SOPAC Technical Report 104

April 1990

SURVEY OF CYCLONE OFA DAMAGE TO THE NORTHERN COAST OF UPOLU, WESTERN SAMOA

by
Douglas M. Rearic*
Techsec

Prepared for: South Pacific Applied Geoscience Commission (SOPAC)
Western Samoa Project: WS.13

**Contributed by:* United Stated Geological Survey (USGS)

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

ACKNOWLEDGEMENTS

SOPAC wishes to thank the Apia Observatory, and in particular Mr Fa'atoia Malele, Acting Director of Apia Observatory, for providing their generous assistance in completing this survey. Special thanks go to Maselino Mataafa and Faleniko Tupufia for their guidance and critical comments during the survey.

INTRODUCTION

On 2 February 1990 Cyclone Ofa struck Western Samoa after having formed in late January about 120 km east of Funafuti, Tuvalu. The 2-3 day duration of the cyclone in Western Samoan waters (Figure 1) resulted in the formation of large waves as well as strong winds and caused extensive damage along the northern coasts of the islands of Upolu and Savai'i. The types of damage on Upolu varied depending on the area of coastline affected and ranged from the beaching of the passenger ferry Queen Salamasina in Apia to loss of lives, homes, and reclaimed land to the east and west of Apia.

SOPAC Technical Secretariat was requested by the government of Western Samoa to assess the physical damage to coastal structures and facilities. In response to this request, SOPAC sent a marine geologist from Techsec to make a preliminary assessment. This survey was made as part of the SOPAC Work Programme, Task 90.WS.13a, and was assigned Survey Number WS9001.

This report documents the damage and coastal changes in the form of photographs and descriptions and was made with the help of the staff of the Apia Observatory which, itself, suffered extensive damage to buildings and loss of historical meteorological records. Sediment samples were also collected from selected sites. Members of the survey team included the following personnel:

Douglas Rearic	- Marine Geologist, SOPAC Techsec
Maselino Mataafa	- Hydrologist, Apia Observatory
Faleniko Tupufia	- Hydrologist, Apia Observatory

Previous Work

Since 1978, many reports have been published by Techsec documenting both the coastal and nearshore environment of Upolu from Solosolo Beach in the east to Mulifanua Harbour in the west. These reports detail the bathymetry of the nearshore areas of the coastal zone (Roy and Richmond, 1986; Richmond and Roy, 1989), Apia Harbour (Halunen, 1978; Gauss, 1981; Rubin, 1984), and Mulifanua Harbour (Gauss, 1982) and discuss the environmental hazards to the coastline in regards to the dredging of landfill materials (Rubin, 1984) and the mining of beach sands (Eade, 1979).

