# Catastrophe Insurance Pilot Study, Port Vila, Vanuatu:

## Developing Risk-Management Options for Disasters in the Pacific Region

*by*

G.G. Shorten, S. Goosby, K. Granger, K. Lindsay, P. Naidu, S. Oliver, K. Stewart, V. Titov, G. Walker

# Volume 2 of 2

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**Authors and Affiliations:**

Dr Graham G. Shorten, Environmental & Community Risk International (ECRi) Pty Ltd, Brisbane, AUSTRALIA
Mr Stan Goosby, Pacific Disaster Center (PDC), Hawaii, USA
Mr Ken Granger, Risk Scientist, Buderim, AUSTRALIA
Mr Kevin Lindsay, Risk Management International Consulting (Riskman) Ltd, Port Vila, VANUATU
Ms Purnima Naidu, SOPAC, Suva, FIJI ISLANDS
Mr Stephen Oliver, Global Environmental Modelling Systems (GEMS) Pty Ltd, Melbourne, AUSTRALIA
Mr Kerry Stewart, DunlopStewart Ltd, Auckland, NEW ZEALAND
Dr Vasily Titov, Consultant, Seattle, USA
Dr George Walker, Aon Re Australia Ltd, Sydney, AUSTRALIA

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# Appendix 1

# Quantitative Assessment of Risk to Infrastructure due to Large Natural Catastrophes in the Port Vila-Mele Area, Vanuatu

*by*

**Kerry Stewart**

DunlopStewart Ltd, Auckland, New Zealand

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SOPAC

South Pacific Applied
Geoscience Commission

# Quantitative Assessment of Risk to Infrastructure due to Large Natural Catastrophes in the Port Vila – Mele Area, Vanuatu

**Prepared By**

**-DunlopStewart-**

**May 2002**

# 1 Executive Summary

This report quantifies the potential damage to infrastructure in the Port Vila and Mele areas due to natural catastrophe and has been derived from interviews, research, anecdotal evidence and site inspections of the asset groups identified. For simplification, the results have been represented in both tabular and graphical form. The exercise has not included any allowance for any consequential losses due to the failure of the infrastructure. We believe the significance of quantitative estimates of risk to infrastructure should be considered in conjunction with the consequences of these losses, as some of the low value losses may have the greatest consequential impacts.

Based on our findings reinstatement estimates for each infrastructural asset type and for each scenario are provided in Table 1.

**Values in $AUD 000's**

| | Cyclonic Winds | Earthquake | Severe Rainstorm | Storm Surge | Tsunami | Total |
|---|---|---|---|---|---|---|
| Airport | 310 | 2,500 | 200 | - | - | 3,010 |
| Bridges | - | 1,250 | 1,190 | 40 | 30 | 2,510 |
| Communications | 200 | 15,050 | - | - | - | 15,250 |
| Oil & Gas | 140 | 3,700 | - | - | 100 | 3,940 |
| Power | 120 | 120 | - | - | - | 240 |
| Roads | 90 | 320 | 150 | 40 | 20 | 620 |
| Seawalls | 1,060 | 690 | 50 | 50 | 240 | 2,090 |
| Sewerage | - | - | - | - | - | - |
| Water | 20 | 1,050 | 680 | - | - | 1,750 |
| Wharf | 1,340 | 7,210 | - | 1,340 | 30 | 9,920 |
| **Grand Total** | **3,280** | **31,890** | **2,270** | **1,470** | **420** | **39,330** |

Table 1 – Total Reinstatement Estimates

The estimate of reinstatement seeks to restore the service to current standards i.e. providing the same service potential as currently provided by the existing infrastructural assets. With the data currently available we cannot accurately define the effects of the defined risks. As there have not been any natural disasters in Port Vila of the magnitude under consideration for this project and due to the uncertainties involved in predicting the damage caused by any such events, the quantification of potential losses can only be considered as order of magnitude estimates of potential loss.

These figures have been graphically represented in Chart 1 which provides the total estimated reinstatement for all infrastructure assets by catastrophe type and Chart 2 which shows the total exposure per infrastructure asset type for all scenarios.

The results show that the losses anticipated in a major earthquake are significantly more than the losses expected under all other natural disasters scenarios combined. While this is an expected outcome, the recent January 2002 earthquake in Port Vila highlights the realty of this scenario and the exposure that particular sectors of infrastructure have.

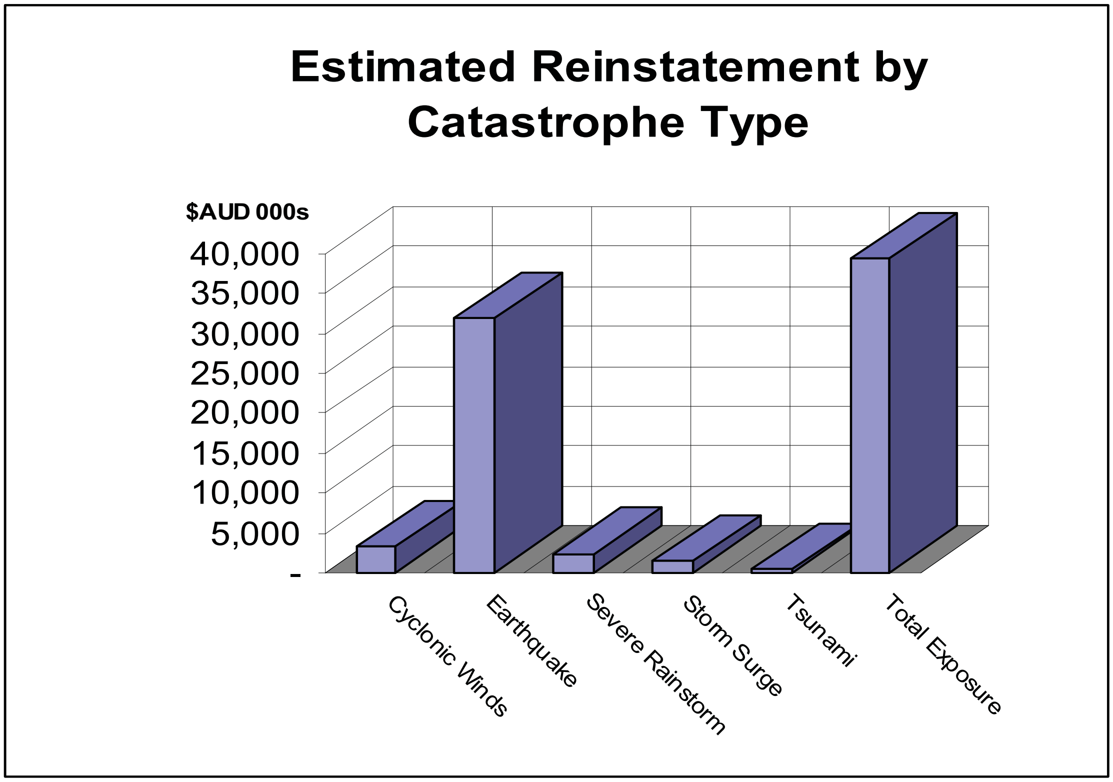

Chart 1

The infrastructure asset with the greatest exposure to earthquake (in dollar terms) is communications, due to the potential loss of the main exchange (building and equipment) in Port Vila. The wharves, airport, oil, gas and petroleum supplies are also likely to suffer significantly loss.

Despite less exposure in value terms, the infrastructure assets that are likely to have the most significant immediate effect on the local community relate to the loss of the bridges and water supply.

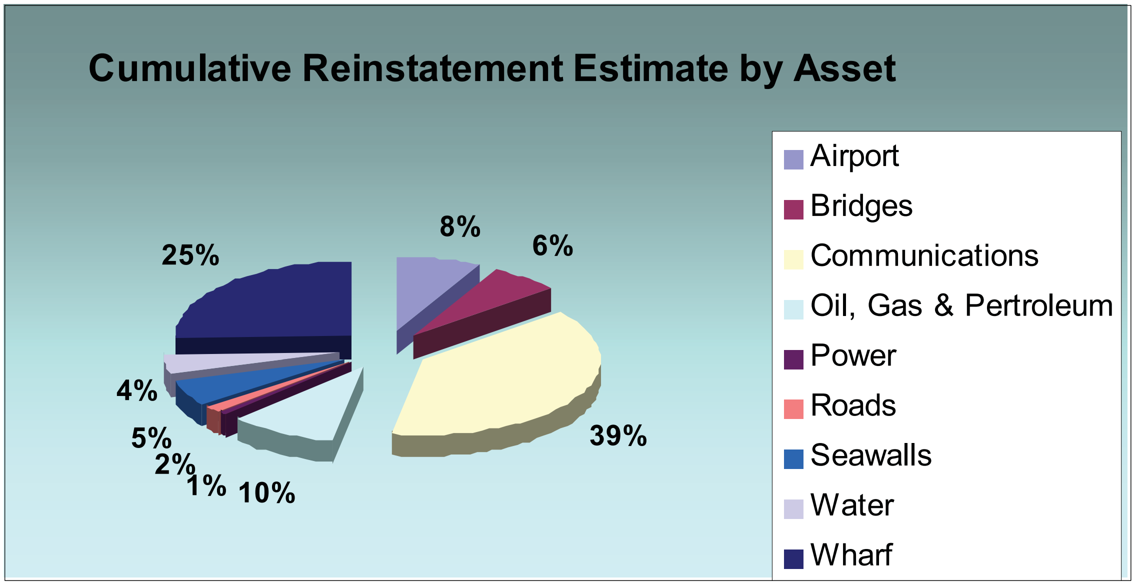

Chart 2

# 2 Introduction

## 2.1 Background

This work is part of a first-pass attempt to quantify the effects of catastrophes in Pacific Island countries. The South Pacific Applied Geoscience Commission (SOPAC) have chosen Port Vila and Mele in Vanuatu as a pilot study area and are investigating methodologies to support the development of a realistic mechanism for the provision of catastrophe insurance in the Pacific region.

DunlopStewart Ltd has been engaged by SOPAC to undertake a quantitative assessment of risk to infrastructure due to large natural catastrophes in the Port Vila and Mele areas.

Specifically, this project seeks to quantify the potential damage to infrastructure in the Port Vila and Mele areas due to natural catastrophe as an input to a catastrophe insurance pilot scheme. Additionally, the project seeks to determine the effect of the 1-in-450 year event (10% probability of occurrence in 50 years) so as to consider the fate of infrastructure roughly within its predicted life-span.

## 2.2 Scope

Defined Project Area[1]

The Port Vila-Mele area is defined as extending from the western side of Mele Bay, north along the Efate ring-road to Klem's Hill, and east including the plain on which Bauerfield

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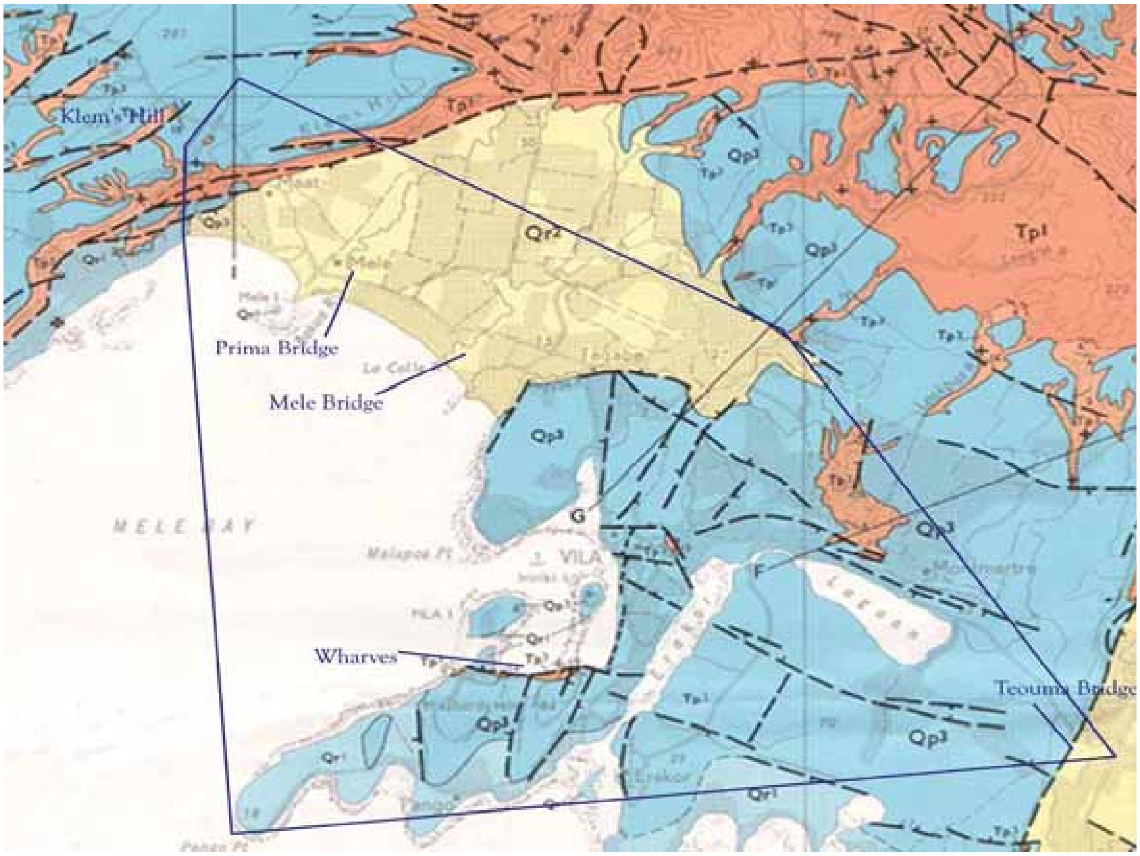
[1] Map reproduced from South Pacific Maps Pty Ltd 2001

International Airport is situated (Tagabe) and Mele, Melemaart, Blacksands and other villages are situated between Mele Bay and the Efate foothills, the greater Port Vila city area itself including the water supply area and facilities (Fres wata) to the north, the peninsula to the south including the Pango area, the coastal area surrounding Port Vila Harbour including Ifira Island, and the lagoons and facilities immediately to the east of Port Vila city in the Erakor, Tassiriki and Bellevue areas.



Geology of Project Area[2]

Note: Areas designated as Qr2 are alluvial soils, Tp1 comprises pumice formations, Tp3 Rentabau tuffs and associated detrital limestones, Qp3 older raised reefs and detrital limestones, and Qr1 recent raised reefs.

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[2] Taken from map prepared by British Government's Overseas Development Administration

Defined natural catastrophes affecting Port Vila and Mele that have been considered include:

- Earthquake
- Tsunami
- Cyclonic Winds
- Storm Surge
- River Flooding

Infrastructure reviewed includes:

- Roads, bridges and seawalls
- wharves and airport
- water supply
- stormwater, sewerage or septic systems
- electricity supply
- communication systems
- gas, oil and petroleum products storage and distribution

We have undertaken a brief visual inspection in respect of the infrastructure described in this report, but must advise that we have not commissioned a structural survey or tested any of the services and are therefore unable to confirm that these are free from any defect. We are unable to give any warranty as to structural soundness of any of the infrastructural assets.

No soil analysis or geological studies were carried out in conjunction with the preparation of this report. Nor does this report constitute an environmental audit.

# 3 Defined Risks

## 3.1 Earthquake

We have assumed for the purposes of this project that the earthquake event would register 8.1 on the Moment Magnitude Scale[3] and would be centred approximately 30 kilometres west of Efate.

## 3.2 Tsunami

The scenario envisaged assumes a sea floor rupture causing around 2-3 m flooding above Mean High Water Springs (MHWS).

## 3.3 Cyclone

This assumes a cyclone of the magnitude of Tropical Cyclone Uma or worse scenario – this being a direct hit Saffir-Simpson[4] Category 4 strength storm.

## 3.4 Storm Surge

This assumes a worst case scenario of around 3 metres flooding plus wave effects.

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[3] Because fault geometry and observer azimuth are a part of the computation, moment is a more consistent measure of earthquake size than is magnitude

[4] This assumes winds of 114-135 knots or 210-249 km/hr. Storm surge generally 13-18 ft (4-6 m) above normal. Extensive curtain wall failures with some complete roof structure failures on small residences. Shrubs, trees, and all signs are blown down. Extensive damage to doors and windows. Low-lying escape routes may be cut by rising water 3-5 hours before arrival of the cyclone centre. Major damage to lower floors of structures near the shore. Terrain lower than 10 ft above sea level may be flooded requiring massive evacuation of residential areas as far inland as 6 miles (10 km).

### 3.5 River Flooding

River flooding is applicable mainly to Mele communities. We have considered normal flooding and temporary damming of rivers caused by large landslides

## 4 Port Vila - Mele - General

Vanuatu comprises a chain of approximately 80 islands situated some 2,250 km north-east of Sydney, Australia and 800 km west of Fiji. The total land area is approximately 14,700 sq. km. The capital is Port Vila, which is situated on the south-west of the island of Efate. Port Vila the township, adjoins the Bay of Port Vila – a natural harbour within the larger Bay of Mele. The south-eastern portion of the town is bounded by the Erakor Lagoon, which links to the south with Erakor Bay and ends in the Emten Lagoon. Iririki and Ifira islands separate Port Vila from Mele Bay.

The country has a dualistic economy with a large smallholder subsistence agricultural sector and a small monetised sector. The latter is based on established plantations, ranches and associated trading, manufacturing, banking and shipping services as well as the country's tourist industry.

The development of the offshore financial centre in 1971 added new dimensions to the economy and it now contributes considerably to Government revenue through the payment of annual registration fees for all companies, business licence fees, insurance, banking and trust company licence fees, stamp duties and other smaller fees. The offshore financial centre has also brought to the country increased employment opportunities, and an excellent infrastructure of telecommunications, banking, legal, accounting and other financial and commercial services.

## 5 Disaster Management - Overview

A meeting with the Director of this office Mr Job Esau, indicated that immediate concerns for Port Vila in the event of a disaster of the types under consideration would focus on the provision of social services, the continued supply of power and water and on maintaining the integrity of the fuel installations situated on Port Vila Bay.

Comment was made that the National Disaster Recovery Committee is chaired by the Minister of Economic and Social Development and of major concern to the committee is the impact on the country through a loss of trade.

Should a disaster strike, the National Disaster Committee receives a situation report from the service providers. This is a quick appraisal of the impact of the event. The second stage requires the completion of a Technical Assessment Report summarising the full extent of damage and defining the works required to reinstate the infrastructure. It was noted however, that some groups do not have the available resources to prepare this report.

In the event of a disaster, the need for major repairs is a very real concern for some asset groups. Large repairs are currently dependant on external aid. This requires a tendering process plus government and aid agency approvals. This can be a slow process, at times taking a number of years to complete. In fact even the provision of the technical assessment report can often be delayed as aid funding will often be required to complete this part of the appraisal.

For example it was noted that the Asian Development bank (ADB) responded quickly to the need for funds to repair the flood damage to the Mele bridge western abutment. However approval processes delayed implementation by at least 6 months.

Civil defence initiatives are being established. Workshops with villagers in Mele prior to the earthquake lead to the villager’s evacuation to higher ground to avoid the risk of tidal wave (tsunami). It is noted that the tidal wave followed about 15 minutes after the first earthquake shock – the villagers would not have been able to reach high ground in that time frame.

Medical assistance is a serious consequential issue particularly if a disaster forces the closure of the main international airport at Bauerfield or closes the approach roads into Port Vila. Port Vila and Mele do not have sufficient medical resources for a major event so transport infrastructure plays a critical role.

# 6 Description of Infrastructure

## 6.1 Roads, Bridges and Seawalls

The road network management responsibility is shared between the Public Works Department (PWD) and the Municipality within Port Vila Township, while all other roads and bridges are managed and maintained by the PWD. Limited Government funding is available to remediate catastrophe damage, which may result in increased periods of interruption of service and consequential losses.

There are over 1,400 km of roads within Vanuatu with several hundred more planned to be completed over the next four years.[5] Generally, pavements have a relatively low risk of failure and material damage is limited to cracking, impact damage from falling debris and undermining of the road formation. However, the roading network as a whole is subject to interruption during each of the identified catastrophe events due to potential for failure for a number of specific assets.

There are several very key bridges on the two main roads into Port Vila, a hillside pass and the main port road adjacent to unstable land that have high likelihood of failure in a catastrophic event, effectively limiting access to Port Vila to inter island shipping only.

### 6.1.1 Teouma Bridge

This bridge is sited on the Teouma stream on the single eastern road link into Port Vila. This road is a key link between Port Vila and its export facilities and the northern parts of Efate Island. Loss of access would represent the potential of medium term loss of trade from the rural areas to Port Vila and to the wharves and export facilities. This bridge was significantly damaged during the 3rd of January 2002 earthquake. A Technical Assessment Report for remediation is awaited.

### 6.1.2 Mele Bridge

This bridge is a Bailey structure spanning between two embankments. The bridge is sited on the western access from Port Vila through Mele to the northern parts of Efate Island. The road through Mele crosses a low-lying alluvial plain. The bridge is founded on piles and the abutments are formed with Gabion baskets. The baskets also line the riverbed under the bridge.

