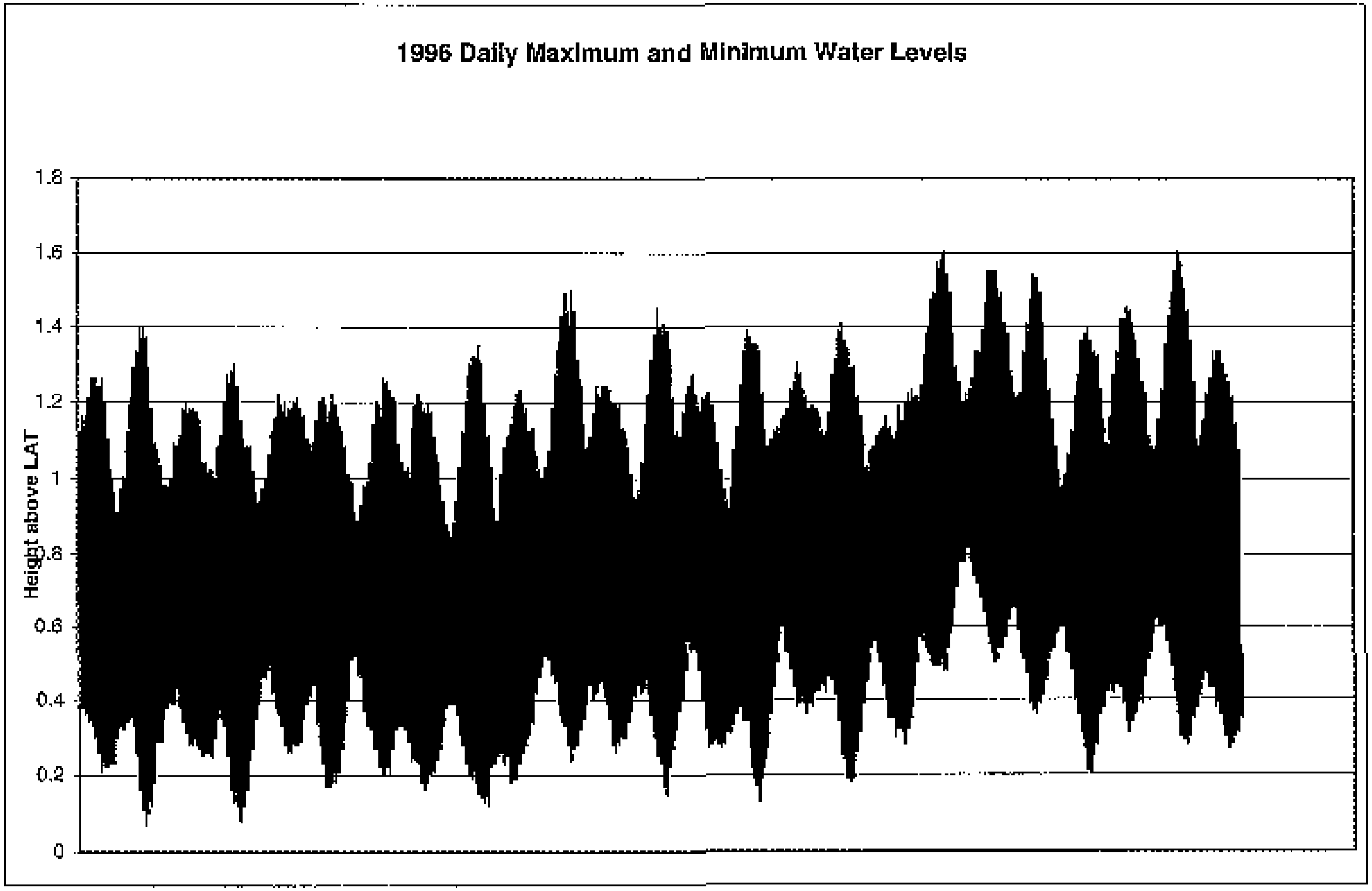
Maximum recorded level
1.56 m above LAT

Minimum recorded water level
-0.17 m below LAT

FIGURE B.10

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



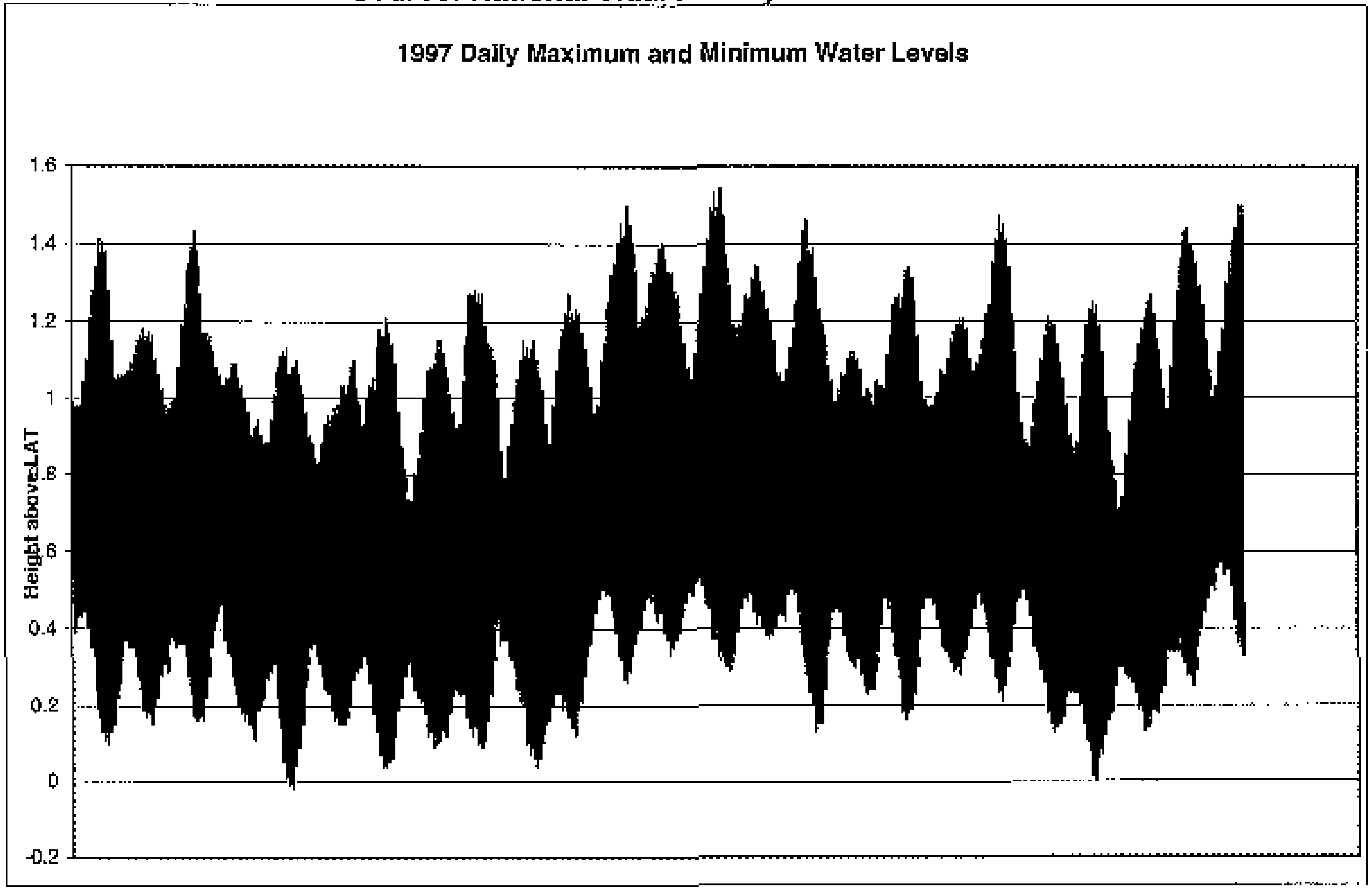
Maximum recorded level 1.60 m above LAT