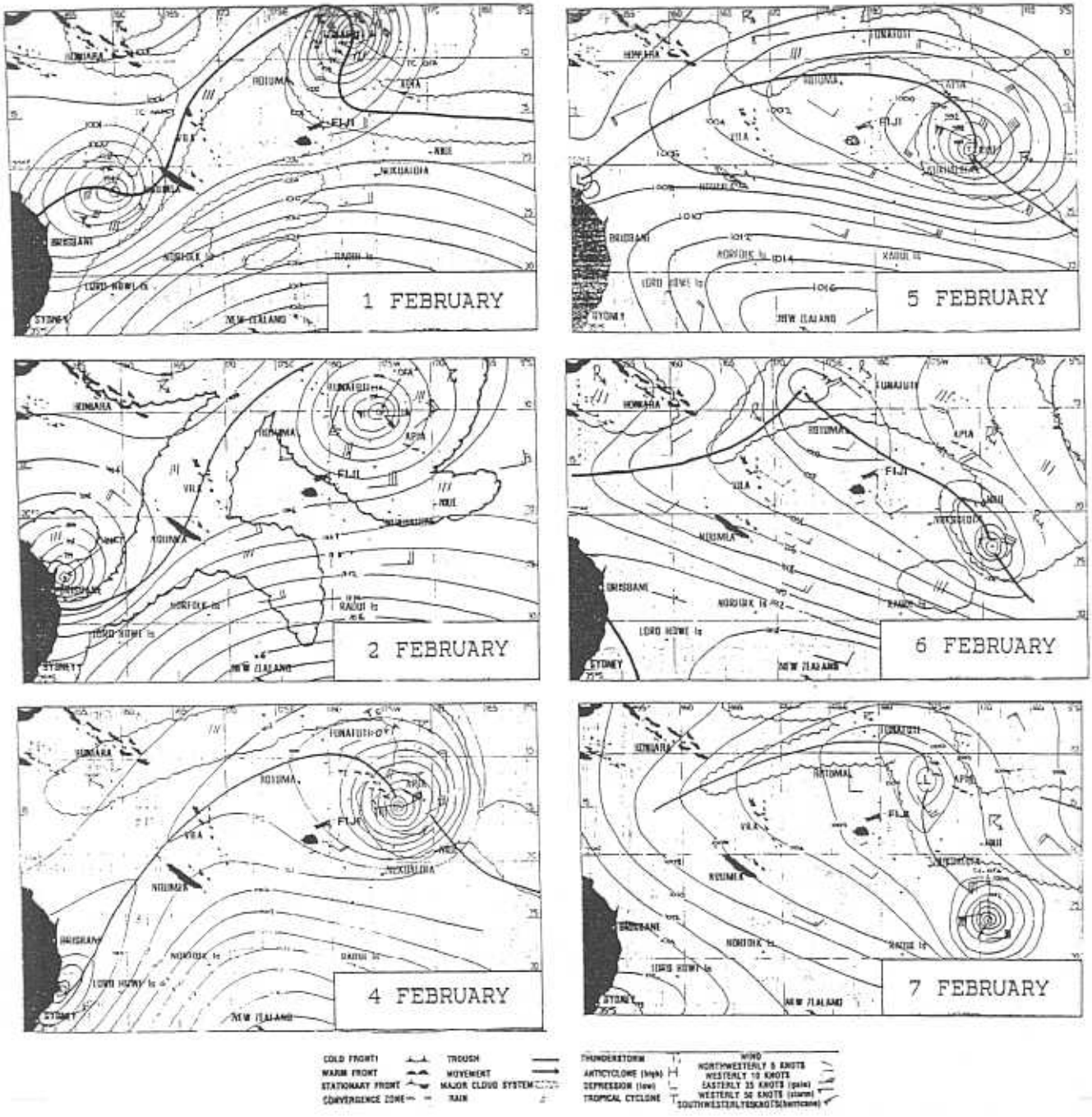


Figure 1. Track of *Cyclone Ofa* in the South Pacific as given by the Fiji Meteorological Service and published in the *Fiji Times*. There is no weather map included for 3 February 1990 because the *Fiji Times* does not publish on Sundays.

A SOPAC Technical Report by Carter (1987) detailed the possible effects of a cyclone to the area surrounding Mulinu'u Point and the coastline of parts of Apia. In his report Carter suggested that a seawall surrounding the end of the peninsula could give protection to the facilities on the point. He also calculated the theoretical forces of the 100-year storm. Further information on *Cyclone Ofa* and its effects on reclaimed land at Apia can be found in a Preliminary Report by Carter (1990).

RESULTS OF SURVEY

Between 26 February and 1 March 1990 a survey of cyclone damage was made of Apia and coastal areas to the east and west of the capital city. Discussions with Apia Observatory staff on the size and duration of the cyclone allowed determination of the strength of winds and size of seas responsible for the damage to Western Samoa. Meteorological measurements, a5 well as observations and estimates of storm strength by the observatory staff, are included in this report.

The types of damage sustained as a result of *Cyclone Ofa* include the following:

1. Loss of life.
2. Damage to structures such as houses, buildings, schools and churches.
3. Damage to plantations and agricultural facilities.
4. Damage to shipping facilities.
5. Damage to government facilities, buildings and monuments.
6. Damage to roads, bridges and electrical power and water facilities.
7. Loss of reclaimed land.
8. Coastal erosion and landslides.
9. Loss of government and scientific records.

Cyclone Ofa Statistics

Cyclone Ofa struck the coast of Upolu leaving in its wake many of the disastrous results estimated by Carter (1987) of the 100-year storm. The actual force of the cyclone was not as intense as theoretical calculations performed by Carter (1987), however the duration of the storm increased the effective strength of and damage caused by the storm. A post-cyclone survey by Carter (1990) indicated that a storm of the measured intensity and force (wind speed of 70 knots) of *Cyclone Ofa*

could hit Apia, Western Samoa on an average of once every 24 years. This frequency makes disaster preparedness and the construction of protective structures of immediate concern to Western Samoa. Table 1 compares theoretical storm intensity to that of *Cyclone Ofa*

Table 1. Comparison of theoretical 100-year storm intensity (Carter, 1987) with *Cyclone Ofa* intensity.

Storm Measurements	Carter (1987)	*Cyclone Ofa*
Maximum Wind Velocity	93 knots	70 knots
Maximum Deep Water Wave	12 m	7.5 m
Storm Surge + Astronomical Tide	2.3 m	1.6 m
Significant Wave Height	11.3 m	Unknown
Maximum Washover at Observatory	1.4 m	0.5 m
Apia Barometric Pressure	983 mb	986 mb

Gusts reached 97 knots.