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[5] Asian Development Bank Technical Assistance T.A. No 1952 – VAN Urban Infrastructure Draft Final Report, July 1994

The integrity of this bridge and approach embankments during high flow events is an area of risk. The stream under the bridge serves a large catchment. The embankments are lower than the bridge and at risk of overtopping.

### 6.1.3 Prima Bridge

This bridge is a concrete structure spanning between two shallow embankments. The bridge is sited on the western access from Port Vila through Mele to the northern parts of Efate Island. The stream passing under this bridge rises adjacent to the weak over-steepened material forming Klem's Hill. Landslide blockage of this stream in its upper reaches is possible, with possible impacts on the lower stream and bridge.

### 6.1.4 Klem's Hill

A further point of weakness to the transportation network into Port Vila can be found at Klem's Hill. This hill accommodates the western road access from Port Vila to the north. The road rises steeply out of the Mele alluvial plain up the steep cliffs on the eastern side of Klem's Hill. The hillside is composed primarily of soft tuff materials. There are indications of a long history of slides on this steep hillside. At the time of inspection this road remains at risk of becoming impassable.

### 6.1.5 Road Access to Port Vila

The Teouma Bridge and the Klem's Hill road cutting represent the key eastern and western links between rural Efate Island and the markets and export facilities in Port Vila. Both remain with a strong potential for loss principally related to heavy rainfall events, though also due to a further earthquake. Both require early implementation of more permanent solutions. Appropriate seismic design solutions to the Teouma Bridge should reduce the risk of loss of access from the east.

More permanent solutions to improve the road on Klem's Hill are required as early as possible to reduce the risk of loss of access in heavy rains. However due to the nature of the underlying ground conditions the western access over Klem's Hill would remain at risk of loss in a significant seismic event.

### 6.1.6 Sea Wall

The sea frontage through the commercial area of Port Vila is formed with a seawall. The greater length of this wall is sheet piled with a concrete capping. Towards the eastern end the construction varies from concrete walls to riprap. Behind the markets wharves have been constructed for the inter island vessels. These include roll-on – roll-off facilities. It is noted that the sea wall parallels a fault line and is exposed to heavy seas. There is a risk of ships and debris washing over or crashing into the wall in cyclonic events. Vessels were lifted onto the foreshore during cyclone UMA (1997).

## 6.2 Water

In Port Vila, a private company (UNELCO) signed a 40-year concession contract with the government in 1993. Water comes from an artesian supply and is pumped to the storage reservoirs and from there it is reticulated (gravity fed) to the end user. Connections increased subsequently to the award of the concession to UNELCO and a metered reticulated water supply is now available in all areas. The water supply in port Vila is generated by a pumping station with a capacity of 18,000 cubic metres per day and is distributed through a network of 130 kilometres of cast iron and PVC pipes. The storage capacity is approximately 8000 cubic metres and there are a total of 4600 customers. Several issues that hamper efficient delivery of services for neighbourhoods that are not yet connected include the presence of land disputes, lack of social mobilization in low-income settlements, limited trained personnel in government agencies and the absence of clear policy and legislation.

It was indicated to us during our interview with John Chaniel, the Water Manager of UNELCO, that they consider themselves to be a proactive operator and have sufficient resources to ensure a continuity of supply. Current capital programmes in this regard include upgrading water pipes to polyethylene and PVC to provide improved response to ground movement.

As a result of this policy of preparedness, UNELCO have not experienced much damage or loss of service during major storms or the recent earthquake.

## 6.3 Sewerage or Septic Systems

Port Vila and Mele do not have a public sewerage or septic system. Privately owned septic tanks on land parcels provide for disposal. Large organisations including the hospital and some resorts have their own treatment systems. A public sewerage treatment service has been suggested; however there has been no funding to support implementation. The standard of the private systems is not known. As the tanks are privately owned there is a possibility that reinstatement insurance policies will include the repair of septic tanks.

A risk of contamination of soils and the water table exists in the event of a rupture of tanks and joints due to an earthquake. Private funds may not be available to repair septic tanks.

## 6.4 Power

UNELCO is also responsible for the production and distribution of electricity in the townships of Port Vila and Luganville on the island of Santo. UNELCO's distribution network extends to some 350 kilometres over the two islands. The electricity in Port Vila is generated by two diesel power stations with an overall capacity of 18.4 megawatts and reticulated to their 7200 customers primarily by way of overhead reticulation. The facilities comprise an older diesel fired power station in “downtown” Port Vila; however primary generation is being relocated over time to a new generation station near Bauerfield International Airport.

UNELCO have been undergrounding power and undertaking tree trimming as part of a risk reduction programme. As a result of this policy of preparedness, UNELCO do not experience much damage or loss of service during major storms or the recent earthquake.

## 6.5 Communications

Owned by Telecom Vanuatu Ltd (TVL), which was founded in 1989. Ownership of TVL is shared between, The Government of Vanuatu, Cable and Wireless (UK) and France Cable (France). The company is fully self funded and it has resources to support aid funding if required, which would be repaid out of income.

Approximately 90% of the telephone network is underground, although there are still some overhead connections and these are at risk in cyclones. Some cables cross bridges, which is another weak area. The 45m tower in Port Vila is a key link to the rest of Vanuatu. This tower also carries radio and television antenna. The tower links to the microwave network around the country. There is a single exchange serving the whole country, which is located in the first floor of the Post Office building in Port Vila. Villages, Health and Education Departments also run HF radio systems as back up emergency services.

## 6.6 Airport

Airports Vanuatu Limited is a government owned corporation, which took over management of all aviation operations in Vanuatu in January 2000. The corporation is self funding via the collection of aircraft movement fees, passenger service charges, leasehold rentals, business concession fees and other service charges.

Bauerfield Airport is Port Vila’s main international link for trade. It comprises a single airstrip situated approximately 8 kilometres from the main town centre. The local tourism is dependent on air travel. Medical aid and assistance in the event of a disaster also relies heavily on air support. In the event of severe flooding or damage to the airport, assistance may be limited to local shipping and helicopter support. Two inoperable airstrips are situated in the north of Efate at Forari and Quion Hill. Even if it were feasible to utilise these airstrips for emergency air support, access to these areas cannot be relied upon as they lie on the opposite side of the unstable Klem’s Hill road cutting to the north and the Teouma Bridge to the east of Port Vila.

The Bauerfield Airport runway is at risk at the western end due to potential flooding of an adjacent stream. Erosion is also a concern that needs to be addressed. Streams on the Mele floodplain pass through alluvial materials and can change course in a large flood. This has been experienced in the past.

## 6.7 Gas, Oil and Petroleum Terminals

### 6.7.1 Natural Gas Terminal

A private supplier, Origin Energy Limited operates a natural gas terminal near the oil terminal at the southern end of the town. They provide the sole supply of cooking and heating gas to Port Vila.

This operation relies on the main wharf for delivery of gas. Natural Gas is unloaded to a tanker truck and trucked along Wharf Road to the terminal. Wharf road is noted as being a high-risk area due to unstable land above it and its proximity to the foreshore. During the January 2002 earthquake while the wharf road was closed, Origin Energy were able to maintain a supply of gas by mooring a tanker in the main channel near the Port Vila sea wall and floating hoses from the vessel to the shore facilities.

The terminal is situated on a waterfront site approximately five metres below Wharf Road. A fault line passes near the site, however the land parcel appears sound with a limestone base and the site appears to be free of major risks of falling debris and landslides. Above ground cylinders for storage of gas have been recently replaced with underground storage. Origin management believes the main risk is severing of pipes at the entry to tanks rather than from tanks rupturing. Predominant risks associated with the gas terminal are fire resulting from a severed pipe and the consequence of severing the supply of cooking gas to the community. A loss of the gas supply would encourage villagers to revert to cutting timber for fires.

The location of the terminal exposes the operation to heavy seas. Cyclones raise heavy seas in the approximately two-kilometre fetch approaching the depot. Waves break across the low-lying foreshore. These waves are generally directed at the area containing the hazardous goods storage and bottle filling areas. The recent earthquake significantly damaged the sea wall protecting the site. We believe this will require repair prior to the next major storm event to reduce the risk of loss of fill materials on the foreshore.

### 6.7.2 Oil Terminal

Shell, Mobil and BP operate the oil and petroleum facilities on adjacent sites on the foreshore within the western communities of Port Vila. The Government monitors and regulates the operations. The terminals are situated near the eastern end of the Kumul Highway by the foreshore. This locality is called Nambatu and is characterised by a mixture of residential, light industrial and oil storage facilities. The oil terminals are situated on elevated sites and tanks are all set back approximately 70 metres from the foreshore. The location of the terminal exposes the operation to heavy seas. Cyclones raise heavy seas in the approximately two-kilometre fetch approaching the depot. Waves break across the low-lying foreshore. Key facilities are sited on high ground behind the foreshore berm. The corner of the harbour is suitable for oil storage as it provides deep-water anchorage and mooring in the shadow of Iririki Island. The island can assist with the isolation of spills by the use of two booms.

Consideration has been given to the relocation of the fuel facilities away from the adjacent residential areas since 1985. The Municipality of Port Vila has placed restrictions to limit development until a suitable alternative is provided. Shell has submitted plans to relocate its facilities to the IFIRA wharf. The Vanuatu Investment Promotional Authority (VIPA) has approved these plans. However there are risks associated with this new site and environmental concerns that have not been addressed by the proposal. The new site has a higher earthquake risk, is more exposed to heavy seas, and it would be more difficult to manage spills raising considerable environmental concerns. This proposed relocation may create more risks than remaining at the present site.

Some 45% of the cost of fuel is a government levy. A loss of the fuel supply would also mean a loss of government revenue.[6]

## 6.8 Port Vila Wharves

Vanuatu relies heavily on marine transportation, both for trade and domestic transportation. The Ports and Harbour Department currently own the two main international wharves in Port Vila and Santo. Management of the wharves are contracted out to local stevedoring companies. The main wharf in Port Vila is situated just off Wharf Road. Both the wharf and Wharf Road (the sole road access to the wharf) run parallel with and immediately adjacent to an historic fault line.

The second wharf is known as the Star wharf and this is also situated with access off Wharf Road, within 1 kilometre of the main wharf.

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[6] Current annual fuel consumption is 41 million litres. Current fuel retail price is 106 vatu per litre.

# 7 Damage in Historical Events

## 7.1 Roads, Bridges and Seawalls

The roading network as a whole has been subject to significant interruption during catastrophic events in recent history. The road network's weak points with the largest consequential effects are the bridges at either end of the town, Klem's Hill pass and the main Wharf Road. Failure of these sections of the network can isolate Port Vila and Mele from the rest of Efate by road and sea transport. The most recent events include damage incurred as a result of the January 2002 earthquake and Cyclone Dani (1999).

### 7.1.1 Teouma Bridge

On the 3rd of January 2002 the Teouma Bridge incurred significant earthquake damage. The bridge deck tilted due the settlement and fracture of the eastern piers. This bridge severed all road transport to the eastern rural areas of Efate. Reinstatement of access across the deck by locals was achieved within two days of the earthquake. This involved forming a ramp at each end to allow vehicles across the bridge deck.

Within a month the PWD completed an exercise to support the failed eastern abutment with concrete fill, and to improve access up onto the deck at the western end. These works represent the minimum required to maintain access. The works will have modified the stress patterns in the bridge decking possibly limiting its load capacity. They do not represent a medium term repair. The PWD has limited capacity as it lacks the resources and funding necessary to carry out the comprehensive emergency repairs required at this site.

A medium term repair will be required prior to the next wet season. The strength of the eastern abutment and its load carrying capacity is at risk of weakening in wet conditions. Flooding in the Teouma Stream to bank height previously passed under the deck of the bridge, however the tilted deck is now a restriction to the flood path. The upstream approach of the stream is directed towards the weakened eastern abutment. The stream is also known to carry significant debris (logs and vegetation) during storm events. There is a strong likelihood that the eastern bridge abutment could be eroded and access could again be severed in a frequent (annual) storm event. A comprehensive medium term repair is most likely reliant on aid assistance.

A permanent solution will most likely require replacement of the bridge structure and realignment of the approaches. A project of this magnitude is likely to be reliant on external assistance. Such assistance generally comes with long implementation time frames. It is anticipated that a permanent solution for this bridge could take from 2 – 4 years to complete. In the meantime the community is at significant risk of loss of access.

### 7.1.2 Mele and Prima Bridges

The abutment of the Mele Bridge was lost during Cyclone Dani. High river flows scoured out the western abutment. The concrete approach slabs spanned the scour hole and permitted light vehicle access after the storm. The PWD undertook to underfill the approach slabs with concrete and rock as a short-term solution. With aid assistance abutments were rebuilt and improved and river bed gabions have been added.

Subsequent to the earthquake minor damage was reported to the Gabion abutments and to both approach embankments. The gabions exhibited minor settlement on the soft alluvial materials and minor lateral failure of the embankments formed longitudinal cracks in the approach road. Access was not affected. Repairs to the cracks have been limited to filling with sand cement mixture and resealing the surface.

The stream under the bridge serves a large catchment and is subject to high flows. On this alluvial plain the river may choose a new course severing access to the bridge. The January 2002 earthquake induced landslides dammed the upper reaches of this stream. Had it not been for the awareness of the villagers who opened the top of the dam and allowed the damned water to escape a 'dam-break' wave may have resulted.

### 7.1.3 Klem's Hill

During the January earthquake a large landslide caused loss of half of the road. Further cracking indicating a further slip plane is evident behind the landslide and the remainder of the road is considered to be at risk. A large cutting into the hill above the road has been undertaken to reduce the risk of loss of access. However this cutting is still at risk of landslide falling onto the new road surface.

The new road is not paved and at risk of washout in heavy rains. A significant amount of work has been carried out to reduce the risk of loss of access including attempts to redirect surface water from the slip planes created by the earthquake. The repairs still require additional effort to ensure surface drainage is correctly managed to avoid exacerbating the situation. PWD resources are carrying out this remediation work.

### 7.1.4 Port Vila Sea Walls

Subsequent to the January earthquake portions of the seawall behind the markets and near the Waterfront Restaurant moved. No significant damage occurred and cracks in the ground parallel to the walls have been filled. The sea wall near the Waterfront restaurant settled and has now been reconstructed by private groups.

Heavy seas supported by low pressure systems and high tides common with cyclonic events break over the sea wall and run over the open land between the wall and the commercial area. Under severe events (UMA 1987) vessels loading at the wharf adjacent to the markets in downtown Port Vila were lifted over the sea wall and deposited on the foreshore open land. Others were sunk in the harbour. Those sunk have not been recovered.

## 7.2 Water

The area of greatest concern with respect to the water supply relates to the imminent failure of the access bridge to the main pump station. The access to the pump station is over an aged and damaged bridge. The continuation of supply from the boreholes is also of concern as the boreholes are susceptible to collapse. In fact, one did a week after the January earthquake. A policy of casing the boreholes should reduce the risk of collapse.

Some of the primary water supply storage tanks also suffered damage during the earthquake, primarily at the connections and bending at the bases. Some of these tanks drained. One tank tilted about 7cm. The water supply tank above wharf road is at a risk of loss during landslide.

The reticulation network suffered some mainline breaks, where the main line was suspended from a bridge or wharf. A number of minor breaks were also found at joints in the underground reticulation. One interesting longitudinal failure was experienced at the crown of a 200mm ductile iron pipe about a week after the earthquake.

All service was reinstated within 12 hours of earthquake.
Cyclones are generally not of significant concern for the continued supply of water, as the power supply is a dedicated underground supply. There is an alternative aerial supply and further an emergency generator at the pump station. Water tanks are filled prior to cyclones to ensure they do not blow away. Telemetry has not been affected in the past. There is a minor risk of pipe damage when trees are uprooted by high winds.
Again, the major risk would be the loss of the aged and damaged bridge providing access to the pump station.

## 7.3 Sewerage or Septic Systems

No investigation has been undertaken to ascertain whether there has been a change in the coastal waters as a result of potential failures to private septic systems. If there are failures they are not known.

## 7.4 Power

During the January earthquake, there was a loss of two power poles and one transformer slid off its foundation. No transformers have PCB's. There was a minor interruption to services.
Most of the loss of service during cyclones occurs on private property where branches affect house connections.

## 7.5 Communications

There were minor problems with telephone and power after the January earthquake. These services were both fully reinstated by midday (8 hours after the first shock). Most concern regarding the continuation of services relates to cyclones. In Cyclone Uma, 90% of buildings lost roofs, however as 90% of the telephone network is underground cyclone damage is limited. Some overhead connections are at risk in cyclones and cables crossing bridges are at risk of damage in earthquakes.

The 45m communications tower in Port Vila is a key link to the rest of Vanuatu and this is also exposed in a cyclone and earthquake. This tower also carries radio and television antenna and links the exchange to the telephone microwave network around the country.

Microwave towers are at risk of landslide, earthquake or high winds. Spare 30m towers are available. These could also be used to replace the 45m main transmission tower in the event of significant tower damage. These cost about $AD40, 000 plus installation say 50% extra.

There is a single exchange serving the whole country. This is located in the first floor of the Post Office building in Port Vila. The building did not suffer serious damage in the recent earthquake, though minor cracking is apparent. It would take 3 – 4 months to replace the exchange during which time telephone communications would be lost. Recent introduction of GSM networks does not reduce this risk as these also rely on the exchange for switching.

Proactive works are implemented with cyclone warnings. The satellite dish is locked down until storm passes. This results in some loss of communication outside Vanuatu during the few hours at the peak of the storm. Power supply to all facilities is mains powered with full backup generation. Proactive maintenance programmes are practiced.

Loss of telephone network does not mean total loss of communication in Vanuatu. Villages, Health and Education Departments also run HF radio systems as back up services.

## 7.6 Airport

There was no reported damage to infrastructural assets at the airport in the last earthquake however some of the terminal buildings suffered cracking to their external walls.

## 7.7 Gas, Oil and Petroleum Terminals

The recent earthquake damaged one tank at the Mobil facility. The short-term loss of use of this tank created concern regarding maintaining supply of fuel to the southern part of the country.

## 7.8 Wharf

As a result of the January earthquake, a landslide from the cliffs above blocked the wharf access road. The fallen debris was removed within a short period restoring access. However of greater concern was the slumping of portions of the road. Slumping causes a loss of access until the road can be reconstructed. As a risk mitigation action, containers are now no longer stored at the wharf. They are moved immediately to the IFIRA storage area. This is only a partial solution as the road between the storage area and Port Vila is also subject to landslide or slumping.

The main wharf suffered minor earthquake damage. Most occurred at the joints between the bridges and the wharf proper. This damage has not been repaired and is not on any plans for repair. The wharf agency has sought funding from the government to repair. At this stage there is no certainty that funding will be available.

Cyclone Uma in 1987 caused significant wind damage to the main wharf storage shed. Temporary repairs were carried out to secure the shed after the storm; however nothing has been done in the intervening 15 years to complete the repairs. The building remains at a high risk of loss in a similar event. With most goods transported in containers only a small portion of the storage shed is used, and then only for storage of copra. It is probable if it were further damaged then budgets should be directed at its removal, not replacement.

The access to the main wharf facilities parallels a fault line and is on a relatively weak foundation. As already mentioned, the January earthquake caused the steep hillside above the road to collapse closing the road with debris. Some spectacularly large boulders embedded themselves in the road. The adjacent shoreline provides evidence that large boulders (30 – 50m$^3$) have fallen in earlier times. Of possibly greater concern were the longitudinal cracks in the road indicating the potential for the road to slide into the sea. Reinstatement of access in such a scenario would be more difficult to achieve than simply removing over-slip material, as was the case in January.

Heavy seas pounding across the narrow section of this road between the main wharf and the Star wharf would erode and weaken the steep cliffs leading to an increased potential for landslides. These landslides may not necessarily be directly coincident with an extreme event. The extreme event however may have weakened conditions such that normal rainfall conditions may subsequently trigger the failure.

Other than loss of access the main wharf is not likely to be affected by landslide. The wharf generally stood up well to the January earthquake. Detailed analysis of the structure would be required to confirm whether it would sustain a larger event. Had contractors not concreted the sliding joints between the wharf and land bridges damage to the wharves would have been nominal. It is to be recognised that correctly reconstructing theses joints is important to maintaining the integrity of the structures. Neither the PWD nor the port authority has the budget to undertake these repairs.

# 8 Quantification of Potential Losses

## 8.1 Reinstatement Policies

Short-term repairs are the works required to provide a minimum acceptable level of service. This will ensure that consequential losses are minimised and mitigated. These repairs in themselves may introduce short-term risks until the permanent repairs are achieved. These short-term risks would include reduction in safety and risks from washout or loss during flood events or medium windstorm events.

Permanent long-term reinstatement works are to restore the service to current standards i.e. providing the same service potential as currently provided by the existing infrastructural assets. Improvements desired at the time of reinstatement are not included in the estimates.