Minimum recorded water level 0.07 m above LAT

FIGURE B.11

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



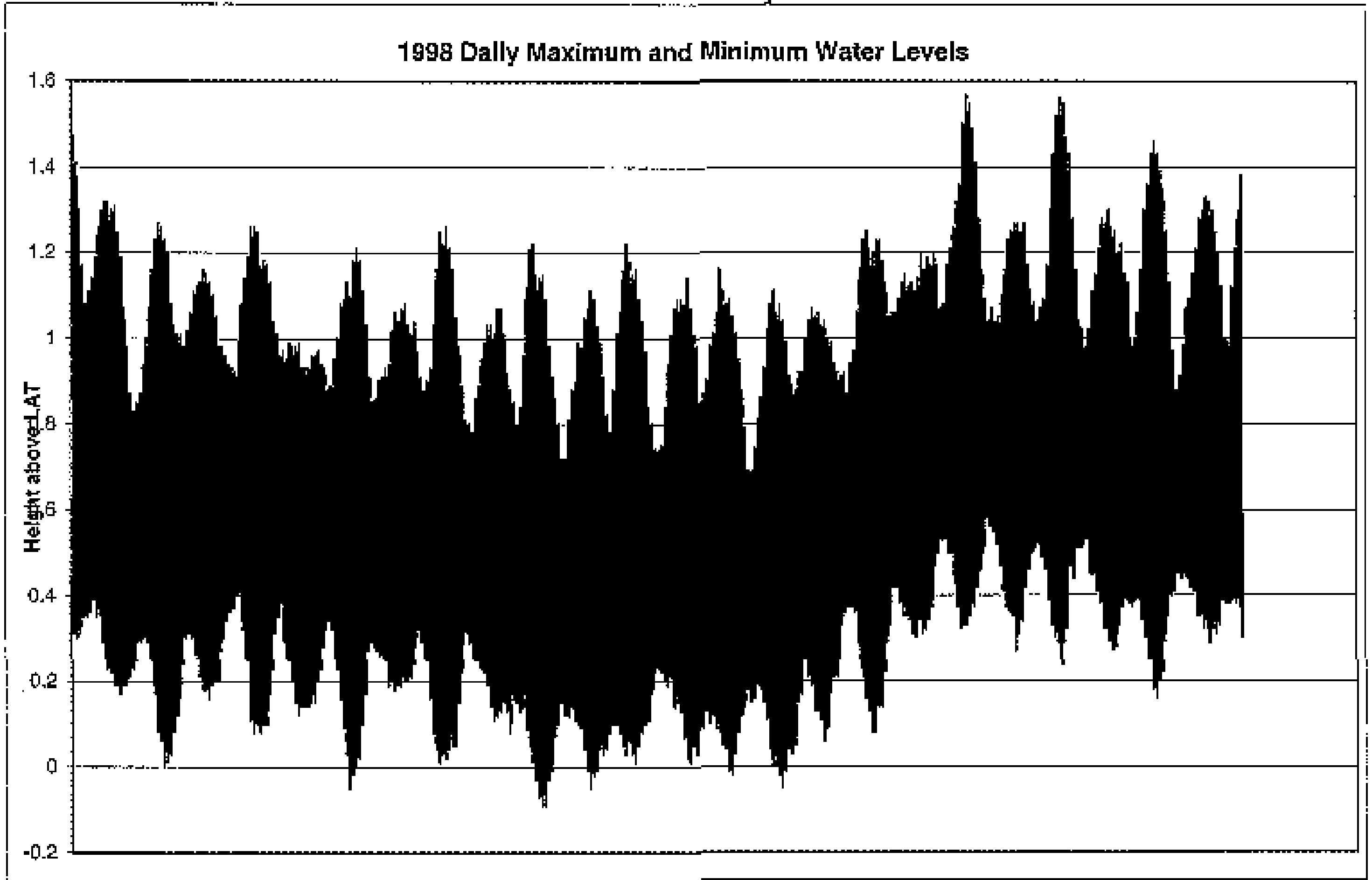
Maximum recorded level
1.54 m above LAT

Minimum recorded water level
-0.02 m below LAT

FIGURE B.12