*Recalculated from wave rider buoy data.

Estimates by Apia Observatory staff.

Measured at Apia Observatory.

Damage and Coastal Changes from Cyclone Ofa

Natural disasters can affect a society in many distinct ways. The physical consequences are the most readily apparent effects and are generally the easiest to assess in terms of cost. However, there are other effects to a society which are not as easily assessed and these include disruption of a peoples normal daily routines, development of a fear of your natural environment, and the loss of loved ones. The young people of Western Samoa had never experienced a disaster of the magnitude *of Cyclone Ofa. It* is the duty of the people of this country therefore to remember the effects of this disaster and to educate their children in the preparedness that is needed to survive these disasters.

The information reported here assesses only the physical effects of the cyclone, but the author docs not wish to minimise the psychological changes that occur in society when a disaster the

proportion of Cyclone Ofa strikes a nation. In this report the physical damage experienced by Western Samoa is documented by photographic evidence as this medium is considered by the author to be the most demonstrative.

Loss of Life

The final count of lives lost due to the cyclone in Western Samoa stands at 7. The causes for the deaths are varied and range from drowning due to large seas and waves (Figures 2 and 3) to being struck by flying debris in the high winds of the storm.

Houses, Buildings, Schools, and Churches

Damage to dwellings, businesses and social facilities was extreme and generally caused by either large waves which inundated the coastal zone (Figures 4, 5 and 6) or high winds which reached further inland (Figures 7, 8 and 9). Wave and wind damage was particularly severe to the coastal villages east of Apia where coastal protection is minimal. In these areas, the sea moved inland through the villages, removing homes from their foundations and distributing coral rubble over the village grounds. In the areas lying to the west of Apia, the coastline is more protected and most damage resulted from high, sustained winds which removed the roofs of many homes and facilities.

Agriculture

Because there is a subsistence economy in many of the coastal villages, the loss of family gardens means a loss in the production of food crops for some time to come (Figure 10). The people of Samoa take pride in their village appearance and spend many hours tending to the upkeep of their land. The inundation of the sea caused a widespread ground cover of coral debris which destroyed lawns, gardens and trees (Figures 11 and 12). Saltwater poisoning of the trees which survived the high winds is a common occurrence along the northern coast of Upolu (Figure 13). There is also a fear of food shortages as present supplies are used up and there are none available to replace them.

Shipping Facilities

Shipping was disrupted in several ways. The most destructive was the beaching of the passenger/cargo ferry Queen Salamasina in Apia. The ferry broke away from the main wharf during the storm and drifted across the harbour finally coming to rest on an area of reclaimed land (Figures 14 and 15). Wharf facilities at Apia Harbour suffered damage from the battering of boats against the facility. Strong currents and waves at the harbour facilities at Mulifanua, the main ferry terminal between Upolu and Savai'i, caused shoaling of the harbour which has disrupted transportation between the islands.

Government Facilities, Buildings, and Monuments

Government buildings suffered considerable damage during the cyclone. Possibly the hardest hit by the full force of the cyclone was the Apia Observatory, where many of the older structures were destroyed (Figures 16-19). The Department of Lands and Survey building, on the main road fronting the harbour was also damaged severely (Figure 20). Other structures were destroyed. A grave monument (considered by Carter in 1987 to be at high risk during a cyclone) on Mulinu'u Peninsula survived the cyclone with little additional damage (Figure 21). It had been protected by a rock fill placed in December 1989, just prior to the storm. The importance of this type of protection to coastal structures can not be over emphasised. The western side of Mulinu'u Peninsula suffered little or no damage because it was sheltered from the more severe effects of the storm. Carter (1987) had noted that there would be little damage from a cyclone to this side of the peninsula and that coastal protection (a seawall) would not be necessary for this part of the peninsula.

Roads, Bridges, and Electrical Power and Water Facilities

The coastal roads, in particular, received a lot of damage from the force of the waves breaking on them and overtopping them (Figures 22-26). Damage ranged from erosion of the seaward sides to complete removal of the road and its foundation (Figure 22). Some of the coastal roads lie at the high tide level (Figure 26) and are at great risk even during normal seasonal storms. The cyclonic storms that strike the coastal zones bring unusually high tides, such as might be experienced in the future if mean sealevel rises, and highlight the need to build roadways and dwellings away from the

immediate coastline. Electrical power (Figure 27) and water facilities were cut to most of the villages along the coast.