With the data currently available we cannot accurately define the effects of the defined risks. The estimates included are based on interviews and reports of previous damage due to actual events of varying magnitudes. As there have not been any natural disasters in Port Vila of the magnitude under consideration for this project and due to the uncertainties involved in predicting the damage caused by any such events, the quantification of potential losses can only be considered as order of magnitude estimates of potential loss.

A minimum cost for temporary or permanent repairs has been assessed as $10,000 regardless of extent of remediation required.

All potential losses have been expressed in Australian dollars.

## 8.2 Roads

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| **Earthquake** | Klem's Hill. Landslide 100m of road lost | 1 month | Loss of access from west to Port Vila | 30,000 | 3 – 4 years | 110,000 |
| | Mele Road embankments. Minor slumping of embankment slopes, road not closed. 100m of embankment damaged. | Nil | | 10,000 | 6 months | 30,000 |
| | Wharf Road. Collapse of weak rock cutting above road. 100m of slump material on road surface | 2 weeks | Loss of access to main wharf | 10,000 | 2 weeks | 20,000 |
| | Wharf Road. Under slip of wharf road into harbour. 100m of road lost for half width of road | 2 weeks concurrent with collapse of cutting | Limit access to wharf. Anticipated one lane would remain open after removal of slump material | Included | 24 months to reinstatement of road to two lanes | 70,000 |
| | Remainder of road network.<br>Anticipate no significant loss of access. Minor slumping of cuttings particularly in the Pango area. Assess 1,000m of minor slumping | Nil | Nil | 50,000 | Dependant on priorities slumping repaired within 2 weeks | 200,000 |
| **Tsunami** | Foreshore roads – Port Vila. Not anticipated to cause major damage to foreshore roads. Deposition of debris is anticipated. This may cause short-term restriction to access. Scouring of storm drain inlets and outlets due to concentration of high velocity flows (10 incidences). Some riprap protection may be damaged (50m). | 1 day | Nil | 10,000 | Permanent restoration of storm drains and sea walls 3 – 6 months. | 20,000 |
| | Mele Road embankments. No significant damage anticipated | Nil | Nil | Nil | Nil | Nil |

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| **Cyclonic Winds** | Road network. Accumulation of debris would cause short-term restriction to access | 1 week | Nil | 10,000 | | Nil |
| | Foreshore roads – Port Vila. Primary impact would be heavy seas. These are not anticipated to cause major damage to foreshore roads. Accumulation of debris would cause short-term restriction to access. Scouring of storm drain inlets and outlets due to concentration of high velocity flows (30 incidences). Some riprap protection may be damaged (100m). Damage is anticipated to be more severe than tsunami event due to extended duration. | 1 week | Nil | 10,000 | Permanent restoration of storm drains and sea walls 3 – 6 months | 50,000 |
| | Wharf Road. _Scouring of sea wall and fill materials forming the foundations to this road between the IFIRA wharf and the main wharf. Loss of 50m section of road – half road width lost. | 1 week | Minor disruption to wharf access | 10,000 | 1 – 2 years | 40,000 |
| **Severe Rainstorm** | Road Network. Minor damage to storm drains (25 incidences) | 1 week | Nil | 10,000 | 1 month | 20,000 |
| | Mele Road embankments. Embankments restrict river flood discharge to bridge waterway channels. Over topping of the embankments near the Mele bridge is possible. Assume up to 50m lost. | 1 week | Loss of access to Port Vila from west. | 10,000 | 2 – 4 months | 40,000 |

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
|  | Klem's Hill<br>Current status (temporary repair). Landslide caused by rainwater entering slip plane. (50% loss of existing road over 150m, current temporary access remains open) | Nil | Nil | Nil | 3 – 4 years | 70,000 |
|  | Future Road (permanent repair on current temporary alignment). Scour damage to drainage channels and turn-outs. (5% damage to road surface, 50% damage to drains). | Nil | Nil | Nil | 3 months | 20,000 |
| **Storm Surge** | Road Network. No damage | Nil | Nil | Nil | Nil | Nil |
|  | Foreshore Roads – Port Vila. Potential inundation due to sea level rise. Damage would principally relate to building damage. Road damage would be limited to drainage channels and storm drains. | 1 week | Nil | 10,000 | Nil | Nil |
|  | Mele Road embankments. Potential inundation due to sea level rise. Potential to cause rivers on the alluvial plain to alter their courses. Assess 50m of road embankment lost. Damage would be more severe if associated with cyclone or rainstorm event. | 1 week | Loss of access to Port Vila from west. | 10,000 | 2 – 4 months | 40,000 |

## 8.3 Bridges

The Teouma Bridge has been damaged severely by the 3 January 2002 earthquake. The bridge crosses a fault line at the boundary between coralaceous limestone and alluvial materials. It is a vulnerable site. The risks quantified here acknowledge that the current condition of the bridge places it at serious risk of loss from significant rainstorm or minor earthquake. It is anticipated a replacement bridge constructed within the next 3 – 4 years would be appropriately designed for the location.

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| **Earthquake** | Teouma Bridge.<br>Current bridge. Total loss.<br>Future bridge constructed to international earthquake standards, medium damage to abutments. | 6 months<br>Nil | Loss of access from east to Port Vila<br>Nil | 580,000 | 3 – 4 years<br>3 – 6 months | 1,150,000 |
| | Mele Bridge. Abutment slumping. Damage to structure and decking. | 2 – 3 weeks | Loss of access from west to Port Vila | 10,000 | 6 months | 50,000 |
| | Prima Bridge. Damage to abutments and piles. | 2 – 3 weeks | Loss of access from west to Port Vila | 10,0000 | 6 months | 50,000 |
| **Tsunami** | Teouma Bridge.. | Nil | Nil | N/A | Nil | N/A |
| | Mele Bridge. Minor abutment and waterway damage. | Nil | Nil | 10,000 | 6 months | 30,000 |
| | Prima Bridge. | Nil | Nil | N/A | Nil | N/A |
| **Cyclonic Winds** | Teouma Bridge.. | Nil | Nil | N/A | Nil | N/A |
| | Mele Bridge. | Nil | Nil | N/A | Nil | N/A |
| | Prima Bridge. | Nil | Nil | N/A | Nil | N/A |
| **Severe Rainstorm** | Teouma Bridge.<br>Current bridge. Scour of eastern abutment and dislodgment of bridge deck. Total loss.<br>Future bridge constructed to international standards. | 6 months<br>Nil | Loss of access from east to Port Vila<br>Nil | 580,000<br>N/A | 3 – 4 years<br>Nil | 1,150,000<br>N/A |

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
|  | Mele Bridge. Scour of river bed upstream and downstream of waterway may affect stability of waterway protection works and approach embankments. Assess partial damage to waterway protection works and abutment gabions (20%) and minor damage to adjacent embankments (10m). | Nil |  | N/A | 2 – 4 months | 40,000 |
|  | Prima Bridge. Waterway damage | Nil | Nil | N/A | Nil | N/A |
| **Storm Surge** | Teouma Bridge. | Nil | Nil | N/A | Nil | N/A |
|  | Mele Bridge. Inundation in severe storm surge event. Principal concern will be scour of abutments and waterway on recession, or if associated with severe rainstorm. Assess partial damage to waterway protection works and abutment gabions (20%) and minor damage to adjacent embankments (10m). | Nil |  | N/A | 2 – 4 months | 40,000 |
|  | Prima Bridge. Waterway damage | Nil | Nil | N/A | Nil | N/A |

## 8.4 Seawalls

In central Port Vila there is little to prevent heavy seas that over top the seawalls from running into the commercial area. The majority of the commercial buildings are a distance away therefore much of the wave energy will have been dissipated. However the markets and Roll-on – Roll-off wharf facilities are located at the seawall and therefore at risk of damage during sustained pounding by the heavy seas. In the commercial area it is anticipated there would be considerable consequential damage in broken shop frontages and stock damage. Scour of the fills immediately behind the sea wall is also probable. The structures adjacent to the sea wall are east of the deep reef between the mainland and Iririki Island and may be afforded some protection from heavy seas. However it is assessed that these buildings would suffer considerable damage in extreme events.

The geological maps show the principal sheet piled seawall runs more or less concurrent with a fault line.

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| **Earthquake** | Main sheet piled sea wall. Yielding of wall anchors, damage to capping beam and minor slumping of fills behind wall. | 1 month | Nil | 30,000 | 3 – 4 years | 230,000 |
| | Roll-on – Roll-off facilities. Cracking and damage to seawall. Minor slumping of ground behind wall.. | 1 month | Limited use of facilities | 10,000 | 3 – 4 years | 100,000 |
| | Various walls east of Roll-on – Roll-off facilities. Cracking and damage to seawalls. Some failures. Intermediate slumping of ground behind wall. | 2 – 3 months | Minor interruption to business. | 20,000 | 1 – 2 years | 200,000 |
| | Riprap sea walls – Port Vila. Minor dislodgement of rocks in the Port Vila area. Reconstruction of about 5% of the walls is anticipated. | 1 month | | 10,000 | 2 – 3 months | 50,000 |
| | Riprap sea walls – Wharf road area. Slumping of ground supporting the riprap. Reconstruction of about 25% of the walls is anticipated. | 2 – 3 months | Minor reduction in access to wharf facilities | 10,000 | 1 – 2 years | 110,000 |

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| **Tsunami** | Main sheet piled sea wall. Assuming the wall has been damaged by accompanying earthquake it is assessed there would be some erosion of alluvial materials from behind the wall. | 1 month | Nil | 10,000 | 3 – 4 years | 50,000 |
| | Roll-on – Roll-off facilities. Assuming the wall has been damaged by accompanying earthquake it is assessed there would be some erosion of alluvial materials from behind the wall. | 1 month | Limited use of facilities | N/A | 3 – 4 years | 10,000 |
| | Various walls east of Roll-on – Roll-off facilities. Assuming the wall has been damaged by accompanying earthquake it is assessed there would be some erosion of alluvial materials from behind the wall. | 2 – 3 months | Minor interruption to business. | 10,000 | 1 – 2 years | 20,000 |
| | Riprap sea walls – Port Vila. Extensive removal of rocks in the Port Vila area. Reconstruction of about 10% of the walls is anticipated. | 2 – 3 months | Nil | Included | 2 – 3 months | 50,000 |
| | Riprap sea walls – Wharf road area. Removal of remaining loose rocks. Reconstruction of about 25% of the walls is anticipated. | 2 – 3 months | Minor reduction in access to wharf facilities | 10,000 | 1 – 2 years | 110,000 |
| **Cyclonic Winds** | General. Cyclonic winds will give rise to heavy seas. These are also likely to be coincident with high sea levels and high tides. It is anticipated the seas will break across the sea walls run across the flat foreshore areas into the commercial centre of Port Vila. Much of the wave energy will be dissipated at the sea walls. | | | | | |
| | Main sheet piled sea wall. It is anticipated there will be significant erosion of alluvial materials from behind the wall. Potential for erosion to expose wall anchors and initiate wall failures. Loss of 20% of wall and loss of ground behind 70% of wall. | 2 – 3 months<br>Riprap protection | Nil | 180,000 | 3 – 4 years | 450,000 |

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| | Roll-on – Roll-off facilities. Significant damage to buildings on and immediately adjacent to facilities, including markets. Damage to vessels tied-up at the wharf or moored nearby. Potential for erosion of alluvial materials behind walls. | 3 months | Loss of use of facilities for up to 2 months. Interruption to business and inter-island trade. | 10,000 | 3 – 4 years | 100,000 |
| | Various walls east of Roll-on – Roll-off facilities. Potential for erosion of alluvial materials behind walls. Yielding and damage to walls. Significant damage to businesses immediately behind the walls. | 3 – 6 months | Interruption to business. | 10,000 | 1 – 2 years | 50,000 |
| | Riprap sea walls – Port Vila. Extensive removal of rocks in the Port Vila area. Reconstruction of about 50% of the walls is anticipated. | 2 – 3 months | Nil | 40,000 | 2 – 3 months | 230,000 |
| | Riprap sea walls – Wharf road area. Removal of remaining loose rocks. Reconstruction of about 50% of the walls is anticipated. | 2 – 3 months | Minor reduction in access to wharf facilities | 40,000 | 1 – 2 years | 230,000 |
| **Severe Rainstorm** | Main sheet piled sea wall. Minor erosion of alluvial materials from behind the wall. | 1 – 2 weeks | Nil | Included | 2 – 3 weeks | 10,000 |
| | Roll-on – Roll-off facilities. Minor erosion of alluvial materials from behind the facilities. | 1 – 2 weeks | Nil. | Included | 1 – 2 weeks | 10,000 |
| | Various walls east of Roll-on – Roll-off facilities. Superficial soil erosion. | 1 – 2 weeks | Nil. | Included | 1 – 2 weeks | 10,000 |
| | Riprap sea walls – Port Vila. Minor erosion of alluvial materials from behind the wall | 1 – 2 weeks | Nil. | Included | 1 – 2 weeks | 10,000 |
| | Riprap sea walls – Wharf road area. Minor erosion of alluvial materials from behind the wall. | 1 – 2 weeks | Nil. | Included | 1 – 2 weeks | 10,000 |
| **Storm Surge** | General. A storm surge unless accompanied by cyclonic winds will not cause significant damage to the sea walls. The walls are anticipated to be over topped by the extraordinary high seas. Damage to the walls will be minor, however some foreshore businesses will suffer water damage. | | | | | |

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
|  | Main sheet piled sea wall. Minimal erosion of alluvial materials from behind the wall. | 1 – 2 weeks | Nil | Included | 1 – 2 weeks | 10,000 |
|  | Roll-on – Roll-off facilities. Minimal erosion of alluvial materials from behind the wall. Some business disruption | 1 – 2 weeks | Minor business disruption | Included | 1 – 2 weeks | 10,000 |
|  | Various walls east of Roll-on – Roll-off facilities. Minimal erosion of alluvial materials from behind the wall. Some business disruption. | 1 – 2 weeks | Minor business disruption | Included | 1 – 2 weeks | 10,000 |
|  | Riprap sea walls – Port Vila. Minor erosion of alluvial materials from behind the wall | 1 – 2 weeks | Nil. | Included | 1 – 2 weeks | 10,000 |
|  | Riprap sea walls – Wharf road area. Minor erosion of alluvial materials from behind the wall. | 1 – 2 weeks | Nil. | Included | 1 – 2 weeks | 10,000 |

## 8.5 Water

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| **Earthquake** | Water Source. Aquifer secure. Pump station and reservoir would sustain minor damage with minor disruption to supply. | 1 – 2 days | Nil | Included | 1 – 2 weeks | 10,000 |
| | Boreholes. Collapse of boreholes and risk of loss. Assess 50% loss of boreholes. | 1 month | Restriction to supply | 40,000 | 1 month | 40,000 |
| | Road access to water source. Bridge would be lost. | N/A | | N/A | 3 – 6 months assumed UNELCO would initiate and fund replacement. | 680,000 |
| | Reservoirs. Main reservoirs on hill above Port Vila would suffer damage splitting tank walls and emptying. Reservoir above Wharf Road would suffer similar fate. Possible loss due to landslide. | 2 – 3 weeks, temporary liners and repairs | Loss of supply | 10,000 | 6 months Installation of new tanks. | 200,000 |
| | Reticulation. Minor damage at joints and to aged pipes. Damage at connections where pipes cross bridges etc. 0.5 – 1% of network affected. | 1 week | Localised loss of supply | 10,000 | 3 – 4 weeks | 120,000 |
| **Tsunami** | Water supply and reticulation would be unaffected by a Tsunami. | | | | | |
| **Cyclonic Winds** | Water Source. Power supply to pump station and reservoir may be lost. Backup generation would maintain water supply. | Nil | Nil | N/A | 1 – 2 weeks | 10,000 |
| | Reservoirs. UNELCO maintain a policy of filling reservoirs on advice of cyclonic conditions. Risk of loss is low. | Nil | Nil | N/A | Nil | Nil |

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| | Telemetry. Loss of telemetry devices has been assumed. | 1 – 2 days | Nil | Included | 3 – 4 weeks | 10,000 |
| **Severe Rainstorm** | Water Source. Aquifer secure. | Nil | Nil | N/A | Nil | N/A |
| | Road access to water source. Bridge would be lost. | 1 month | | N/A | 3 – 6 months assumed UNELCO would initiate and fund replacement. | 680,000 |
| **Storm Surge** | Water supply and reticulation would be unaffected by a Storm Surge. | | | | | |

## 8.6 Sewerage or Septic Systems

Wastewater infrastructure is privately owned. No records are available in Government departments of the nature and extent of the private wastewater systems. The hospital, major resorts and hotels and key government buildings are known to have treatment facilities installed.

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| **Earthquake** | Private systems. Fracture of pipe work connecting to buildings and underground tanks. Fracture of some tanks. It is likely this has occurred during the 3 January earthquake but not investigated.<br>Contamination of ground water. Present development does not extend into aquifers used for water supply. | Nil | Possible environmental contamination of Port Vila harbours and lagoons.<br>Reconstruction of private systems. | Private | Decades, private systems with no real mechanism for enforcement. | Private |
| **Tsunami** | Wastewater disposal and reticulation would be unaffected by a Tsunami. | | | | | |
| **Cyclonic Winds** | Wastewater disposal and reticulation would be unaffected by cyclonic winds. | | | | | |
| **Severe Rainstorm** | Private systems. Surface and roof water can enter private systems and overload the soakage systems. | Nil | Possible environmental contamination of Port Vila harbours and lagoons. | Private | Decades, private systems with no real mechanism for enforcement. | Private |
| **Storm Surge** | Wastewater disposal and reticulation would be unaffected by a Storm Surge | | | | | |

## 8.7 Power

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| **Earthquake** | Generation – Port Vila. Old facility founded on sound rock foundations. Dislodgement of equipment. Moderate building damage. | 1 – 2 weeks | Short-term 1 – 2 days power interruption. | 50,000 | Event would provide motivation to complete transfer of all generation to airport. | Nil |
| | Generation – Airport. New facility, modern design founded on alluvial materials. Dislodgement of equipment. Minor interruption to generation. Medium building damage. | 1 – 2 weeks | Short-term 1 – 2 days power interruption. | 50,000 | 1 – 3 months equipment. Building damage may never be fully repaired. | 100,000 |
| | Overhead reticulation. Majority of the power reticulation is overhead. Steel poles on alluvial materials of landslip locations may be damaged. Falling trees or structures may damage wires. Assess 0.25% loss of poles and wires. | 1 – 2 weeks | Short-term 1 – 2 days power interruption. | 10,000 | 1 – 3 months | 20,000 |
| **Tsunami** | Transformers sited near the foreshore and power lines near the foreshore are unlikely to be affected by Tsunami.. | | | | | |
| **Cyclonic Winds** | Generation. Not affected by Cyclonic winds | | | N/A | | N/A |
| | Overhead reticulation. Majority of the power reticulation is overhead. Principal vulnerability is to damage caused by debris and falling trees. UNELCO have policies of maintaining powerlines clear of trees. Private connections are often not maintained. Assess 10% loss of overhead reticulation. | Up to 1 week | | 10,000 | Within 1 month | 70,000 |

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| | Overhead reticulation to Iririki Island. High voltage lines cross Port Vila harbour. Assess 100% loss in severe wind conditions. | Up to 1 week | | 10,000 | Within 1 month | 50,000 |
| **Severe Rainstorm** | Power supply would be unaffected by a severe rainstorm. | | | | | |
| **Storm Surge** | Power supply would be unaffected by a Storm Surge | | | | | |

## 8.8 Communications

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| **Earthquake** | 45m Communications Tower. Old steel tower founded on sound rock foundations. Reasonably ductile structure. Dislodgement of equipment. Moderate damage to adjoining building. | 1 – 2 weeks | Short-term 1 – 2 days primary communications interruption. HF systems provide backup. | 10,000 | 1 – 2 weeks. | 20,000 |
| | Cell Phone towers. New 30m steel pipe towers. Dislodgement of equipment. | 1 – 2 weeks. Spare towers in store. | Short-term 1 – 2 days service interruption. | 10,000 | 1 – 2 weeks. Spare towers in store. | 10,000 |
| | Exchange. Building housing exchange does not comply with current earthquake design codes. Significant earthquake would cause major damage or loss of the building with consequential loss of the exchange. | N/A | Loss of telephone and cell phone networks until permanent repair can be achieved. | N/A | 3 – 6 months in temporary building. | 15,000,000 |
| | Overhead reticulation. 10% of the telephone network is overhead. Poles on alluvial materials of landslip locations may be damaged. Falling trees or structures may damage wires. Assess 0.25% loss of poles and wires. | 1 – 2 weeks | Short-term 1 – 2 days service interruption. | 10,000 | 1 – 2 weeks | 20,000 |
| **Tsunami** | Communications facilities are unlikely to be affected by Tsunami.. | | | | | |
| **Cyclonic Winds** | 45m Communications Tower. Old steel tower founded on sound rock foundations. Exposed location vulnerable to high winds. Dislodgement and damage of communications equipment. Damage (not loss) to tower. | 1 – 2 weeks | Short-term 1 – 2 days primary communications interruption. HF systems provide backup. | 10,000 | 1 – 2 months. Damage to tower would motivate replacement with 30m steel pipe towers in store. | 160,000 |

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
|  | Cell Phone towers. New 30m steel pipe towers. Dislodgement and damage to equipment. | 1 – 2 weeks. | Short-term 1 – 2 days service interruption. | 10,000 | 1 – 2 weeks. | 10,000 |
|  | Overhead reticulation. 10% of the telephone network is overhead. Falling trees or flying debris may damage wires. Assess 5% loss of poles and wires. | 1 – 2 weeks | Short-term 1 – 2 days service interruption, longer in some residential areas. | 10,000 | 1 – 2 months | 30,000 |
| **Severe Rainstorm** | Communications systems would be unaffected by a severe rainstorm. |  |  |  |  |  |
| **Storm Surge** | Communications systems would be unaffected by a Storm Surge |  |  |  |  |  |

## 8.9 Airport

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| **Earthquake** | Runway. This is located on alluvial materials. Severe earthquake may disrupt pavement slabs necessitating replacement or repair. Assume 10% damage of 2600 metre runway by 45 metres wide. | 2 – 4 months | Loss of tourism and inter-island transportation until runway repaired. | 300,000 | 2 – 4 years. | 2,000,000 |
|  | Buildings. Cracking is still visible from 3 January 2002 earthquakes. Minor to moderate damage is anticipated. | Nil | Nil | N/A | 1 – 2 years | 500,000 |
| **Tsunami** | Airport facilities are unlikely to be affected by Tsunami.. |  |  |  |  |  |
| **Cyclonic Winds** | Runway. Debris on runway | 1 day | Interruption to air services. | 10,000 | 1 day | 10,000 |
|  | Buildings. Flying debris damage to windows. Roof damage | 1 – 2 weeks | Interruption to air services. Particularly to Immigration and ticketing. | 10,000 | 1 – 2 months | 300,000 |
| **Severe Rainstorm** | Runway. This is located on alluvial flood plain near a major river. Surface flooding may affect airport grounds. Bank erosion in river may require remedial works to ensure continued security of the runway. | 1 day | Interruption to air services. | 10,000 | 2 – 4 years. River protection works | 200,000 |
| **Storm Surge** | The airport would be unaffected by a Storm Surge |  |  |  |  |  |

## 8.10 Oil, Gas and Petroleum Terminals

45% of the fuel cost is a government levy. Loss of installations would mean a short-term loss of government revenue. Current annual fuel consumption is 41 million litres per year (106Vatu per litre). 1,955,700,000 Vatu Per Annum Government Levies on fuel.