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



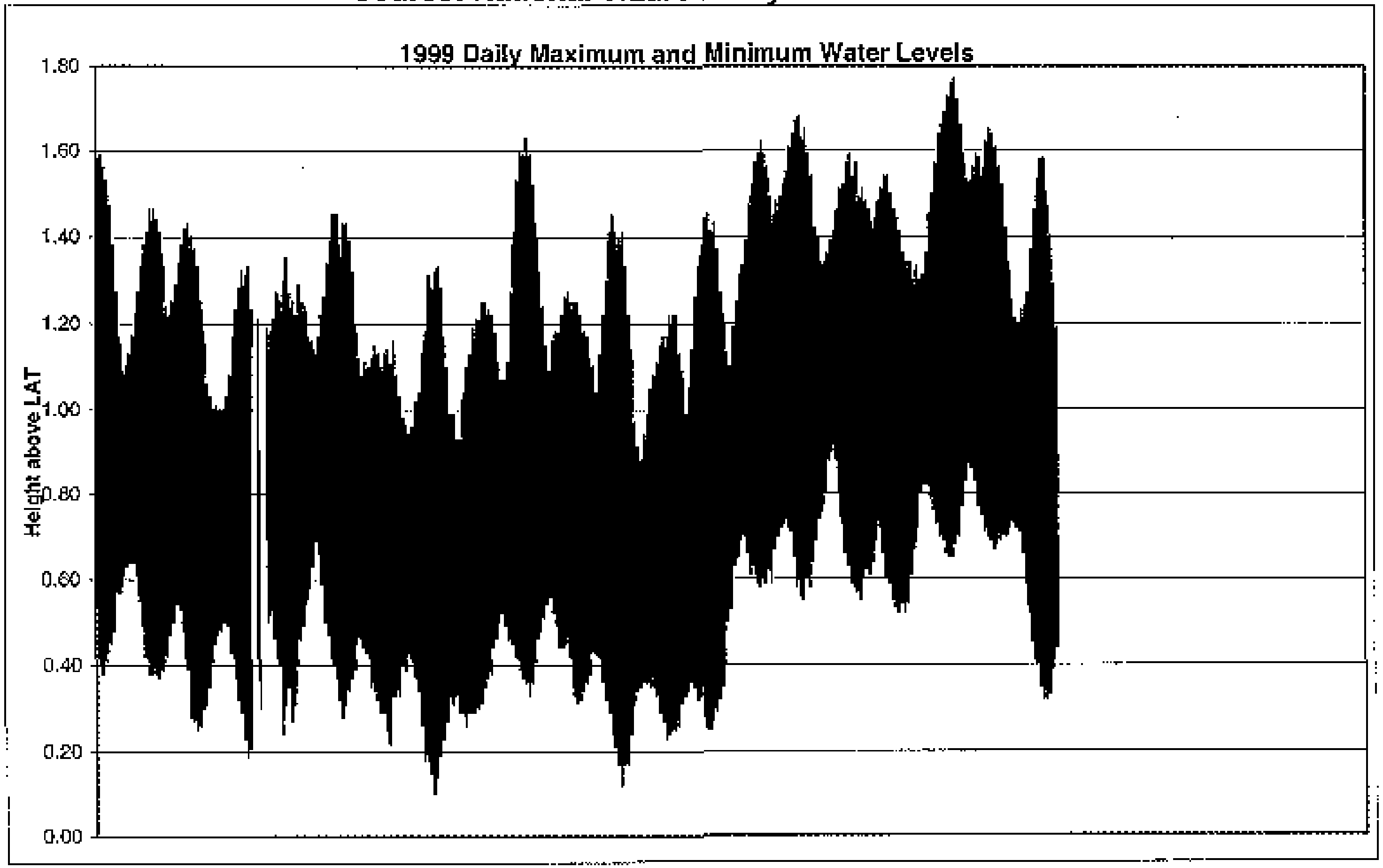
Maximum recorded level
1.57 m above LAT

Minimum recorded water level
-0.09 m below LAT

FIGURE B.13

COCOS (KEELING) ISLANDS

Source: National Tidal Facility



Maximum recorded level
1.64 m above LAT