Coastal Erosion and Landslides

Areas of the coastline that lie on higher ground were not immune from the effects of the heavy seas (Figures 23 and 29). During the cyclone, not only was the coast eroded and washed into the sea, hut vegetation along the coast was also removed, further decreasing the stability of the coast and facilitating the removal of beaches and coastal cliffs.

Landslides were common on the slopes of cliffs and mountains (Figures 30 and 31). Trees were uprooted due to strong winds and the land was destabilised. Heavy rains accompanying the cyclone worked to saturate the soil. Gravity, working on this mixture, was able to force the movement of soil downslope often covering roads and disrupting transportation to the outer parts of the coast. This tended to hinder rescue and relief efforts immediately after the cyclone.

Reclaimed Land

Much of the reclaimed land along the coast was lost to the sea (Figure 32). In many cases, homes that had been built on this type of land were destroyed and the land washed away so that it is now impossible for these families to rebuild even if they have the resources to do so (Figure 6).

Government and Scientific Records

Because of the destruction of many of the buildings at Apia Observatory, historical meteorological and scientific records were lost forever (Figure 33). Some of these records date back to 1904 and the beginning of the Observatory. Most of the contents of the library were also destroyed or severely damaged during the cyclone.

Cyclone Banks

Along the northern coast of Upolu, at the reefs edge, a series of cyclone banks, similar to the 1972 Hurricane Bebe bank formed in Tuvalu, were created by the force of large waves dredging coral debris from the reef and depositing it 10-20 metres inshore of the reefs edge onto preexisting reef (Figures 34-40). During the present survey, two of these banks were visited and sampled by the survey party. The material comprising the banks is for the most part dead coral fragments. At both banks the survey party found only minor amounts of sand in isolated spots along the banks. Even digging up to a half metre's depth on the bank failed to show any change in composition.

A cyclone bank at Laulii Village (Figures 34-37) lies close to the coast because the reef in this area is also near the coastline. The bank exhibits many of the characteristics of large sand bars and barrier islands, although formed of very coarse material. This bank is steep on the shoreward side, laying at an angle of repose of about 40 from the horizontal (Figure 36). On the seaward side the slope is about half that of the shoreward side, or about 20. The profile of this feature is that of a sand wave formed by normal current activity, high at the "updrift" edge and gently sloping to the "downdrift" side until the shoreward edge is reached (Figure 35). The bank is 2-3 metres high, 15 metres wide, and about 250 metres long (dimensions approximate). The bank remains above water at even the highest tides. The bank is being reworked by wave action at a slow rate and the material composing the bank will probably be spread over the inner reef area over time.

At the edge of the reef, just seaward of the Apia Observatory, lies a very large cyclone bank the survey party has named Observatory Bank (Figures 38 and 39). This bank is now being reworked by normal wave activity, particularly during high tides, and the shape is gradually changing from the original depositional form. The survey party walked most of the length of this bank, taking photographs and collecting selected samples (Figure 40). This bank is over 2 kilometres long, over 50 metres wide in places, and of similar height to that of the bank at Laulii Village. During high tide portions of the bank are under water and the bank then appears as 5 separate banks (Figure 41). The surface of the bank contains depositional features similar in appearance to other submarine and eolian bedforms formed in finer grained materials. The seaward edge of the bank now has a high tide berm formed by the reworking of waves (Figure 38). At one location, a crescentic dune of coarse material overlies a base of similar material except for a greater proportion of sand in the base. The slight difference in sorting is evident in the appearance of the two materials, however the size of sample required to document this precluded collection. The dune is considered to have formed by a separate

wave event(s) after formation of the bank itself. Another possibility is formation by the reworking of material on the bank after original deposition, but this is considered by the author as unlikely.

The disposition of the banks is at this time uncertain. Concern has been expressed by the government over the mining of the bank material for use as aggregate for the rebuilding of damaged and construction of new facilities. The grade of the material may make it desirable for such uses as landfill and roadbase. However in some areas, such as Laulii Village, the banks may offer protection to the coastline from future storms. In the case of Observatory Bank, it appears that the material is being reworked at a rapid rate. However, mining of the banks is not recommended as the bank is material for future beach and lagoon sediment replenishment.

Figure 2. Remains of truck that was hit by a large wave and washed from the road above. Two people were killed in this accident.

Figure 3. Cliff erosion at edge of road where truck in Figure 2 was washed from road. Truck remains are circled.

Figure 4. Destroyed homes and power lines at Lautuanuu Village. The road lies next to the coastline. Coral rubble now covers areas that were carefully tended lawns and gardens.

Figure 5. Church at Lautuanuu Village which suffered internal damage from waves and roof damage from high winds. Note the large amount of coral rubble surrounding the church grounds.

Figure 6. Site of house at Lautuanuu Village which was destroyed during the cyclone. Note that much of the land that the house was built on has been eroded from the coast.