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| **Earthquake** | Oil terminals – Mobil, BP, Shell. Located on foreshore of Port Vila harbour. Founded on weak volcanic tuff materials. Fuel tanks split by internal pressures. Pipe reticulation damaged. High potential of fire. Sea wall damage. 50% loss of installation | 1 week. Fuel supply from tankers moored at wharves | Disruption to transportation.<br>Extended period of restricted fuel supply.<br>Harbour contamination. | 300,000 | 6 months – 2 years. | 2,500,000 |
| | Gas – Origin Gas. Pipe reticulation damaged. Underground tanks damaged. Building and sea wall damage. 50% loss of installation | 1 week. | Disruption to supply of cooking gas. | 150,000 | 3 months | 1,200,000 |
| **Tsunami** | Oil terminals – Mobil, BP, Shell. Sea wall damage. | Nil | Nil | N/A | 6 months | 50,000 |
| | Gas – Origin Gas. Sea wall damage. Loss of gas cylinders and equipment at hazardous goods facility. | 1 week | Disruption to supply of cooking gas. | N/A | 3 months | 50,000 |
| **Cyclonic Winds** | Oil terminals – Mobil, BP, Shell. Minor damage to buildings. | 1 day | Nil | N/A | 6 months | 20,000 |
| | Oil terminals – Mobil, BP, Shell. Sea wall erosion and 50% loss | Nil | Nil | N/A | 6 months | 50,000 |
| | Gas – Origin Gas. Minor damage to buildings. | 1 day | Nil | N/A | 6 months | 20,000 |
| | Gas – Origin Gas. Sea wall erosion and 50% loss. Loss of gas cylinders and equipment at hazardous goods facility. | 1 week | Disruption to supply of cooking gas. | N/A | 3 months | 50,000 |
| **Severe Rainstorm** | Oil terminals – Mobil, BP, Shell. No damage of consequence. | Nil | Nil | N/A | Nil | N/A |

| **Defined Risk** | **Assets Damaged** | **Time to Repair Short Term** | **Consequential Loss** | **Cost of Short Term Remediation ($)** | **Time to Permanent Reinstatement** | **Reinstatement Estimate ($)** |
|---|---|---|---|---|---|---|
| | Gas – Origin Gas. No damage of consequence. | Nil | Nil | N/A | Nil | N/A |
| **Storm Surge** | Oil terminals – Mobil, BP, Shell. Minor damage to buildings. Inundation of fire pump house. | 1 day | Nil | 10,000 | Nil | N/A |
| | Gas – Origin Gas. Minor sea wall damage. Loss of gas cylinders and equipment at hazardous goods facility. | 1 week | Disruption to supply of cooking gas. | 10,000 | Nil | N/A |

## 8.11 Main Wharf

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| **Earthquake** | Main Wharf. Located more or less parallel to a fault line. Major event could cause dislodgement of 5 bridge structures connecting wharf to port facilities, slumping of rock slopes in seabed under wharf and cracking of wharf decking. Assess at 20% loss. | 2 – 3 months | Alternative wharf structures are less likely to survive a severe event. Loss of port facilities. | 420,000 | 2 – 3 years. | 4,200,000 |
| | Wharf Storage Warehouse. Minor damage assess 1% loss | Never | Nil | N/A | Never | N/A |
| | Administration building. Minor damage assess 1% loss | N/A | Nil | N/A | 6 months | 10,000 |
| | Star Wharf. Current structure is damaged by earthquake. Assume total loss. | | Private structure. Reduced access to local trade. | N/A | 2 – 3 years | 3,000,000 |
| **Tsunami** | Main Wharf. No anticipated damage. | Nil | Nil. | N/A | Nil | N/A |
| | Wharf Storage Warehouse. Minor damage assess 1% loss | Never | Nil | N/A | Never | N/A |
| | Administration building. No anticipated damage | N/A | Nil | N/A | Nil | N/A |
| | Star Wharf. Minor damage to wharf. Scour of fills behind wharf. | | Private structure. Reduced access to local trade. | Included | 2 – 3 years | 30,000 |
| **Cyclonic Winds** | Main Wharf. No anticipated damage. | Nil | Nil. | N/A | Nil | N/A |
| | Wharf Storage Warehouse. Significant loss of cladding and damage to stored goods. | 1 month | Copra occasionally stored in warehouse otherwise empty | 100,000 | 2 – 3 years a reduced size of warehouse | 1,300,000 |
| | Administration building. Minor damage to glass and roof. | 1 week | Nil | Included | 1 – 2 months | 10,000 |
| | Star Wharf. Scour of alluvial materials behind wharf due to severe wave action. | | Private structure. Reduced access to local trade. | Included | 2 – 3 years | 30,000 |

| Defined Risk | Assets Damaged | Time to Repair Short Term | Consequential Loss | Cost of Short Term Remediation ($) | Time to Permanent Reinstatement | Reinstatement Estimate ($) |
|---|---|---|---|---|---|---|
| **Severe Rainstorm** | Port facilities are unlikely to sustain damage in severe rainstorm events. | | | | | |
| **Storm Surge** | Main Wharf. No anticipated damage. | Nil | Nil. | N/A | Nil | N/A |
| | Wharf Storage Warehouse. Flooding of building, wave action would cause significant loss of cladding and damage to stored goods. | Never | Copra occasionally stored in warehouse otherwise empty | 100,000 | 2 – 3 years a reduced size of warehouse | 1,300,000 |
| | Administration building. Minor damage to lower floor due to inundation. | 1 week | Nil | Included | 1 – 2 months | 10,000 |
| | Star Wharf. Scour of alluvial materials behind wharf due to severe wave action. | | Private structure. Reduced access to local trade. | Included | 2 – 3 years | 30,000 |

# 9 Acknowledgments

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Mr John Chaniel, Water Manager, UNELCO
Mr Des Ross, Chief Executive, Airports Vanuatu Limited
Mr Loic Bernier, Managing Director, CGU Insurance
Mr Tony Care, Project Manager, Fletcher Construction

# 10 Additional References

- Letter 22 February 2002, Sinclair Knight Mertz to Public Works Department – Site Inspection – Earthquake Damage.
- Teouma Bridge 2002 Jan 03 Earthquake Damage Assessment Report, Public Works Department.
- Urban Development Plan – Port Vila, July 1994. Asian Development Bank Technical Assistance TA No 1952 – VAN, Urban Infrastructure Project, Volume B
- Vanuatu Infrastructure Masterplan – Development Framework, 2001, United Nations Economic and Social Commission for Asia and the Pacific
- SOPAC Preliminary Report – 135, Earthquake and Tsunami Damage Assessment in Port Vila, January 2002, Dr G. G. Shorten

## Disclaimers and Limitations

This report has been prepared for the specific purpose stated. Any party that relies upon it for an alternative purpose without reference to DunlopStewart does so at their own risk.

This report has been prepared on the basis that full disclosure of all information and facts which may affect the outcome of the report have been made by all parties.

We have undertaken a brief visual inspection in respect of the infrastructure described in this report, but must advise that we have not commissioned a structural survey or tested any of the services and are therefore unable to confirm that these are free from any defect. We are unable to give any warranty as to structural soundness of any of the infrastructural assets.

# Appendix 2

# Port Vila Peri-Urban Settlements Risk Analysis: Methodology

*by*

**Ken Granger**

RiskScience, Buderim, Australia

**SOPAC JOINT CONTRIBUTION REPORT 147**

*December, 2003*

# PORT VILA PERI-URBAN SETTLEMENT RISK ANALYSIS

# METHODOLOGY

Ken Granger
Disaster Risk Scientist

4 Quambi Place
Buderim   QLD   4556
Australia

riskscience@bigpond.com

# 1 Background

An analysis of the risks faced by three peri-urban settlements north-west of Port Vila was undertaken  at the request of Dr Graham Shorten using sample data collected by SOPAC in 2002 (Schmall, 2002). The three communities studied were Melemart, Mele and Blacksands.

Most studies of these settlements have treated them as single entities (e.g. Schmall, 2002; Chung and Hill, 2002; Mecartney, nd) and have drawn comparisons between them and similar communities around Port Vila. In that approach there is an implied assumption that each settlement is internally homogeneous and that the key differences only exist between the settlements, e.g. between 'custom' villages and 'squatter' settlements. In this study, however, it was decided to test that assumption by investigating the characteristics that exists **within** each settlement and compare and contrast those characteristics **across** all three settlements.

To provide the necessary spatial resolution six 'neighbourhoods' were delineated in Mele and seven in Blacksands. Melemart remained as a single entity thus producing a total of 14 'neighbourhoods'. These 'neighbourhoods' can be equated to the basic geographical unit employed in a national census, such as the Census Collectors Districts employed in Australia, for example.

Twenty-three variables were selected for use in the analysis from the survey datasets collected by SOPAC. These were grouped into five categories: four to represent different dimensions of community vulnerability (shelter, sustenance, security and societal) and one to reflect past hazard exposure experience. These variables were used to construct scaled indexes that were ultimately combined to give an index of relative risk between the 14 peri-urban 'neighbourhoods'. The approach used was in essence an amalgam of the community vulnerability/community risk index approach of Granger (2000) and the EVI methodology employed by SOPAC (Kaly, nd).

The results clearly demonstrate that investigations at the 'neighbourhood', rather than settlement level, produce valuable insights into community vulnerability and risk that would otherwise not be apparent. They also challenge the assumption that these settlements, including the 'custom' villages, are internally homogeneous.

# 2 Peri-Urban Settlement 'Neighbourhoods'

The boundaries of the 14 'neighbourhood' entities were based on criteria such as settlement density, survey sample size and ethnic origin of the inhabitants. The boundaries of these ‘neighbourhoods’ were based, where possible, on natural features such as creeks, and constructed features such as roads.

An attempt was made to make the units as even in sample size and settlement size as possible. The building file developed by Aireseach and showing the ‘footprints’ of all building were used to gauge development (average number of buildings across all 14 neighbourhoods is 93 and ranges from 63 in Blacksands W to 139 in Mele C). The sample household locations were also used (average of 13 and ranging from 7 in Blacksands SE to 20 in Blacksands E). In the Blacksands settlement, the district of origin for households was also used to reflect the ‘ethic’ makeup of this essentially migrant community. Blacksands NW and Blacksands E, for example are predominantly settled by people from Tanna, whilst Blacksands SW population is roughly divided between people from Efate and Malekula.

The boundaries of the 14 neighbourhoods are shown in Figures 1 to 3.

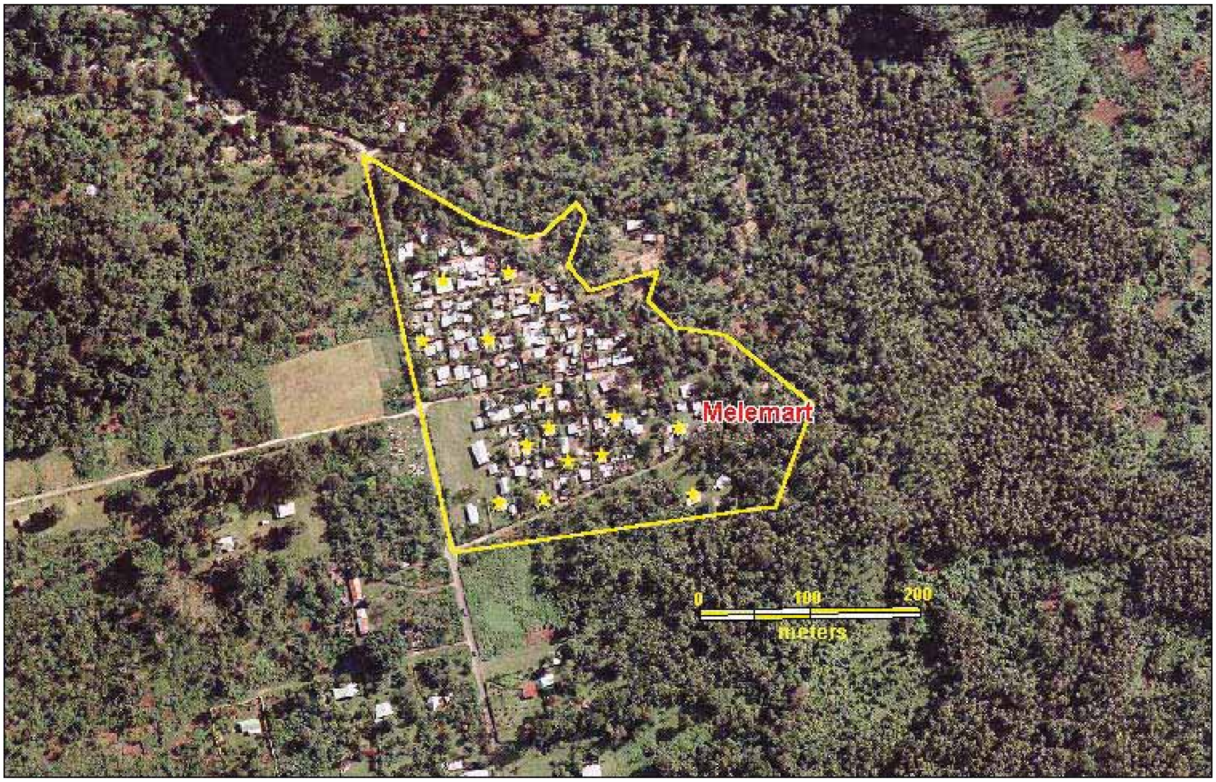

Figure 1: Melemart survey locations.

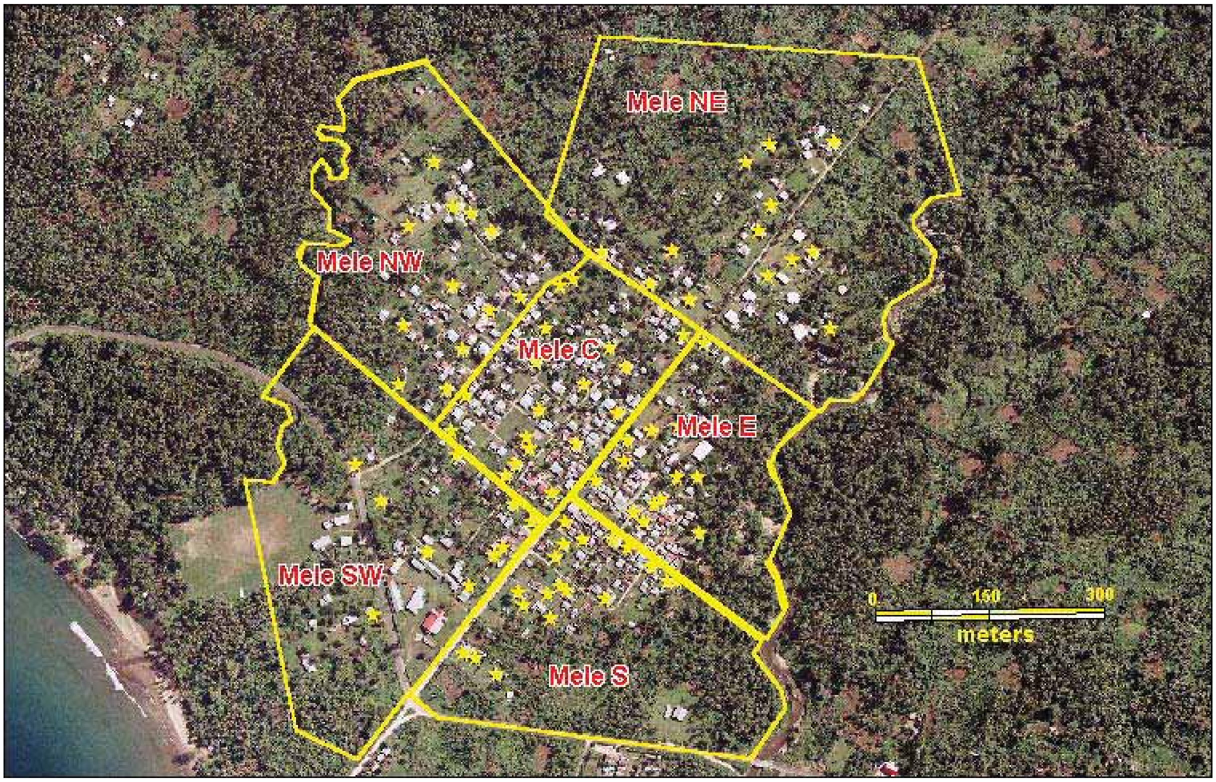

Figure 2: Mele ‘neighbourhoods’ and survey locations

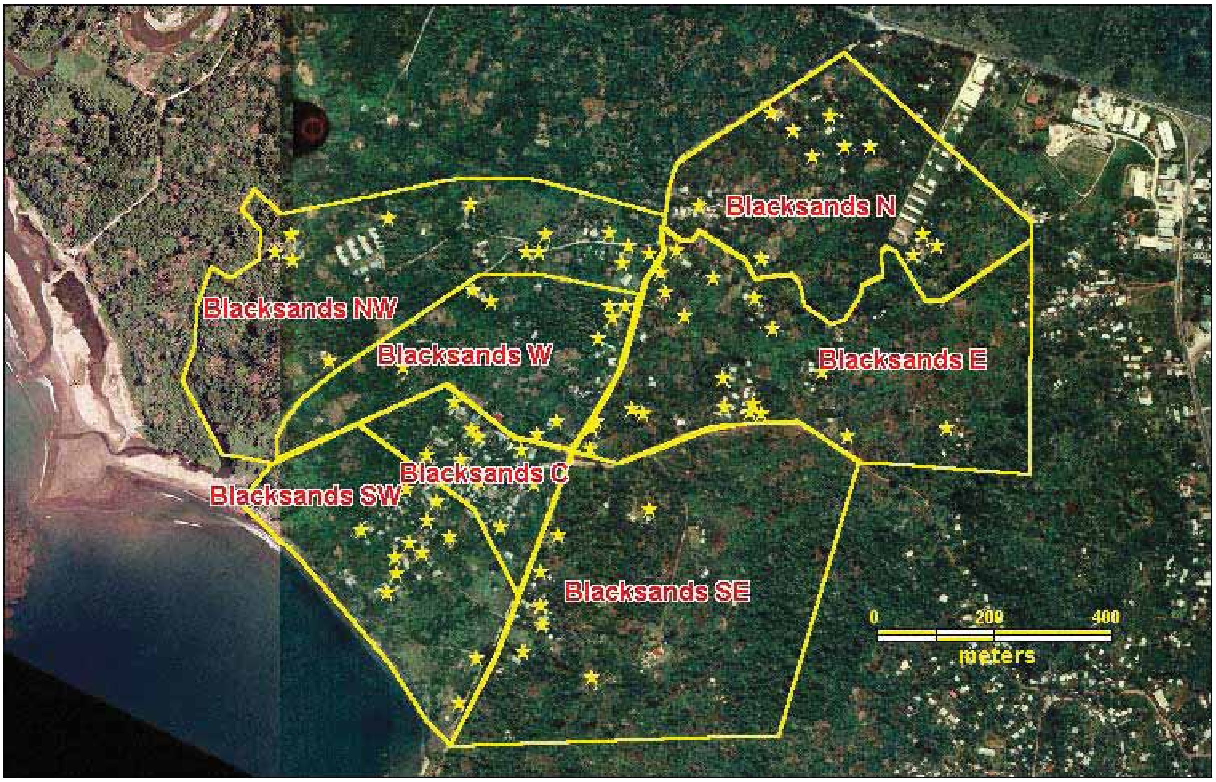

Figure 3: Blacksands ‘neighbourhoods’ and survey locations

# 3 Variables Selected

In the context of this study ‘vulnerability’ is seen as a continuum that ranges from total susceptibility to a disaster impact at one end to total resilience at the other. A comparison of the relative vulnerability of the 14 neighbourhoods was undertaken on 23 separate variables, each of which contribute in some way to overall community vulnerability. These in turn have been grouped into five categories to reflect the key dimensions of the community. The variables included in each category, and their results, are as follows:

## 3.1 Shelter vulnerability

Four variables were included to reflect the relative differences in shelter vulnerability.