Minimum recorded water level
-0.03 m below LAT

FIGURE B.14

Appendix C

Photographs

Figure C1: Northern end of seawall, adjacent to House 1. Note missing planks and dumped material on shoreline in background (Sep 1999).

Figure C2: Erosion of backfill behind seawall adjacent to House 1 (Sep 1999).

Figure C3: Seawall adjacent to House 3 (Nov 1999).

Figure C4: Seawall adjacent to Government House (Nov 1999).

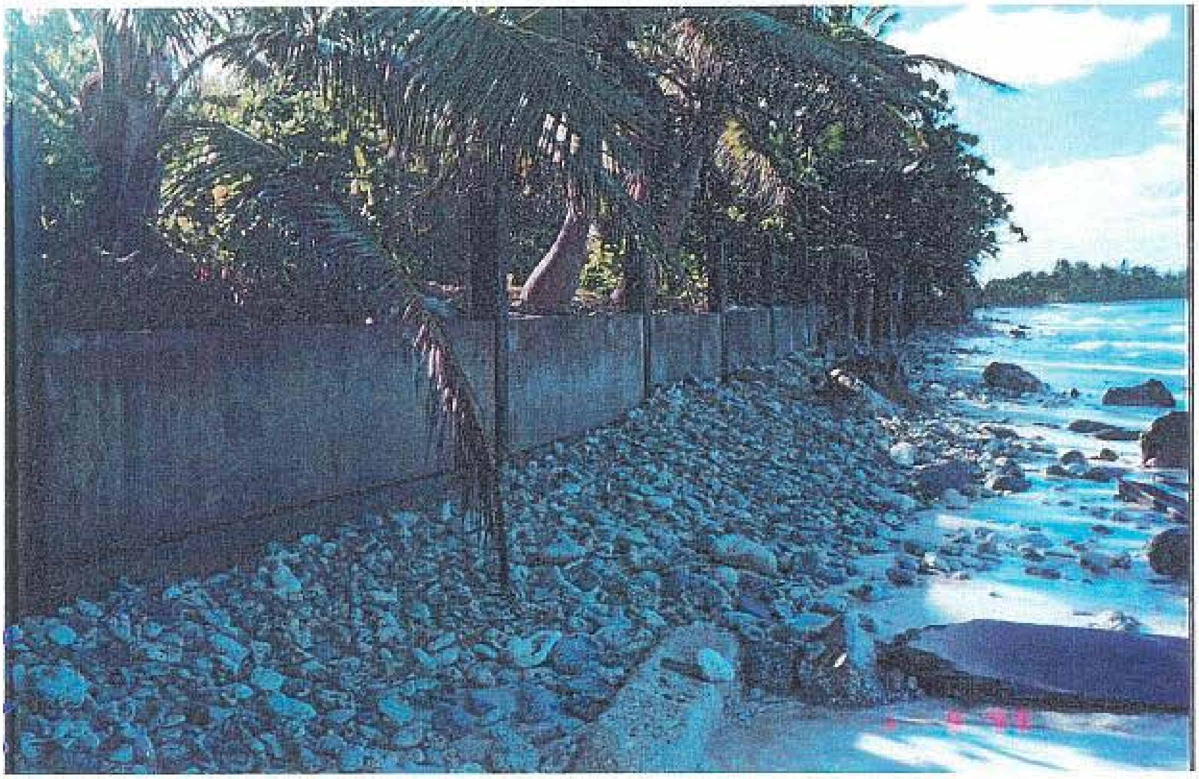


Figure C5: Southern section of seawall showing dumped concrete and coral rubble (Sep 1999).