Figure 7. Destroyed house knocked from its foundation by strong winds. The house lies to the west of Apia and is away from the coastline.

Figure 8. Much of the damage to structures to the west of Apia was caused by strong winds. This church is at Mulifenua Village.

Figure 9. This church at Faleasiu Village suffered damage to its roof. Most structures that lost their roofs also suffered considerable water damage to interior furnishings.

Figure 10. Many of the coconut palms that were uprooted during the storm now litter the coastline of Upolu.

Figure 11. The area in this photograph was a grassy, park-like area near the coastline of Lautuanuu Village prior to *Cyclone Ofa*.

Figure 12. Lautuanuu Village was one of the hardest hit areas by the storm. Because relatively little rain accompanied the storm most of the trees were poisoned by salt from seawater intrusion. A vast amount of coral rubble covers areas that were once grass.

Figure 13. Trees along the road at Solosolo Beach survived the high winds but were poisoned by saltwater intrusion from the sea.

Figure 14. The passenger/cargo ferry *Queen Salamasina* broke away from the main wharf during the cyclone and was beached at the landfill area directly off the main part of the city of Apia. During low tide the area beneath the ferry is completely dry.

Figure 15. The landfill on which the *Queen Salamasina* was beached has been severely damaged, losing about 20 meters of fill to the strong waves that attacked the inner harbour area of Apia.

Figure 16. The Apia Observatory suffered considerable damage both to buildings and the effects housed there. A large amount of sand was deposited during the storm on the end and east side of Mulinu'u Peninsula.

Figure 17. Most of the wooden structures at the Apia Observatory were damaged beyond repair.

Figure 18. Observatory buildings facing the lagoon felt the full onslaught of the cyclone. Interior, as well as exterior, damage was almost total and the buildings are structurally unsafe for use of any type at present.

Figure 19. Coastal erosion on the lagoon facing, northern point of Mulinu'u Peninsula was significant.

Figure 20. The Department of Lands and Survey building suffered considerable damage. The building lies on the main road fronting the harbour at Apia.

Figure 21. A grave site lying along the coast on the east side of Mulinu'u Peninsula survived the cyclone with little additional damage due to the placement of a protective rock fill in December, 1990 which absorbed much of the wave energy expended on the coastline. The rocks from the fill can be seen scattered around the site. These coastal monuments were considered by Carter (1987) to be at high risk during a cyclone.

Figure 22. At Lautuanuu Village the road was completely washed away disrupting travel to the east of Apia and hindering rescue operations after the cyclone. The original road lay along the dashed line in the photograph.

Figure 23. Roads to the west of Apia also suffered considerable damage.

Figure 24. Storm waves to the east of Apia were particularly destructive due to the lack of reef protection in some areas. This photo is of the same area as Figures 2 and 3 and shows the height that storm waves were able to reach during the cyclone.

Figure 25. Although roadways suffered damage, some coastal homes on reclaimed land to the west of Apia survived the storm, however the damage sustained was severe in many cases.

Figure 26. The road at Saleimoa Village lies at the high tide level and even during normal seasonal storms may be awash. Any future increase in sea level will put this area of the coast at high risk from flooding by average tidal fluctuations.

Figure 27. Power lines at Lautuanuu Village were severed when waves knocked the poles from their foundations and high winds severed the electrical lines.

Figure 28. Coastal erosion was severe during the cyclone as waves attacked the coastline and large areas of the coast were washed into the sea.

Figure 29. Wave attack on the coastline uprooted many of the coastal palms, washing many out to sea. They were later to be deposited along the coast after the storm (Figure 10).

Figure 30. Rainfall and high winds damaged many trees on the hillsides, uprooting them and causing landslides.

Figure 31. Many of the landslides blocked the roads hindering rescue efforts to the outlying areas of Upolu.

Figure 32. The loss of reclaimed land was significant along the entire northern coast of Upolu. The landfill area in this photograph lies directly off the city front in Apia and about 20 meters of the ocean fronting portion was lost to wave attack during the cyclone.

Figure 33. Many of the historical meteorological and scientific records were lost at Apia Observatory. The library contents were also either destroyed or damaged during the cyclone as approximately 0.5 metre of water washed across the tip of Mulinu'u peninsula.

Figure 34. Cyclone banks were formed by coral rubble dredged from the front of the reefs along the coast of northern Upolu. The banks tend to be curved and possess many of the attributes of sand bars and barrier islands found in other areas of the Pacific.