*Household size*: The mean size of each household provides an indication of the number of people at risk in each neighbourhood. The statistic was derived by summing the fields *No of household members >16* and *No of household members <16* from the *Household* tables. Numbers ranged from 4.11 in Blacksands C to 7.0 in Melemart, with a mean of 5.91.

*Children at home*: The mean number of children in each household not at school provides an indication of the number of infants and younger children likely to be at home. The statistic was taken directly from the *No of children not going to school* field in the *Household* tables. Numbers range from 0.86 in Blacksands SE to 0.21 in Mele E, with a mean of 0.53.

*House construction*: The percentage of households living in tradition material or tin houses was taken to be an indicator of the relative susceptibility to hazard impact of the population’s shelter. The selection of these two categories was largely arbitrary, and was based on the assumption that timber and concrete block houses would be relatively more resilient to most impacts. The statistics were derived by summing the number of households living in traditional material and tin houses contained in the *Wall material type* field of the *Household condition* tables and expressing the sum as a percentage of the total sample. Values ranged from 84.61% in Blacksands SW to zero in Blacksands E and Blacksands SE, with a mean of 31.54%.

*Number of sleeping rooms*: The mean number of sleeping rooms available to each household was included because it tends to reflect both building size and occupant density. Larger buildings tend to be physically more vulnerable and the greater number of people present also indicates greater vulnerability. The statistics were taken directly from the *No of sleeping rooms* field of the *Household conditions* tables. Numbers ranged from 1.14 in Blacksands SE to 3.07 in Melemart, with a mean value of 2.25.

## 3.2 Sustenance vulnerability

Five variables were selected to reflect the availability of the resources that sustain the community such as water and food supplies. The variables used were:

*Water supply*: The source of water supply identified in the survey for each household were allocated a score according to its likely 'safety' and 'survivability' along the following lines:

| | |
|---|---|
| River | 5 |
| Well | 5 |
| Community tank and well | 4 |
| Community tank | 3 |
| Village standpipe | 3 |
| Shared piped supply | 2 |
| Water vendor | 2 |
| Household tank | 2 |
| Private piped supply | 1 |

The mean 'score' for each neighbourhood serves as the overall measure. Mean scores ranged from a high of 4.69 in Blacksands NW to a low of 1.08 in Mele NE, with a mean overall value of 2.56.

*Toilet type*: A similar approach was followed with the form of toilet used for each household based on the following scores:

| | |
|---|---|
| Pit | 5 |
| Drum | 4 |
| Ventilation Improved Pit | 3 |

|  |  |
|---|---|
| Pour flush | 2 |
| Flush septic system | 1 |

Again the mean 'score' was used as the measure. Scores ranged from a high of 3.62 in Blacksands NW to a low of 2.23 in Mele NE, with an overall mean of 2.90.

*Households per toilet*: The mean number of households to each available toilet was included to reflect the relative 'modernity' of each neighbourhood. The statistics were taken directly from the *No of families to each toilet* field in the *Household condition* tables. Numbers ranged from a high of 3.55 in Mele S to a low of 1.0 in Mele NE and Blacksands E, with an overall mean of 1.68.

*Limited food production*: The percentage of households that produce less than 50% of their own food was taken as an indicator of reduced self sufficiency, and thus susceptibility to disaster. The statistics were derived by expressing the sum of households noted as producing less than 50% of their food from the *Proportion of food grown in own garden* field of the *Land tenure* tables as a percentage of the total neighbourhood sample. Numbers ranged from 92.31% in Blacksands NW to 8.3% in Mele NW, with an overall mean of 51.65%.

*Cooking fuel*: The form of fuel used by each household for cooking provides a good measure of vulnerability to the dislocation of fuel supply. Greater reliance on a single fuel type was seen as a source of potential susceptibility. Electricity was seen as the most easily disrupted form of fuel in a disaster situation. A scoring system was also used here with the following values used:

|  |  |
|---|---|
| Electricity only | 5 |
| Firewood only | 4 |
| Gas only | 3 |
| Gas and firewood | 2 |
| Gas, electricity and firewood | 1 |

The mean score was used as the measure. Results ranged from a high of 3.86 in Blacksands SE to a low of 2.31 in Mele NE, with an overall mean of 2.94.

## 3.3 Security vulnerability

Five variables were included to reflect the relative health and wealth status of households in each ‘neighbourhood’. The variable used were:

*No paid work*: The mean number of people over 16 in the household not in paid employment was chosen as an indicator of unemployment, a significant economic indicator in urban communities. The statistics were derived by subtracting the *Number of people with a paid job* field from the *No of household members >16* field (both fields being taken from the *Household* tables) and dividing by the sample size. Numbers ranged from 3.9 in Mele S to 0.89 in Blacksands W, with an overall mean of 1.95.

*Household income*: The mean weekly household income (in Vatu) is a strong measure of relative wealth. The statistics were derived directly from the *Weekly household income* field in the *Household* tables. Numbers ranged from a low of V2625.00 in Blacksands N to a high of V15,950 in Mele SW, with an overall mean of V9011.55.

*House not owned by occupants*: Home ownership was seen as a strong indicator of relative prosperity and security of tenure, conversely lack of ownership is seen as indicating a degree of susceptibility. The statistics were derived by summing the number of households that indicated that they were not the owner of the house in which they lived from the *House ownership* field of the *Land tenure* tables and expressing it as a percentage of the total number of samples. Numbers ranged from 55.55% in Blacksands C to zero in Mele NE, Blacksands SE and Blacksands NW, with an overall mean of 20.85%.

*People who have had malaria*: A measure of the health of the population was taken to be the mean number of people per household that had suffered from malaria. The statistics were taken directly from the *No of people with malaria* field in the *Household* tables. Numbers ranged from 1.77 in Blacksands NW to zero in Mele NE and Mele NW, and with an overall mean of 0.48 people per household.

*Attended a medical facility*: The percentage of households that had used the resources of a medical clinic or the Port Vila hospital was used as an indicator of the general health of the community. The statistics were derived by summing the households that indicated that they had used the services of either a clinic or hospital from the *Place treatment sought* field of the *Household* tables and expressing that as a percentage of the total sample. Numbers range from 80% for Melemart to 15.38% for Blacksands SW, with an overall mean of 56.20%.

## 3.4 Social vulnerability

Four measures were included to provide an indication of the social conditions that would make a community more or less susceptible to disaster. The variables used were:

*Population born outside settlement*: The peri-urban settlements of Port Vila contain significant proportions of people who have migrated from other areas. The mean number of people per household born outside the settlement in which they live was taken directly from the *No of people born outside Melemart/Mele/Blacksands* fields from the *Household* tables. Numbers ranged from 5.92 in Blacksands NW to zero in Mele NE, with an overall mean of 2.31.

*Households with no TV*: Access to TV was taken to be an indicator of both affluence and access to information from the wider world, both reasonable social indicators. The statistics were calculated by expressing the number of households that stated that they did not have TV from the *TV ownership* field of the *Land tenure* tables as a percentage of the total neighbourhood sample. Numbers ranged from 100% in Blacksands E to 26.67% in Mele E, with an overall mean of 64.37%.

*Households with no radio*: Access to radio is similar to the TV variable but also has an important disaster warning dimension given that community warnings of approaching cyclones etc are provided over the local radio stations. The statistics were calculated by expressing the number of households that stated that they did not have TV from the *Radio ownership* field of the *Land tenure* tables as a percentage of the total neighbourhood sample. Numbers ranged from 45% in Blacksands E to zero in Mele E and Mele SW, with an overall mean of 17.69%.

*Education level*: The level of education attained by the head of the household was scored to provide this measure using the following scores:

| | |
|---|---|
| No education | 5 |
| Primary | 4 |
| Secondary | 3 |
| Vocational | 2 |
| College or university | 1 |

The mean score was used as the measure and results ranged from a high of 4.31 in Blacksands NW to a low of 3.15 in Mele S, with an overall mean of 3.63.

## 3.5 Previous exposure

The actual experience of hazard impacts is an important measure of both exposure to disaster and the awareness of households of that exposure. The variables included were:

*Flood water over floor level*: Previous flooding of the house is perhaps the best indicator of hazard exposure in these settlements. The statistics were derived by summing the number of households that reported previous flooding that went over floor level from the *Encroachment of flood water in the past* field of the *Hazard-vulnerability* tables as a percentage of the total neighbourhood sample. Numbers range from 57.14% in Blacksands SE to zero in six neighbourhoods, with a mean value of 10.13%.

*Past earthquake damage*: Damage to houses from previous earthquakes was measured by summing the households that reported any degree of damage from earthquake in the *Past earthquake damage* field of the *Hazard-vulnerability* tables. Numbers range from 50% in Blacksands E to zero in four neighbourhoods, with a mean of 16.13%.

*Past storm damage*: Damage to houses from previous storms was measured by summing the households that reported any degree of damage from storms in the *Past storm damage* field of the *Hazard-vulnerability* tables. Numbers range from 53.83% in Blacksands NW to zero in Mele NE and Blacksands C, the mean value being 31.14%.

## 3.6 Mitigation strategies

A weighted scale to ‘measure’ awareness of appropriate risk mitigation strategies was developed from the information provided in the *Disaster mitigation measures adopted* field of the *Hazard-vulnerability* tables. Responses were scored on the following basis:

| | |
|---|---|
| where no mitigation measures were used | 0 |
| where measures included moving/evacuating | 1 |
| where measures involve a putting together a disaster kit | 1 |
| where measures involve storing food and water | 2 |

| | |
|---|---|
| where measures involve securing windows/shutters | 2 |
| where measures involve securing the roof | 2 |
| where measures involve clearing the yard | 2 |
| where the measures involve clearing vegetation | 2 |
| where the measures involve comprehensive house improvement | 4 |

Many households reported a number of measures were used. In those instances their scores were summed. The sum were then classified on the following basis:

| | |
|---|---|
| where the sum was 7 or more | comprehensive |
| where the sum was 5 or 6 | significant |
| where the sum was 3 or 4 | basic |
| where the sum was 1 or 2 | limited |
| where the sum was 0 | nil |

The index was measured by summing the households rated as taking basic or lower levels of mitigation and expressing that as a percentage of the neighbourhood sample total. Numbers ranged from 95% in Blacksands E to zero in Mele NE and Blacksands C, with an overall mean of 38.91%.

*Food lost to hazards*: The destruction of food gardens by hazard impacts was measured  by expressing the number of households that reported more than 50% loss of food in previous disasters from the *Disaster impact on food* filed from the *Hazard-vulnerability* tables. Numbers range from 84.62% in Blacksands SW to 14.28% in Blacksands SE, with an overall mean of 48.21%.

## 4 Index Construction

In the first iteration of this study each of the variables detailed above were ranked from 1 (most vulnerable/exposed) to 14 (least vulnerable/exposed). The ranks for each group are then summed and the sum expressed as a reverse proportion of the maximum total rank (e.g. for the physical group the maximum possible rank sum would be 70 (5 [the number of variables] x 14 [the number of neighbourhoods]) in the following way:

Index = 1-{rank sum/(number of variables x 14)}

The index numbers were then used to show the relative performance of each group for each neighbourhood.

This methodology followed that first used by Granger (1999) to create a community vulnerability index for Cairns which involved some 187 census 'neighbourhoods'. This approach was reviewed by King and MacGregor (2000).

Given the much smaller number of entities involved in this study and the range of results within each variable, the ranking strategy was found to 'normalise' the results significantly. A scaling method was then employed to retain the relative spread of the individual measures for each neighbourhood and still permit amalgamation into a composite index. The strategy used to produce these scaled values was to divide all raw values for the given variable by the value of the highest value amongst the 14 neighbourhoods so that the 'most vulnerable' ended up with a scale value of 1 and the other 13 entities having values of less than 1.

The scaling approach appears to have brought out the range of values much more effectively than did the ranking approach.

A composite index was then calculated for each group of measures (shelter, sustenance, security, social and exposure) by summing the scale values for each variable in the respective group and again scaling those values back to a top value of 1.

Two further indexes were also calculated, namely:

- a community vulnerability index calculated by summing the scale values for each of the four vulnerability groups (shelter, sustenance, security and social) and scaling the results to a top value of 1; and,
- a total risk index calculated by summing the exposure index and the community vulnerability index and reducing to a top value of 1.

Figure 4 shows the relative values of the four individual vulnerability group, Figure 5 shows the relative values of the vulnerability, exposure and risk indexes. The spatial distribution of each of these indexes is shown in Figures 6 to 12.

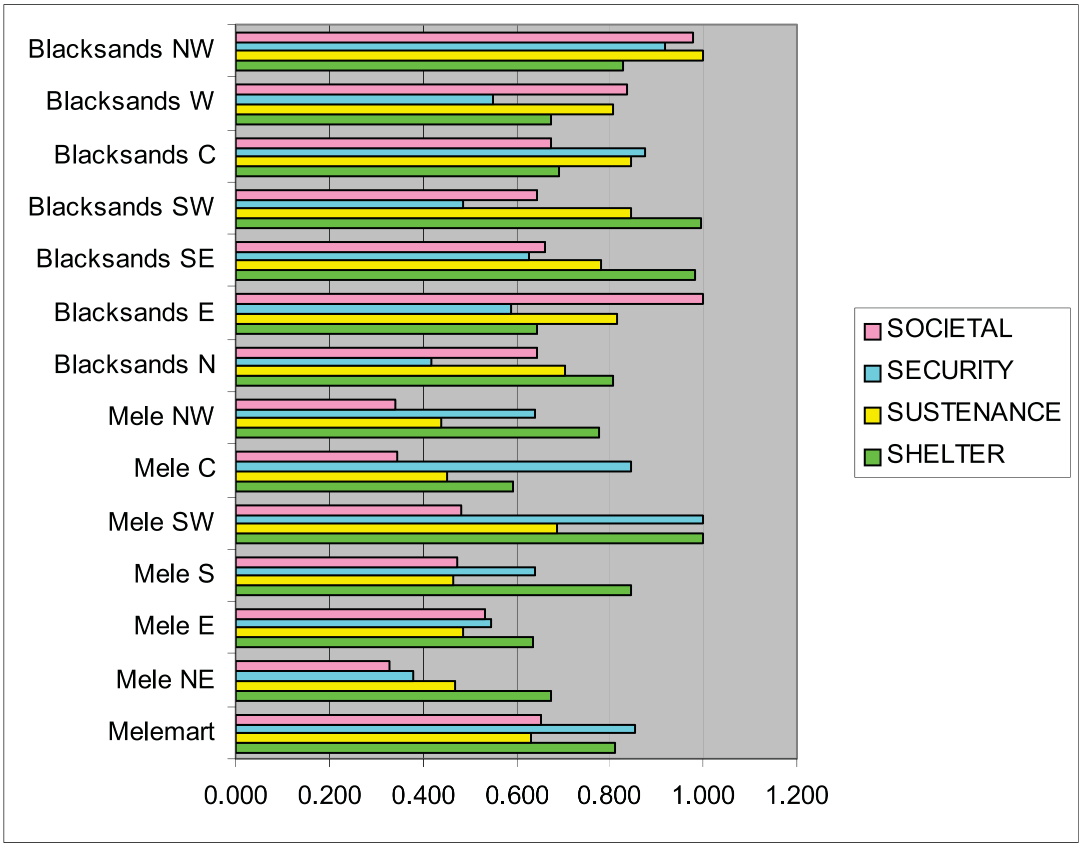

Figure 4: Comparative levels of vulnerability

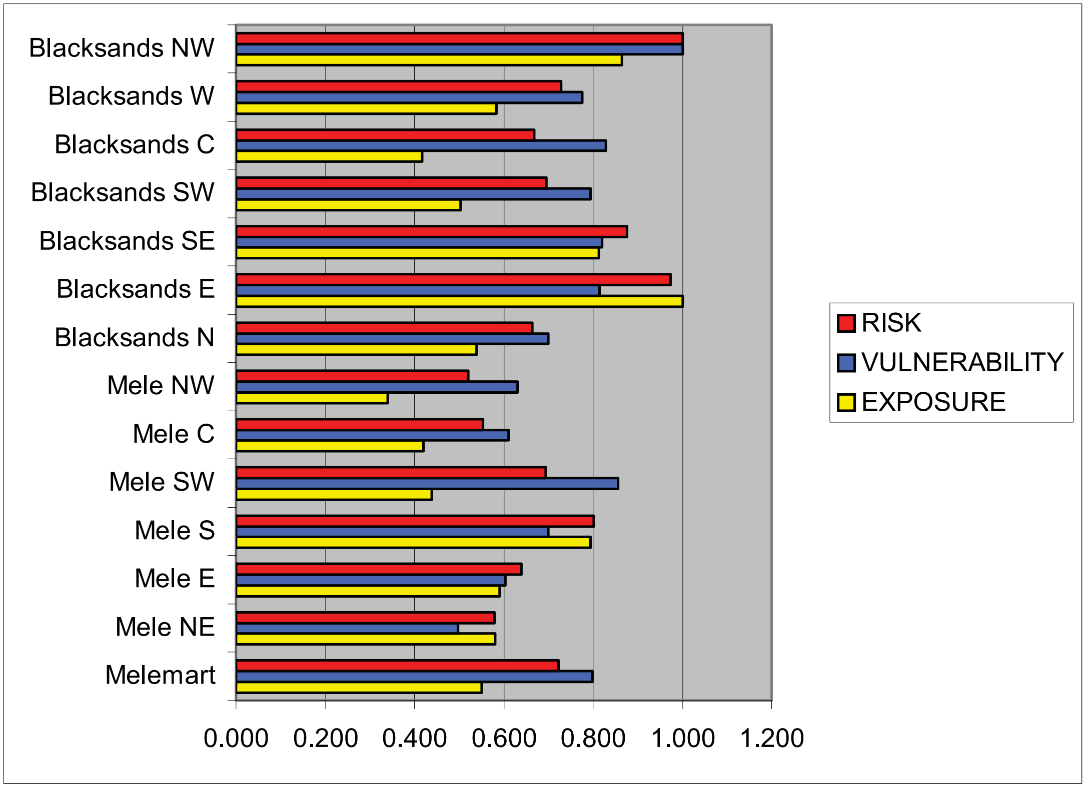

Figure 5: Comparative levels of exposure, overall vulnerability and risk

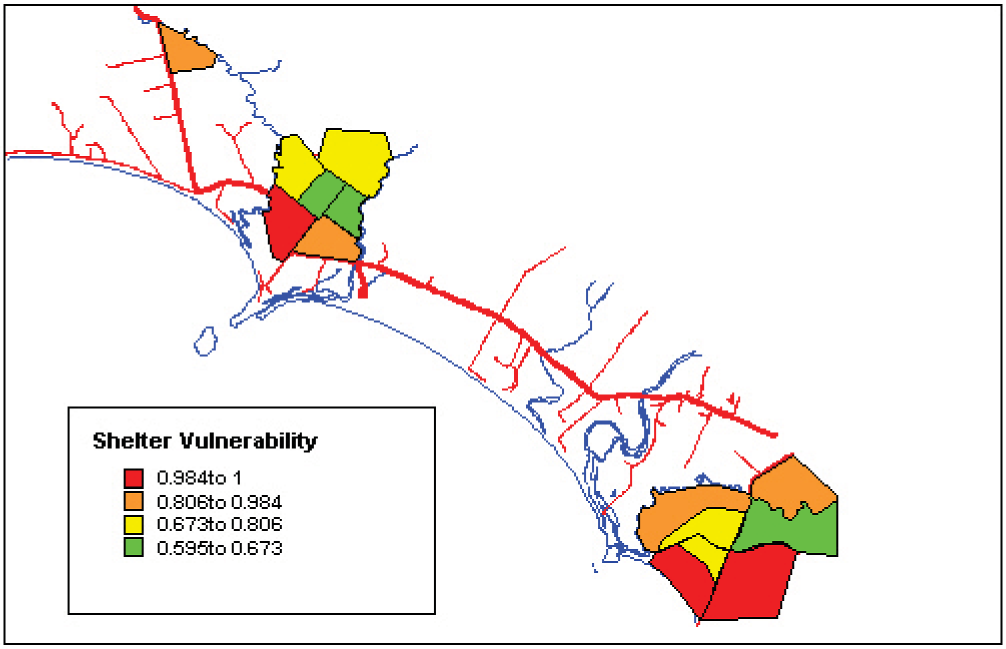

Figure 6: Shelter vulnerability index distribution

It is worth noting the range of index values within both Mele and Blacksands – both extend over the full range of shelter vulnerability classes.