Figure C6: Southern termination point of seawall, showing adjacent erosion and accumulated debris (Sep 1999).

Figure C7: Reef flat in front of seawall showing seaward crown in foreground (Nov 1999).

Figure C8: Seaward edge of reef flat (Nov 1999).

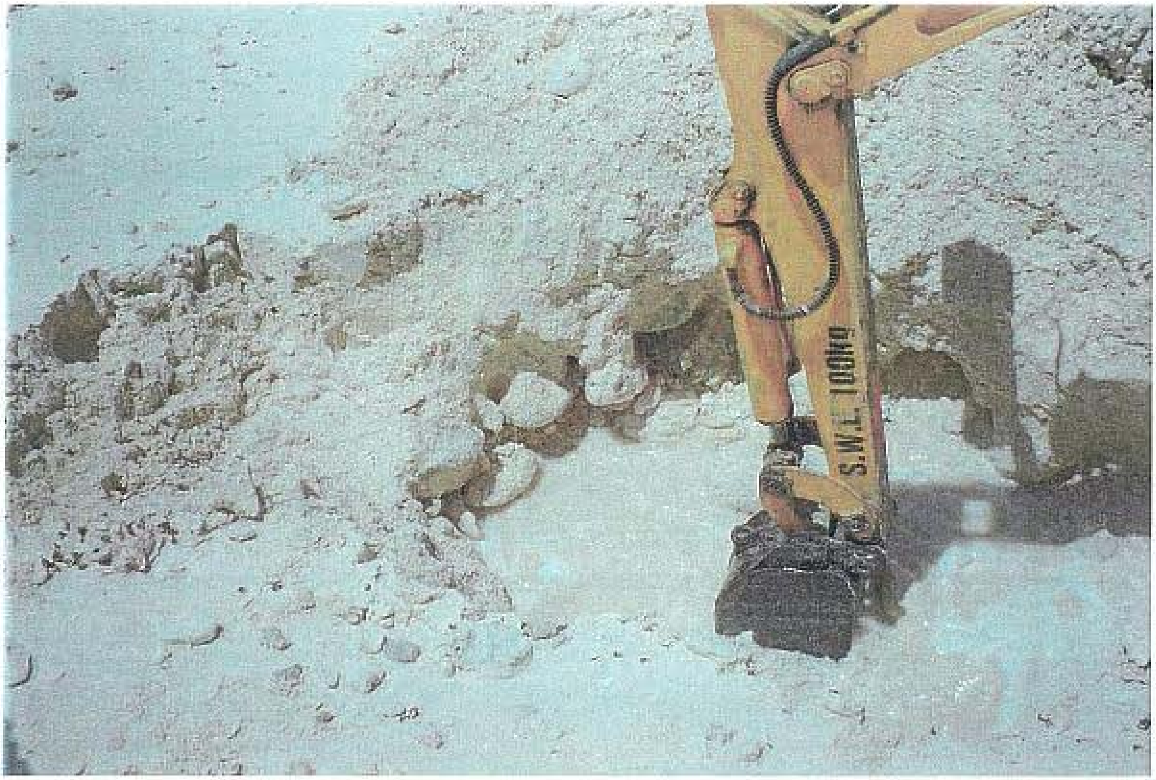


Figure C9: Excavation of test pit on upper beach area.

Figure C10: Test pit showing rock encountered below surface.

Figure C11: Excavated test pit.

Figure C12: Test pit showing rock encountered below surface.

Figure C13: Excavation of test pit No.2.


Figure C14: Excavated test pit.