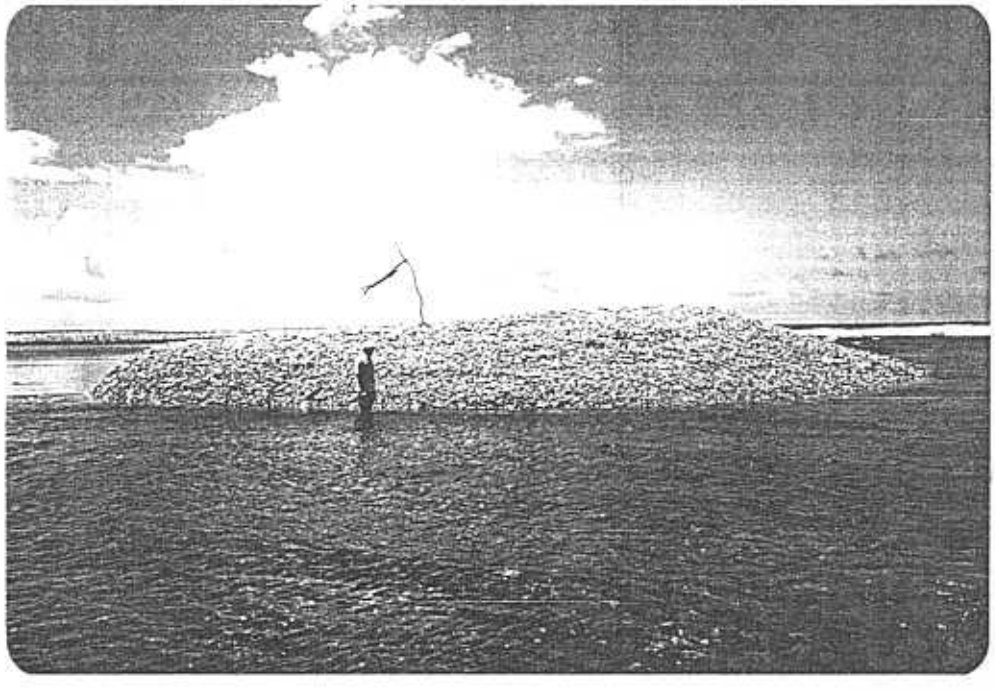


Figure 35. The cyclone banks are 2-3 metres in height and vary considerably in length and width. Some are found near the coast such as this one at Laulii Village whereas others are situated further offshore.

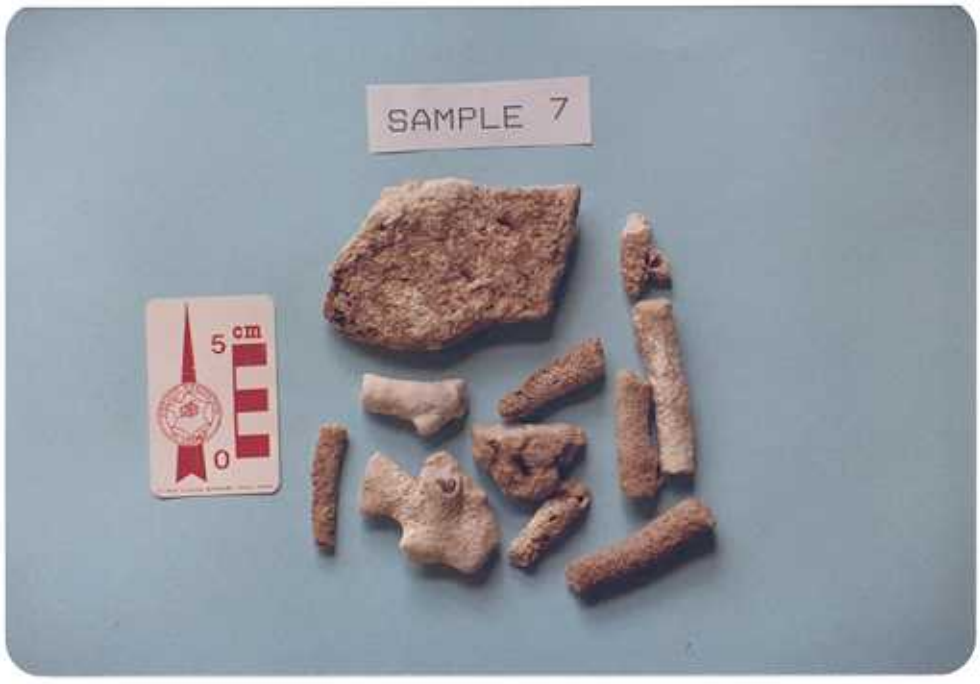
Figure 36. The cyclone banks are steep on the shoreward sides and have a gentler slope on the seaward facing side. In this photograph the coarseness of the material forming the bank can be seen.