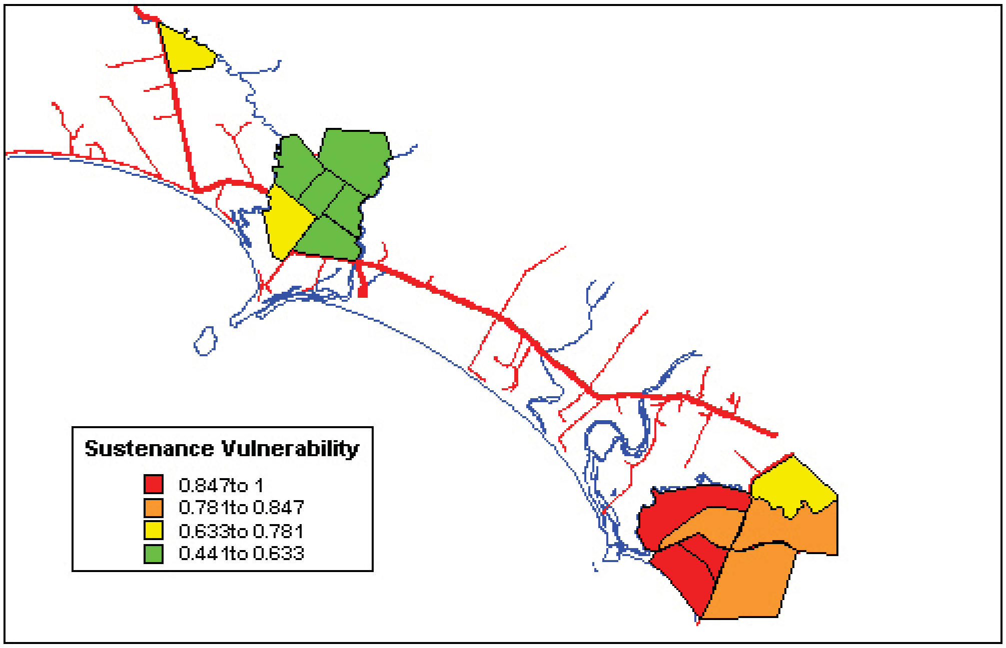

Figure 7: Sustenance vulnerability index distribution

There is a clear bias towards the Blacksands neighbourhoods being at the top end of the scale though even in that settlement there is a wide range of index values.

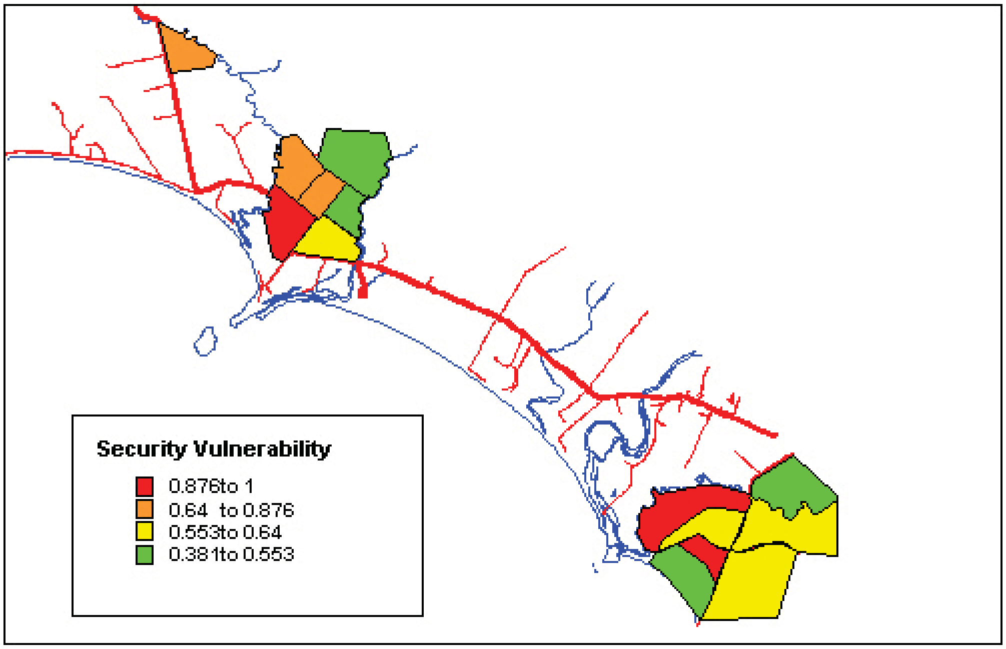

Figure 8: Security vulnerability index distribution

Here again the wide range of values within the two larger settlements is of interest. They are far from homogenous.

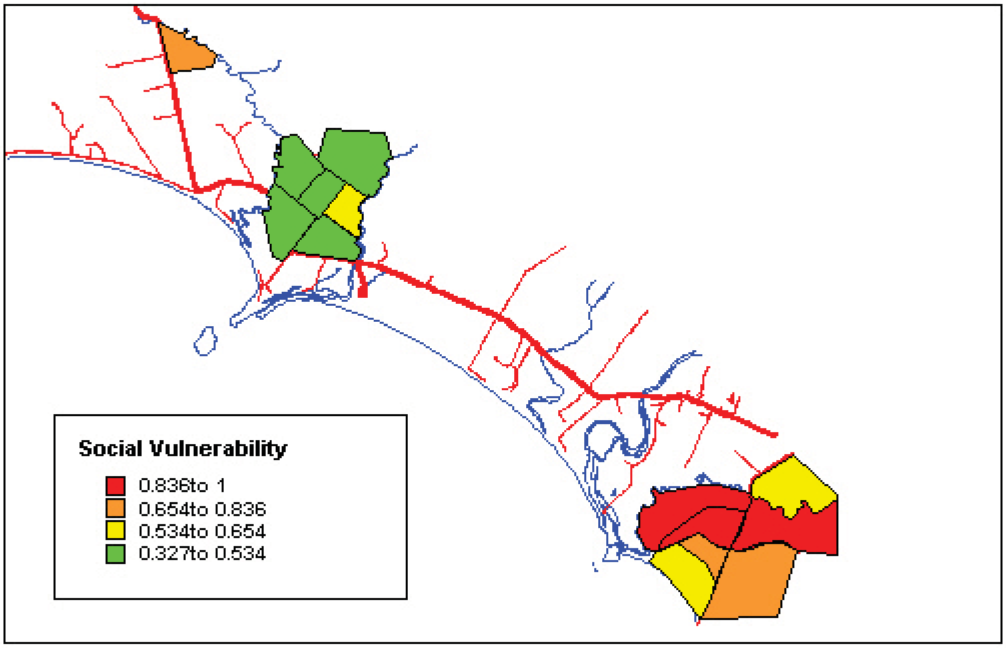

Figure 9: Social vulnerability index distribution

The social vulnerability measures show that Blacksands, especially the neighbourhoods dominated by migrants from Tanna, rate significantly higher than other neighbourhoods but Mele is fairly homogeneous on these measures.

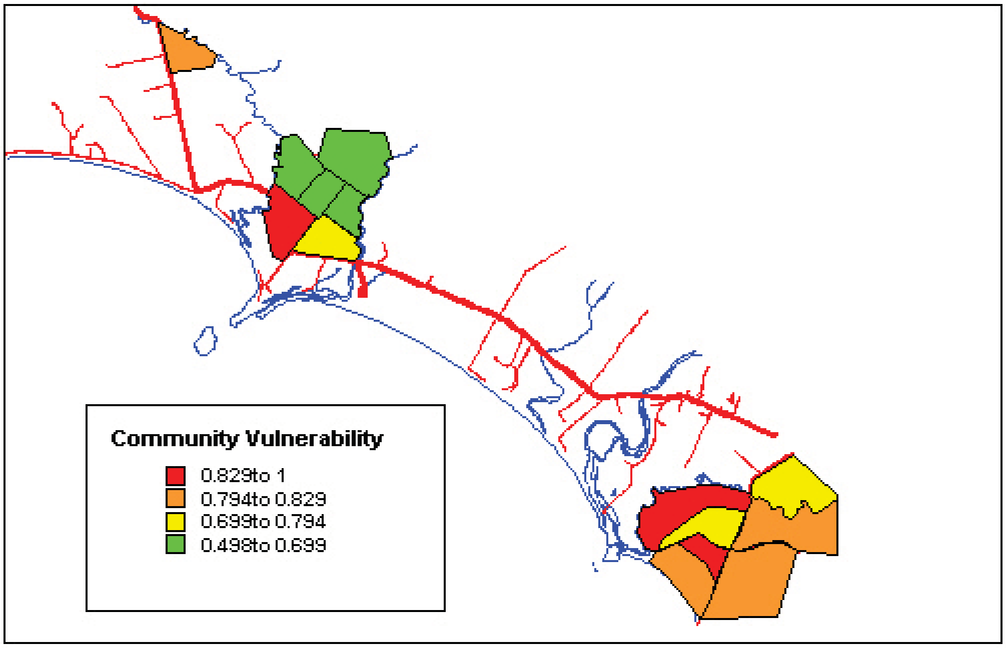

Figure 10: Overall community vulnerability index distribution

There is clearly a greater degree of overall community vulnerability within the Blacksands community than in the Mele settlement overall; the Melemart settlement remains at the upper level. Even with that broad generalisation it is clear that one neighbourhood within Mele has a high level of vulnerability.

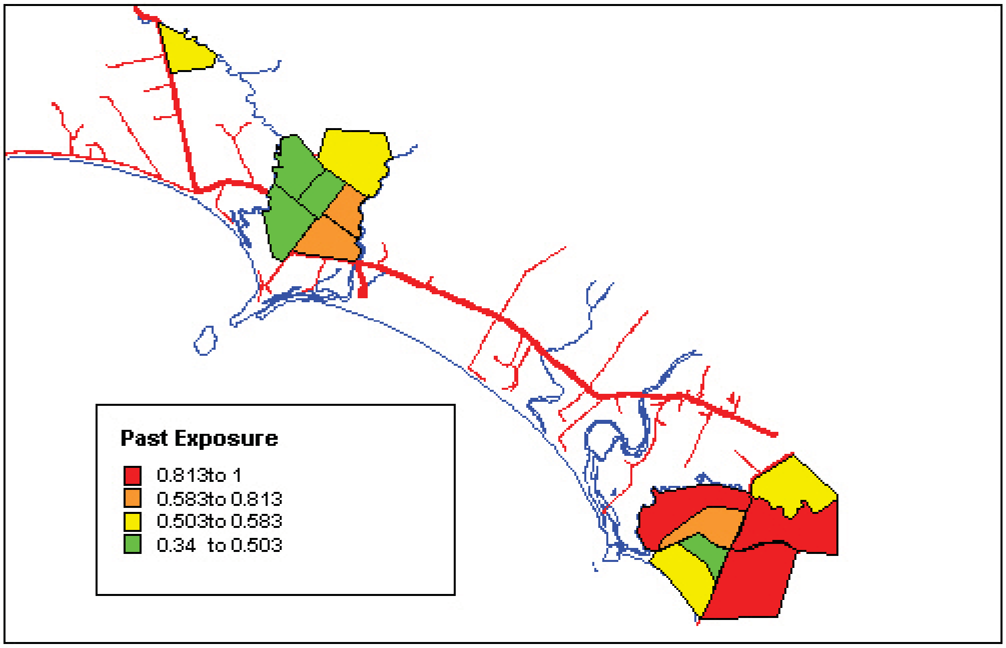

Figure 11: Past hazard exposure index distribution

According to the survey results there appears to have been a higher incidence of hazard impact in Blacksands than elsewhere. This may reflect a range of things including a poorer standard of building construction and development in areas that are more hazard prone. This requires more investigation.

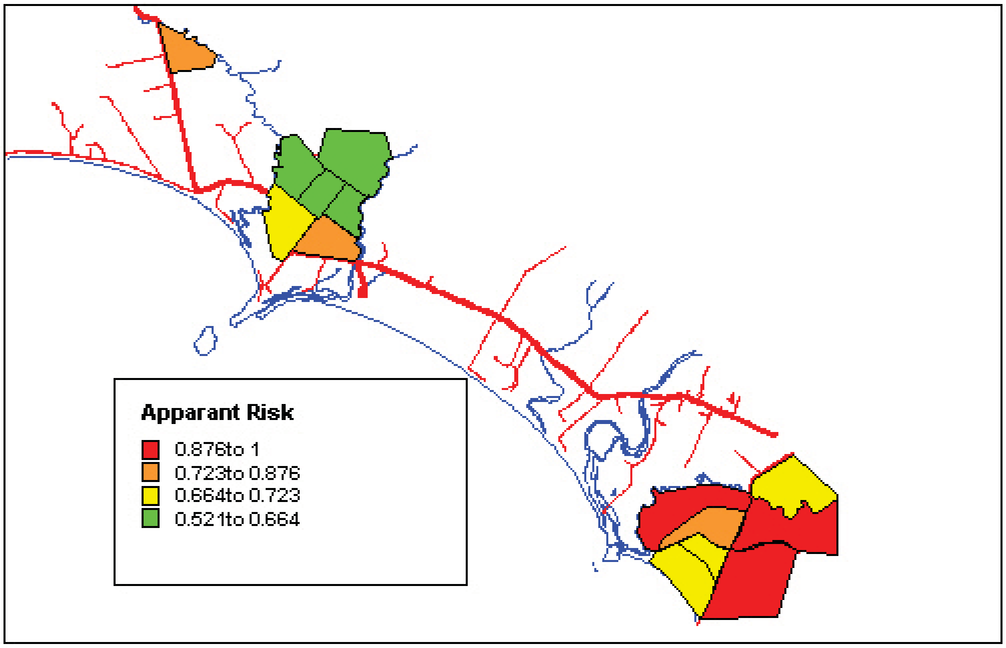

Figure 12: Apparent overall risk index distribution

Overall, Blacksands carries a greater degree of risk than the other two settlements though this is far from evenly distributed across Blacksands or Mele.

## 5 Conclusions

The results certainly appear to demonstrate the value of exploring the internal structure of communities as well as making broad comparisons between communities.

The foundation provided by this analysis could form the basis for a program of risk mitigation strategy development. It will also provide a base against which to measure modelled exposure to a wide range of hazards such as tsunami and flood.

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# Appendix 3a

# Catastrophe Insurance Pilot Project, Port Vila, Vanuatu: Vanuatu Wind Storm

*by*

**Stephen Oliver**

Global Environmental Modelling Systems Pty Ltd, Melbourne, Australia

**SOPAC JOINT CONTRIBUTION REPORT 147**

*December, 2003*

SOPAC

# Catastrophe Insurance Pilot Project

# Port Vila Vanuatu

**Revised August 2002**

Global Environmental Modelling Systems Pty Ltd

PO Box 149 Warrandyte Victoria 3113 AUSTRALIA
Telephone 613 9712 0016 Facsimile 613 9712 0017
E-mail steve.oliver@gems-aus.com

GEMS

**GLOBAL ENVIRONMENTAL MODELLING SYSTEMS PTY LTD**

www.gems-aus.com

# 1 Introduction

## 1.1 Background

The Pacific cities are to varying degrees vulnerable to severe damage as a result of the extremes winds associated with tropical cyclones. A recent example is the damage caused to Vanuatu by tropical cyclone Uma in 1987. This was a severe storm, which passed close to the main island, Efate, and caused damage estimated at $150 Million.

SOPAC has commissioned Global Environmental Modelling Systems Pty Ltd (GEMS) to develop a model for quantifying the risk to major Pacific cities presented by tropical cyclone wind storm. This report describes the model components and the results of applying the model to the island of Efate. This includes, in particular the city of Port Vila.

It is intended that the approach described in the current report should be extended to other Pacific cities in the future. It is also intended that the results be developed in conjunction with a major study of cyclone generated storm surge funded by AUSAID and which is which is currently in progress.

## 1.2 Study Requirements

The current study has the following primary requirements :

- Develop a general methodology for estimating the long term risk associated with wind storm events that can be applied to any of the SOPAC 'major cities' impacted by tropical cyclones;
- Develop an adaptable damage model for building assets within the cities;
- Apply the methodology to the island of Efate, and
- Report the results of applying the model to Efate.
-

## 1.3 Acknowledgements

GEMS gratefully acknowledges the contributions of the following to this study :

The New Zealand Meteorological Service (and in particular Mr Steve Ready); Dr John Holmes of JDH Consulting; Mr Kevin Lindsay of Risk Management International Consulting Ltd; Dr Graham Shorten and Ms Purnima Naidu of SOPAC.

# 2 Study Methodology

## 2.1 Overview

The methodology employed in the study required the following steps :

- Develop a statistical climatology of tropical cyclone events based on historic records;
- Develop a model for generating quasi-random cyclone events consistent with the storm climatology, where the storm event is described in terms of a set of standard parameters such as central pressure (intensity), speed and direction of storm movement;
- Apply an existing empirical model based on the set of cyclone parameters specifications to each storm event to define the temporal and spatial variation of the broad scale wind for that storm;
- Develop a topographically based wind model to convert the broad scale cyclones wind field to location specific wind gusts;
- Develop a regional vulnerability model to estimate rates of damage as a function of wind speed for each building asset (or group of assets) included in the study;
- Apply the wind and vulnerability to a large number of cyclone events representative of storm activity over many thousands of years, and
- Integrate the results to estimate levels of damage over Efate and the related frequency of occurrence of those damage levels.

# 3 Description of Models

## 3.1 Climate Model

### 3.1.1 Data Sources

There are several relevant databases for tropical storm occurrence in the South Pacific.

As a starting point, historic storm tracks held by the Australian Bureau of Meteorology were examined and analysed. Records in this data based date back to the early twentieth century and include details relating to :

- Storm track specified by a date-time and the latitude and longitude of the position of the storm centre, and
- Storm intensity as specified by its central pressure.

On examination, it became apparent that storm central pressure data quoted for the Vanuatu region was inaccurate for the more intense storms as all pressures below 950hpa were reported as 950 hPa. This problem was addressed by seeking access to a South Pacific cyclone track data base developed by the New Zealand Meteorological Service.

Past experience applying storm data bases suggests that reliance on data for storms occurring earlier than the 1950s is unreliable. After this period the evolution of remote sensing (satellites) provided a more reliable basis for identifying and categorizing cyclone events.

### 3.1.2 Cyclone Specification Parameters

The aim of developing the cyclone climatology is to be able to specify the temporal and spatial variation of cyclone occurrence as well as those parameters which can be used to specify the general variation of wind direction and wind speed around the cyclone for a specified time and location of the storm centre.

The parameters to be specified are governed by the requirement to a specify the spatial and temporal frequency of storm occurrence within the region of interest:

- Mean annual frequency;
- Spatial distribution of storms,

as well as the input requirements for the Tropical Cyclone Wind Model described in Section 3.2:

- Speed of movement;
- Direction of movement;
- Central Pressure;
- Radius of Maximum Wind (RMW), and
- Location of storm centre.