Figure 37. Hydrologist Mataafa collects samples from the Laulii Village cyclone bank. The material from the cyclone banks may be a source of aggregate for construction projects in the future. However, if left in their original locations the banks may provide protection from future storms.

Figure 38. Observatory Bank, formed at the reef edge off Mulinu'u Peninsula is a large bank now being reworked by waves during high tides. A high tide berm can be seen in this photograph.

Figure 39. Observatory Bank is a very long and wide feature. In this photograph two scientists from the Apia Observatory can be seen studying the morphology of the bank and collecting samples of the bank material.

A.



B.

Figure 40. Samples of coral debris collected from Observatory Bank (A) and Laulii Bank (B).

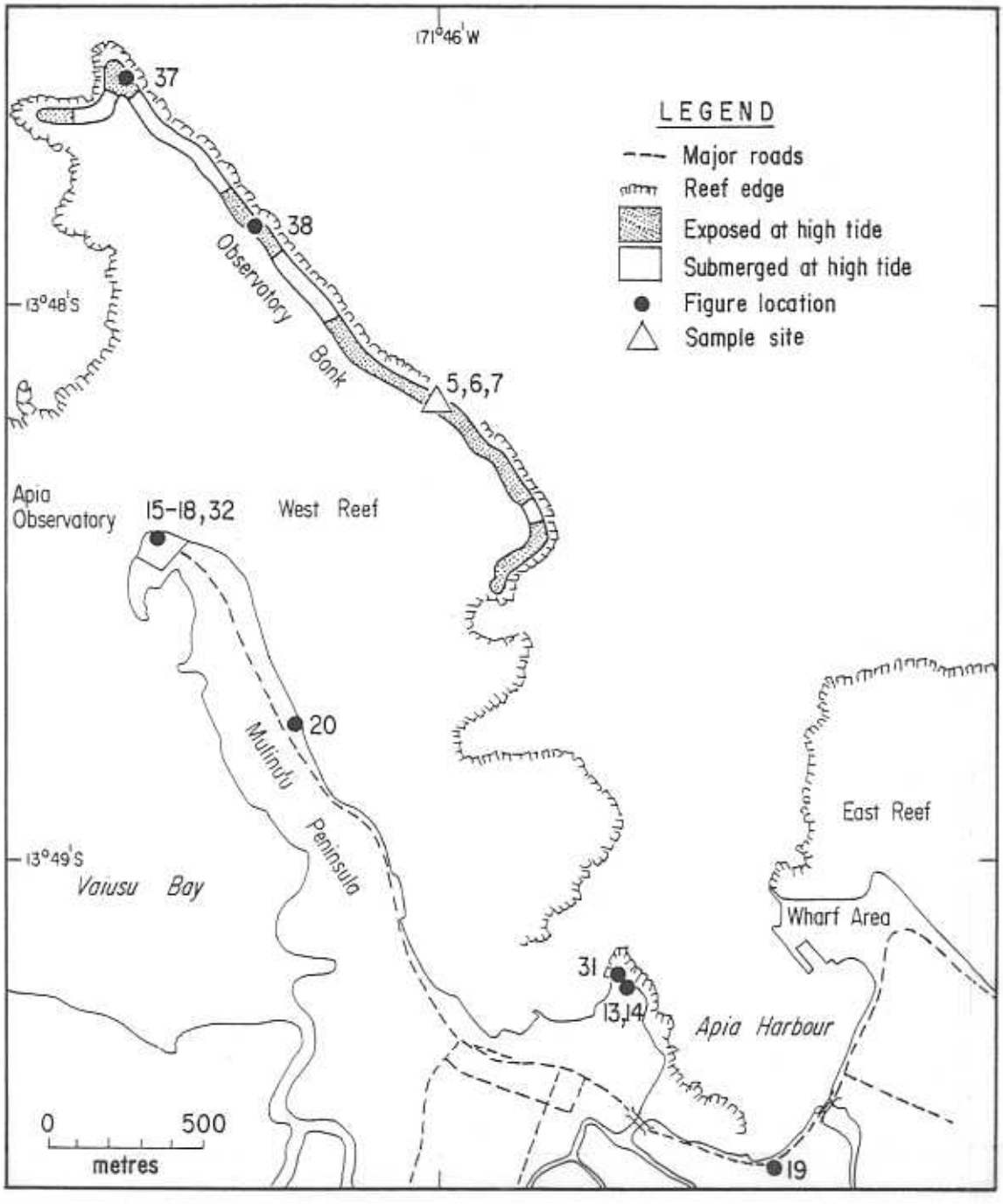


Figure 41. Map of Mulinu'u Peninsula showing approximate location of Observatory Bank and the portions which are submerged at high tide. This bank appears to be being reworked at a relatively rapid rate by wave action during high tides. Note that the locations of some of the figures and sediment samples are included.