### 3.1.3 Efate Cyclone Statistics

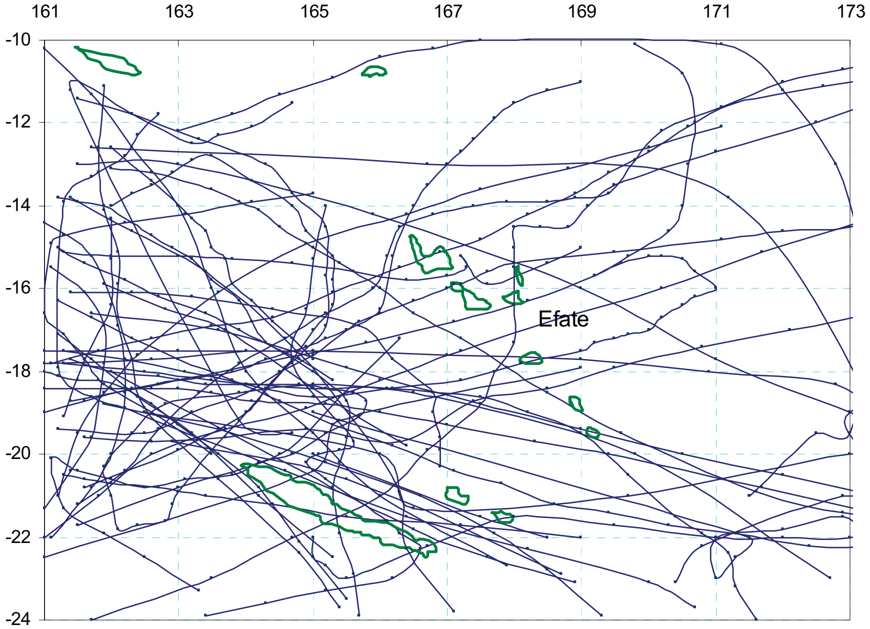

Figure (i) - Tracks of cyclones included in the storm climatology.

To assess the range of possible storms potentially impacting on Vanuatu, all storms occurring after 1950 and which crosses the region bounded by longitudes 161 degrees East and 173 degrees East and latitudes 10 degrees South and 25 degrees south were considered. The tracks of these storms are shown in Figure (i).

(a) Storm Frequency

Storm frequency for the region is based on a total of 50 over 46 years which equates to annual mean of 1.09 storm per annum. The Poisson Distribution can be used to generate the probability of n storms occurring in the region per annum, so that

$$Pr(\text{ n storms }) = m^{n} e^{-m} / n!$$

Where m is the annual mean. Figure (ii) shows the probabilities for up to 5 storms in a year.

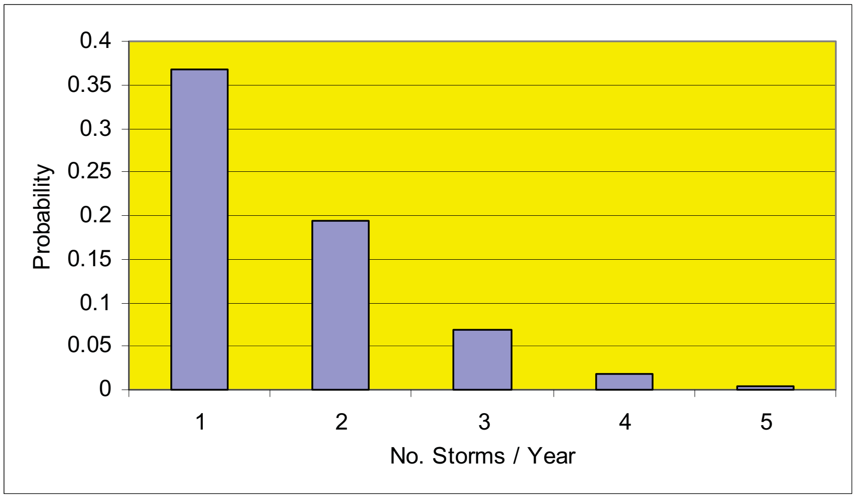

Figure (ii) - Probability of n storms occurring per year within the study region.

(b) Spatial Distribution

In order to specify a probability distribution for the location of storms relative to Efate, storms were initially classified by the longitude at which they crossed Efate's latitude (approximately 17.5 degrees South). These crossing longitudes were tabulated and a probability distribution was fitted to the data. The results of this analysis are shown in Figure (iii). The historic tracks are shown to be weighted to the west of the Vanuatu group.

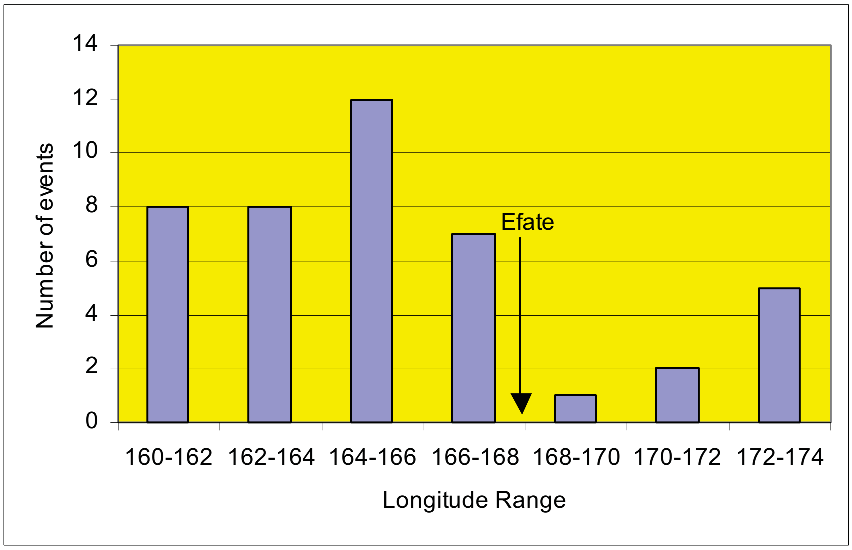

Figure (iii) - Observed crossing longitude for storms passing through Latitude 17.5 degrees South.

c) Storm Track

In order to specify a storm track, a parabolic function was fitted to each storm track in the data base. Two examples are shown in Figure (iv). The idealised track is then used to specify the defining track parameters:

- The direction at the point of crossing Efate's latitude
- The track curvature, ie. the rate of change in direction with latitude

The actual track is used to specify the mean speed of the cyclone.

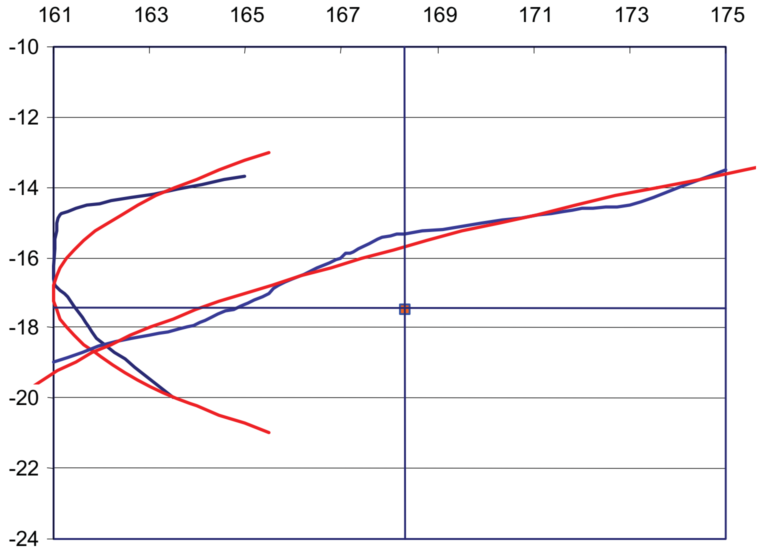

Figure (iv) - Examples of actual (blue) and fitted (red) cyclone tracks showing strong and weak curvature respectively.

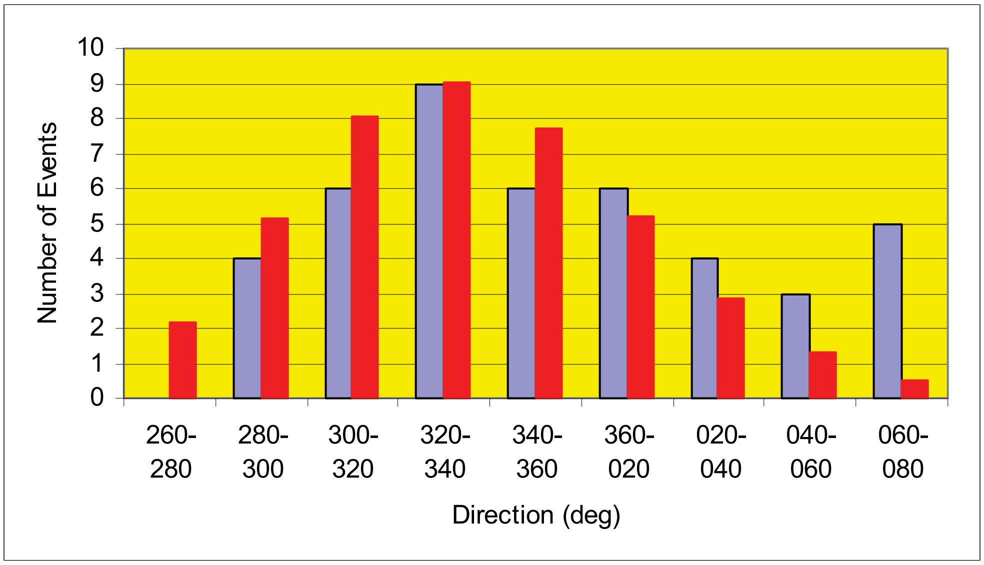

Figure (v) - Observed versus predicted cyclone direction based on analysis of 43 cyclones events included from the defined Vanuatu region.

By specifying a crossing longitude (for the specified latitude), a direction at crossing, curvature and speed, a unique track can be computed .

Direction, curvature and speed data were collected for each of the storms and aggregated.

Probability distributions were then fitted for each parameter and results are shown in Figures (v) to (vii).

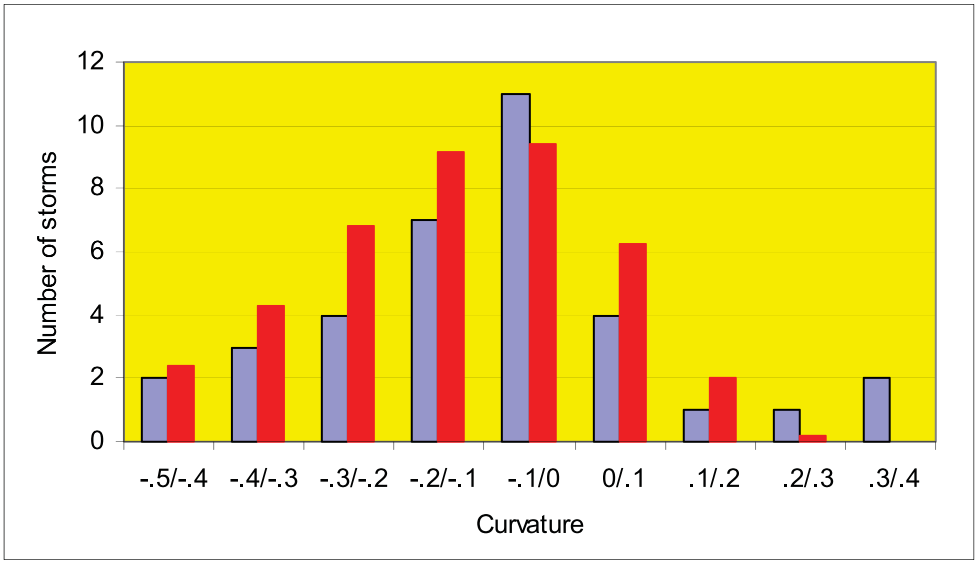

Figure (vi) - As for Figure (v) but for track curvature.

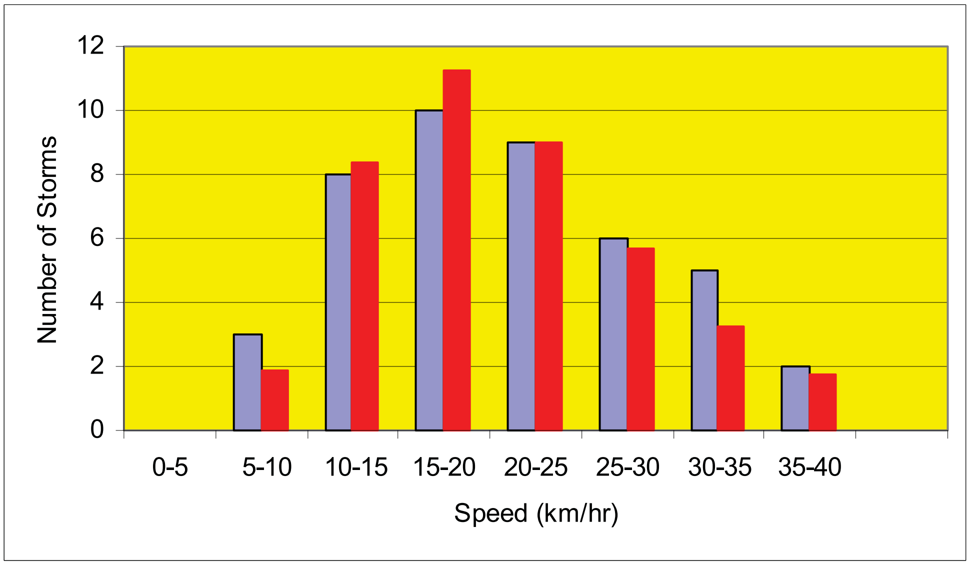

Figure (vii) - As for Figure (v) but for cyclone forward speed.

The track curvature results show a negative bias which reflects anti-cyclonic curvature associated with upper atmospheric ‘steering’ of the storms. In practice, this means storms are more likely exhibit west to east movement at low latitude but then tend to recurve to west to east movement further south.

d) Central Pressure

The primary parameter for specifying storm intensity is its central pressure (wind speed will also depend to some degree on the storms speed of movement). The central pressure of each storm at the time that it crossed Efate's latitude was extracted from the data base. The data exhibit a bi-modal character; most storms were above 980 hpa but there was a secondary, more intense group of storms, with central pressures below 950 hPa. Accordingly, two probability distributions were fitted to the data – a Generalised Pareto Distribution for the weaker storms and a Log-normal distribution for the stronger storms.

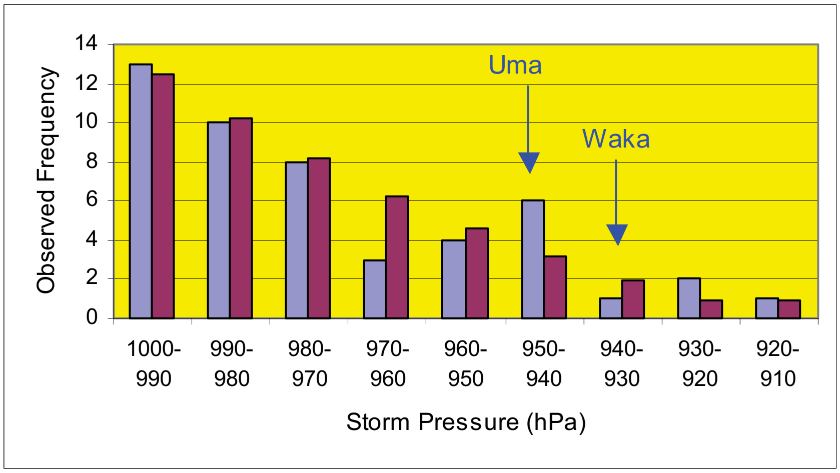

Figure (viii) - Distribution of storm central pressure (24 year observations – blue and fitted distribution - red).

### 3.1.4 Storm Generation

Representative storms can be generated based on the fitted probability distributions shown in the previous section. As each distribution can be expressed as a probability density function, a random number generator can

be used to specify each parameter. By applying the random generation over a large number of events, the synthetic data set of tracks will have the same characteristics (in terms of frequency of occurrence of each parameter) as the observed data set.

The approach adopted to generate the synthetic storms is shown schematically in Figure (ix).

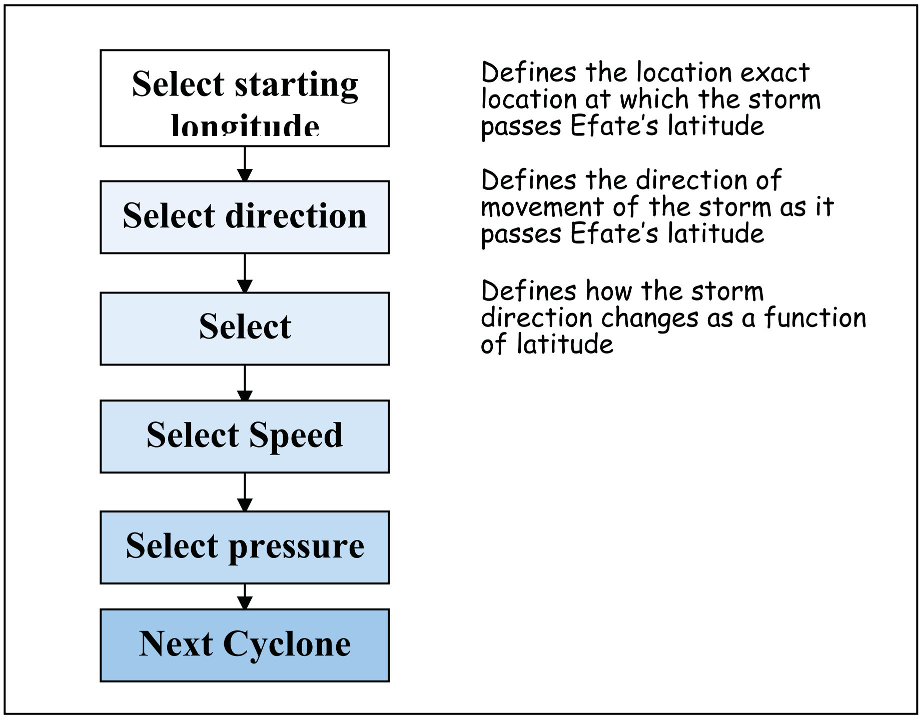

**Figure (ix) - Synthetic cyclone generation process**

## 3.2 Tropical Cyclone Model

The GEMS tropical cyclone model is based on the empirical model developed at the Australian Bureau of Meteorology [6]. The model treats the wind field as an asymmetric vortex.

Wind directions and speed are a function of the storm central pressure and the environmental pressure in which the storm is embedded. The spatial distribution of winds is controlled by the Radius of Maximum Winds (RMW) which defines the distance from the storm centre to the region of strongest winds. Physically, this region of strongest winds is found around the cyclone 'eye-wall'; the eye region is the calm centre of the storm. Typically the radius of maximum winds is of the order of 30-50 km.

Another parameter (the so-called 'B'- parameter) defines the extent to which the strongest winds are concentrated around the eye-wall or otherwise extend outwards from the storm centre. Figure (x) shows some profiles of wind strength as a function of distance from storm centre for arbitrary combinations of central pressure, RMW and the 'B'-parameter.

The (modelled) spatial distribution winds around Tropical Cyclone (Uma, 1987) is shown for the storm's closest approach to Efate in Figure (xi).

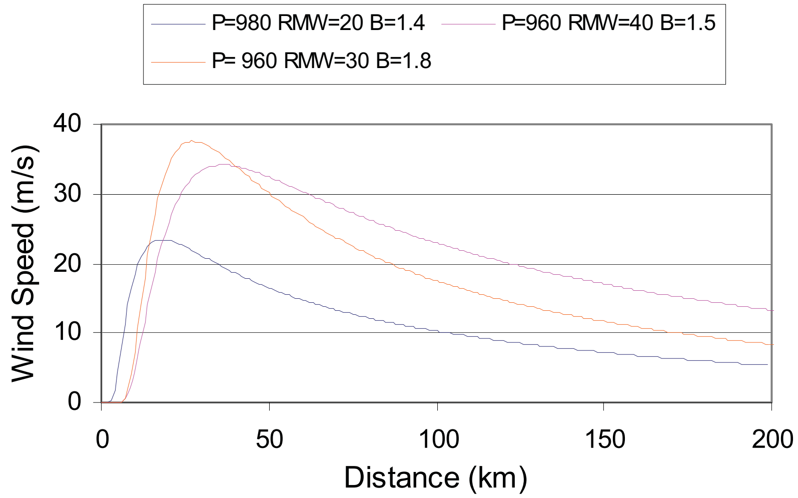

Figure (x) - Profiles of cyclone wind speed for different storm paramteters.

## 3.3 Vulnerability Model

### 3.3.1 Overview

The derivation of damage vulnerability curves for tropical cyclones affecting Efate are described in this Section. The relationships between damage and wind speed developed in the current study are integrated with probabilistic models of tropical cyclones as part of an overall project to assess potential tropical cyclone damage in several cities in the South Pacific.

Vulnerability curves, as used in this report, are relationships between damage index and wind gust speed. The damage index is defined for a building structure, as follows :

Damage index (D) = (repair cost)/ (value of building)

Although, theoretically, D could exceed 1.0, according to the above definition, it is assumed that repair will not take place if D exceeds 1.0, and an upper limit of 1.0 can be assumed.