CONCLUSIONS

Cyclone Ofa caused extensive damage and destruction in Western Samoa with considerable loss of life. The monetary value of the damage has been set in the millions of dollars. The sociological damage to the people of Western Samoa cannot be estimated but also can be considered as very severe.

In this report we have documented a variety of types of damage to the coastal zone in the form of photographs and descriptions obtained during a survey about 3 weeks after the cyclone struck Western Samoa. Housing, agriculture, transportation, and general services were affected and will require months, and even years in some cases, to fully recover.

There is a need to form a plan for disaster preparedness that the population is aware of and able to implement quickly. A storm with the strength of *Cyclone Ofa* can possibly occur in the near future (recurrence interval of 24 years) and, therefore, precautions need to be taken immediately and the rebuilding following this disaster should take this into account.

Structures built at the coastline are at high risk due to the low-lying land and the nearness or absence of reef in many areas of the coastal zone. This is particularly true in the areas east of Apia where damage from waves was severe. Areas to the west of Apia are at high risk due to flooding during these storms but are not as prone to wave damage.

Roads and municipal services, such as electrical and water, were damaged or destroyed during the cyclone. In some places, roads lie at the present high tide level and may be inundated from extremely high tides or normal yearly storms.

RECOMMENDATIONS

The following recommendations are considered necessary by Techsec to lessen future impacts from storms of the magnitude of *Cyclone Ofa:*

1. Detailed coastal mapping and site surveys should be conducted of areas where coastal roads were damaged to provide information for planning and design of coastal protection works.

2. The end of Mulinu'u Peninsula will continue to be at risk during severe storms and, therefore, a detailed study of the peninsula and the coastal processes affecting it is suggested. Other areas of the coast, particularly areas of reclaimed land, are also at high risk and should be included in the study. The study should include an interpretation of both historical and recent aerial photographs to determine coastal changes to the area over time. This information can be utilized by engineers in determining the type of coastal protection works appropiate for the conservation of land and facilities.

3. The mining of sand from beaches increases the risk of wave attack to the coastline. Because the beaches along the coast are, in some cases, the only protection villages have during severe storms, caution should be exercised in the mining of this resource. The possible environmental effects should be considered in consultation with a qualified coastal engineer familiar with this type of island environment before undertaking this type of operation.

4. The cyclone banks should be monitored closely to determine their longevity as a barrier to ocean waves impinging on the coast. Mining of the banks is not recommended because of their importance to the maintenance of the coastal environment.

5. Aerial photography of the northern coasts of Upolu and Savai'i should be flown as soon as possible and copies of the photographs be made available to SOPAC. The aerial photographs will allow Techsec geologists to map the extent of coastal change due to the cyclone in detail and also give information on the extent and location of the cyclone banks along the reefs.

REFERENCES

Carter, R. 1987: Seawall protection facility for Mulinu'u Point, Western Samoa. *CCOP/SOPAC Technical Report 78:* 18 pages, 10 figures, 4 tables.

Carter,R. 1990: The proposed Central Bank Building site in Apia, preliminary comments. *SOPAC Preliminary Report 19:* 5 pages.

Eade, J.V. 1979 Solosolo Beach report. *CCOP/SOPAC Cruise Report* 27: 7 pages.

Gauss, G.A. 1981: Apia Harbour survey, Samoa. *CCOP/SOPAC Cruise Report* 55: 10 pages, 2 appendices.

Gauss, G.A. 1982: Mulifanua and Salelologa Harbour surveys, Samoa. *CCOP/SOPAC Cruise Report* 65: 6 pages, 2 appendices.

Halunen, John A. 1978 Apia Harbour survey, 21-27 April 1978. *CCOP/SOPAC Cruise Report* 13: 28 pages.

Richmond, Bruce M. and Roy, Peter S. 1989 Sedimentological and bathymetric studies of offshore Apolima and Manono islands, Western Samoa. *CCOP/SOPAC Technical Report* 64: 12 pages, 2 appendices.

Roy, Peter S. and Richmond, Bruce M. 1986 Coastal and nearshore mapping in Western Samoa - a proposal. *CCOP/SOPAC Miscellaneous Report* 28: 4 pages.

Rubin, David M. 1984 Landfill materials and harbour surveys at Apia Harbour, Mulinu'u Point, Faleolo Airport, and Asau Harbour, Western Samoa, 15 May - 4 June, 1984. *CCOP/SOPAC Cruise Report* 98 8 pages, 8 figures.