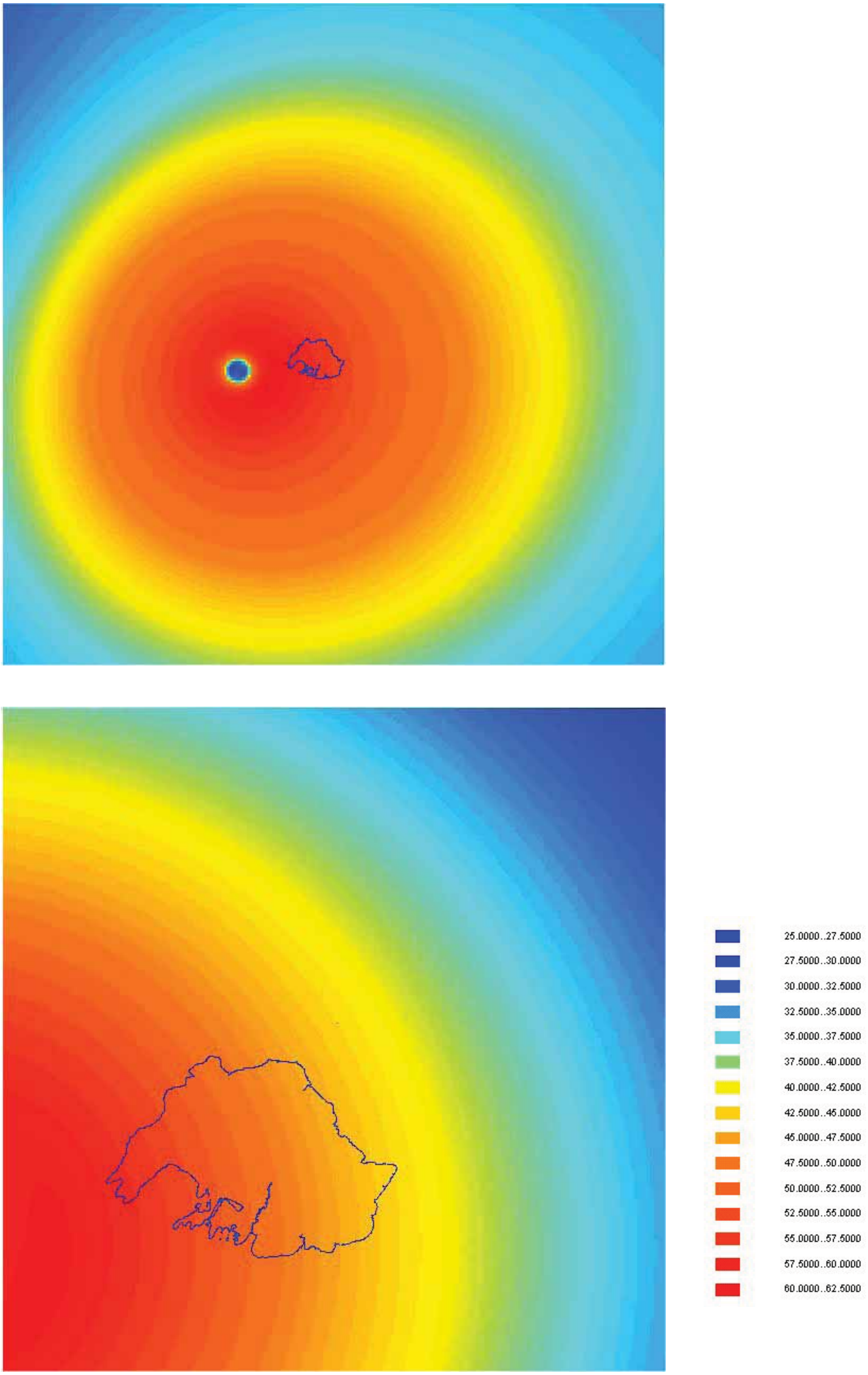

Figure (xi) - Modelled field of wind speed associated with Tropical Cyclone ‘Uma’ at its closest point of approach to Efate.

### 3.3.2 Data Sources

Data was provided by SOPAC on 4803 buildings in Port Vila and another 173 buildings in the Mele Bay area. These data provided information on the usage, position, wall and roof materials, roof shape and pitch, number of storeys, plan area, and foundations of each building.

Answers to additional questions on construction practices in Fiji and Vanuatu, were provided by SOPAC.

Another source of useful information for calibration purposes was a report on the damage caused by Cyclone 'Isaac' in Tonga in 1982 [1]. This report indicated an overall damage index of 0.3 to 0.35, in the main island of Tongatapu, where a maximum gust of 47 m/s was recorded. However only 30% of concrete block houses suffered significant structural damage, whereas 55% of timber framed house received significant damage.

### 3.3.3 Classes of Building Strength

Previous studies of building damage following severe tropical cyclones and hurricanes, have indicated that inadequate structural connections are the main cause of structural failure. It is difficult to assess the strength of connections in individual buildings when they are not exposed. However, the Tonga experience [1] is that concrete block houses are likely to have roof structures that are more securely anchored. Thus wall material can be taken as a good indicator of overall building strength.

Another good indicator of building strength is the building use and function. The more prestigious buildings have generally been engineered by professional structural engineers to resist cyclonic wind forces. In Tonga, 85% of industrial and commercial buildings in the main city of Nuku'alofa had only slight or no damage in Cyclone 'Isaac' [1].

Table I indicates the weightings given to various building characteristics in order to classify the buildings for their potential resistance to cyclone wind forces. Within each characteristic, points were assigned on a scale of ten. For example the system used within 'wall material' is listed in Table II. Building characteristics not listed in Table I were not used in the assessment of strength.

Points for each characteristic were weighted according to the weightings in Table I, and added together to give an overall score for each building. The scores were then grouped into four groups : A, B, C and D. The number of buildings in Port Vila within each class are tabulated in Table III.

Class A included 5.3% of all the buildings, and were primarily commercial and industrial buildings, public safety and health services buildings. Class B buildings (58.8%) included nearly all houses with concrete block walls, as well as commercial buildings not included under A. Class C (33.9%) incorporates most houses with other wall materials. Class D, with the buildings assessed as weakest, only included 2% of the total, and largely consisted of sheds and open shelters.

Table I. Building characteristics used to assess cyclone resistance and their weightings

| Characteristic | Weighting |
|---|---|
| Main use | 0.25 |
| Wall material | 0.20 |
| Windows | 0.20 |
| Roof material | 0.15 |
| Roof shape | 0.10 |
| Roof pitch | 0.10 |

Table II. Points assigned to the 'wall material' characteristic.

| Wall material | Points |
|---|---|
| Concrete | 8 |
| Metal | 7 |
| Bricks | 6 |
| Timber | 5 |
| Fibre-cement sheets | 3 |

Table III. Strength classifications for Port Vila buildings.

| Classification | Number of buildings | Percentage of numbers | Percentage of value | Scale factor (m/s) |
|---|---|---|---|---|
| Class A | 254 | 5.3 | 20 | 70 |
| Class B | 2822 | 58.8 | 52 | 65 |
| Class C | 1629 | 33.9 | 27 | 60 |
| Class D | 98 | 2.0 | 1 | 50 |
| Total | 4803 | 100 | 100 | - |

### 3.3.4 Derivation Of Vulnerability Curves – By Strength Class

The derivation of vulnerability curves for wind storms hs been discussed by Leicester et al

[2], Holmes [3], and Walker [4]. A vulnerability curve describes the relationship between fractional damage i.e. the fraction of the value of the building, as a function of the peak wind gust at the site, or in the vicinity of the building.

Leicester *et al* proposed a vulnerability curve consisting of straight line segments with break points corresponding to the initial onset of minor damage, and the onset of major damage (damage index of 0.2). Walker [3] proposed vulnerability relationships for Queensland buildings consisting of two power law functions added together. However, these curves do not smoothly transition to full damage (damage index of 1.0) at the high wind speed end.

The vulnerability curves derived for this study are continuous functions of wind speed, and smoothly transition from 0 to 1 with increasing gust wind speed. They are based on the Weibull function, usually used for probability distribution functions for the strength of structural elements. This has two parameters : a shape factor, k, which determines the general shape of the curve, and a scale parameter, c, with units of wind speed, which determines the position of the curve on the wind speed axis. The algebraic form of the vulnerability curves is :

$$D(\hat{U}) = 1 - \exp\left[-\left(\frac{\hat{U}}{c}\right)^{k}\right] \tag{1}$$

where D(U) is the damage index and $\hat{U}$ is the gust wind speed at 10 metres height in open terrain (equivalent to an airport anemometer).

A shape factor of 8 was used for all the curves proposed for this study. This value gives a curve which has a generally similar shape to that proposed by Leicester *et al.*

The scale factors assigned for each category are listed in Table III. At the wind speeds corresponding to the scale factor, a damage index of 0.63, (1-(1/e)), is obtained. The scale factors are based on the performance of buildings in Tonga in Cyclone Isaac in 1982, but with a reduction in the expected damage for Classes B and C, based on the descriptions of building practices in Fiji and Port Vila supplied to JDH Consulting.

Figures (xii) to (xxv) show the damage curves for the four building classes.

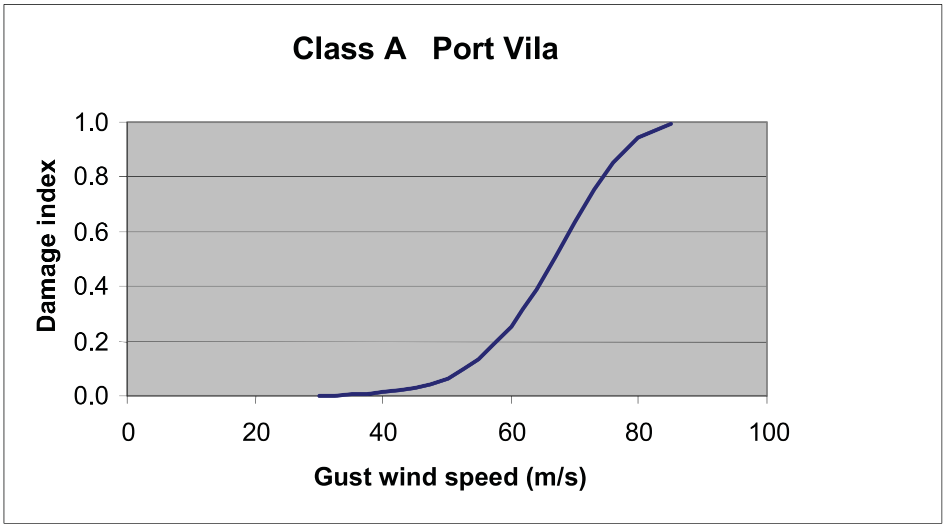

Figure (xii) - Vulnerability curve for Class A buildings.

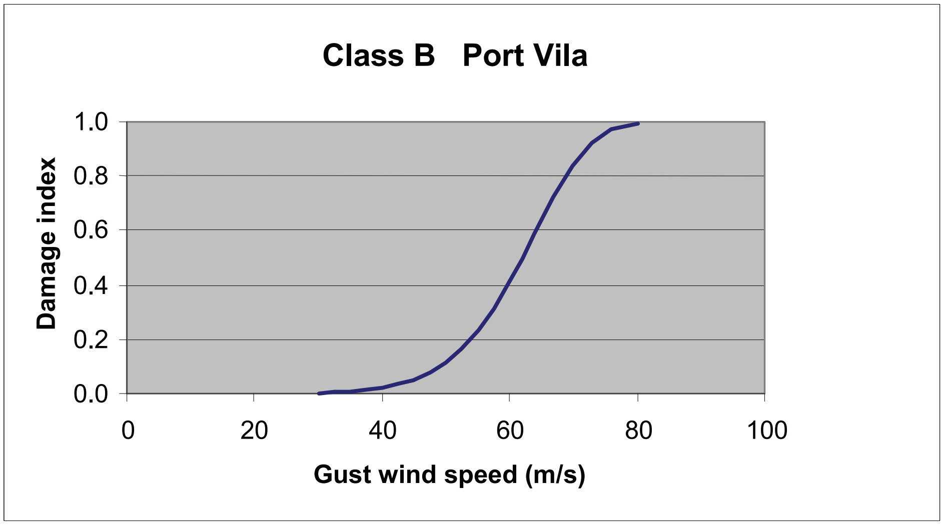

Figure (xiii) - Vulnerability curve for Class B buildings

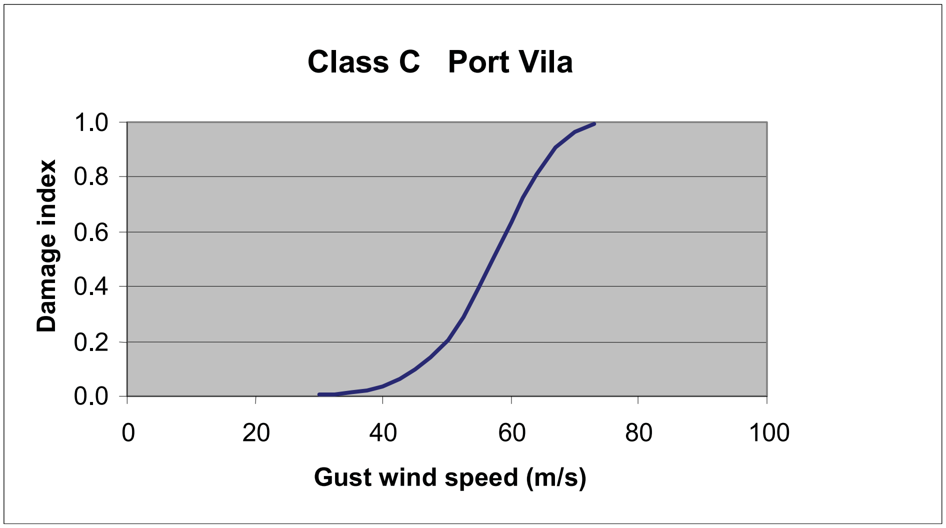

Figure (xiv) - Vulnerability curve for Class C buildings

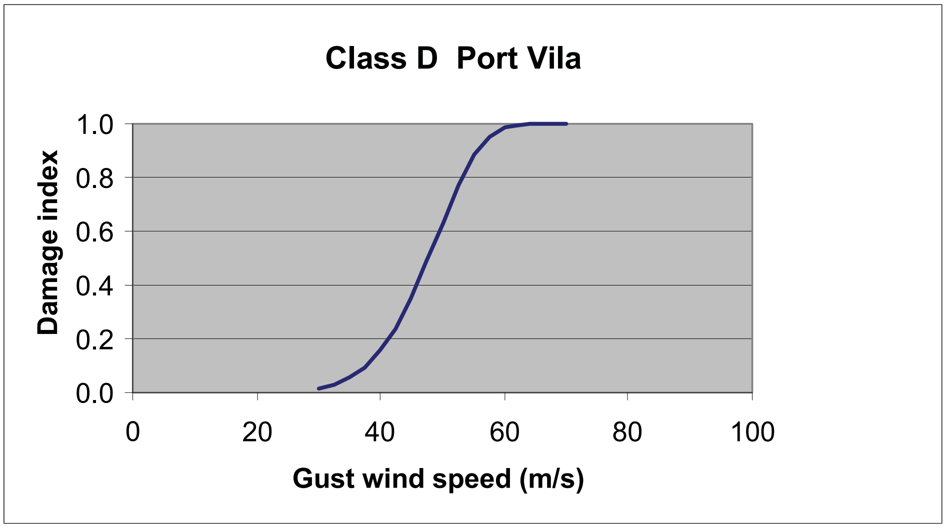

Figure (xv) - Vulnerability curve for Class D buildings

## 3.4 Topographic Wind Model

### 3.4.1 Overview

The risk model developed for wind damage at Port Vila, Vanuatu is described in the previous section This gives estimates of the damage to be expected in the city as a function of the local gust wind speed at each site. If the city were located in flat uniform terrain, this damage could be related directly to recorded gust wind speeds at the airport anemometer. The latter can be related directly to the simulated gradient (mean) wind speeds generated by the GEMS Cyclone model described in Section 3.2. However topography will affect the situation in two ways:

- Large scale topography of the order of the height of the atmospheric boundary layer, and with a width exceeding that of the city area, may affect the overall level of wind speeds in the city, and
- Local topography may affect local gust speeds on a site by site basis, and differently for different wind directions.

Both these aspects are considered for Port Vila and Vanuatu in this report, although the second aspect is treated in more detail.

### 3.4.2 Large-scale Topographic Effects

The large-scale effects of the (approximate) 600m peaks of the volcanoes of Efate Island on winds from tropical cyclones are quite difficult to estimate, (Figure (xvi). Clearly there will be some shielding of Port Vila by this topography. Peaks of this height exceed the height of the over-ocean boundary layer at the centre of a tropical cyclone, and it is likely that topography of this height will change the dynamics of the cyclone itself.

The aerodynamic effects of the large-scale topography of Efate Island could be investigated successfully by means of wind tunnel testing. This technique has been used for Hong Kong Island for example. Some examples of this type of wind tunnel testing is described in Reference [2].

A rough indication of the effect of topography on cyclonic winds can be indicated by the measurements carried out in Hong Kong during Typhoon 'York' in 1999. Measurements at Central Plaza, which is sheltered from southerly winds by 'The Peak', showed about a 14% reduction in mean wind speed compared with those at the exposed Waglan Island [3]. However it is not clear that measurements were at equivalent heights above the ground.

A reasonable estimate of the effect of the high topography of Efate Island on northerly winds would be a 15% reduction. This can be taken as applicable to the quadrant from north-west to north-east. Figure xvii shows overall directional reduction factors applied for wind direction between 270 through 360 to 110 degrees.

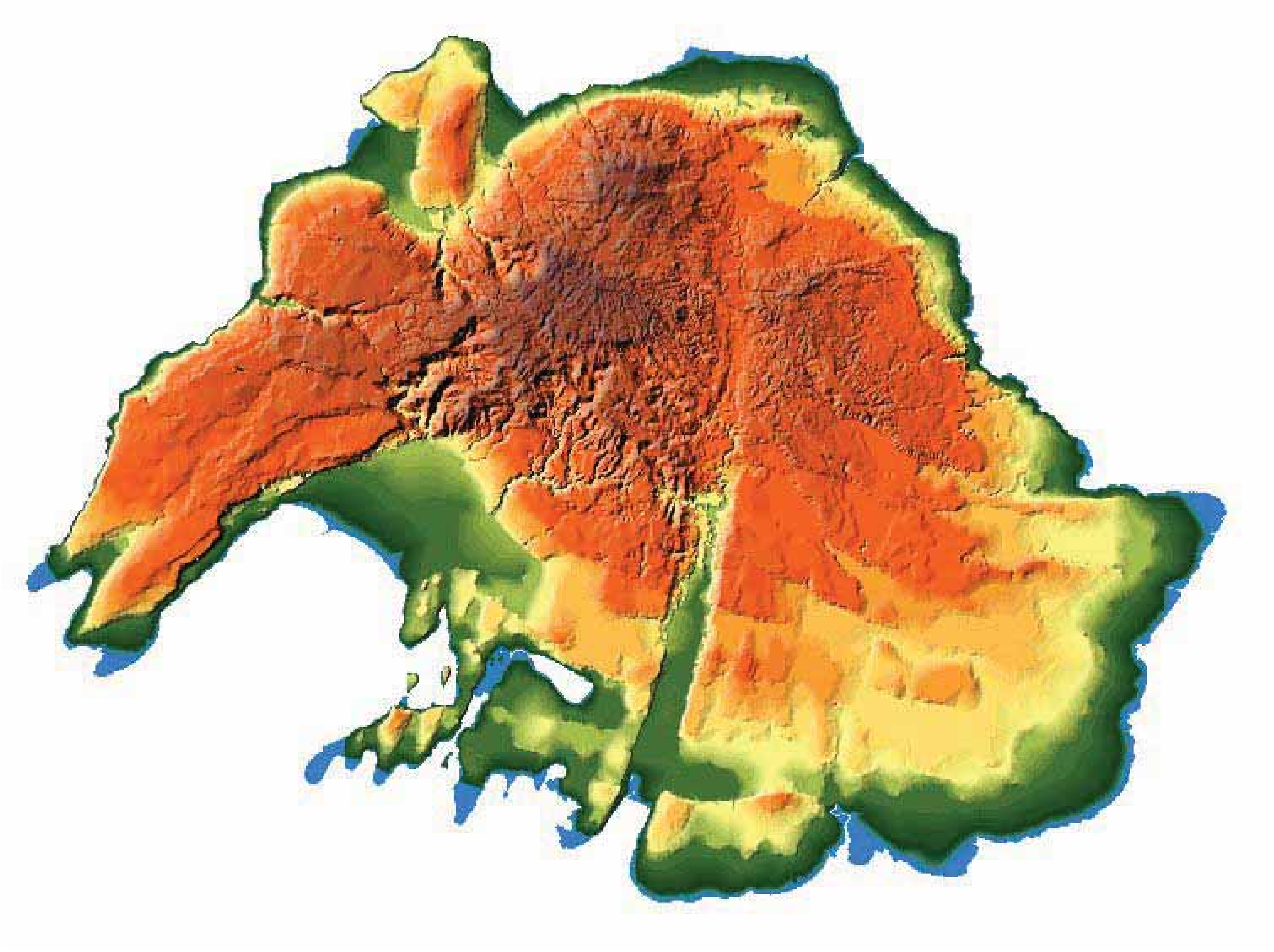

Figure (xvi) - Topography of Efate.

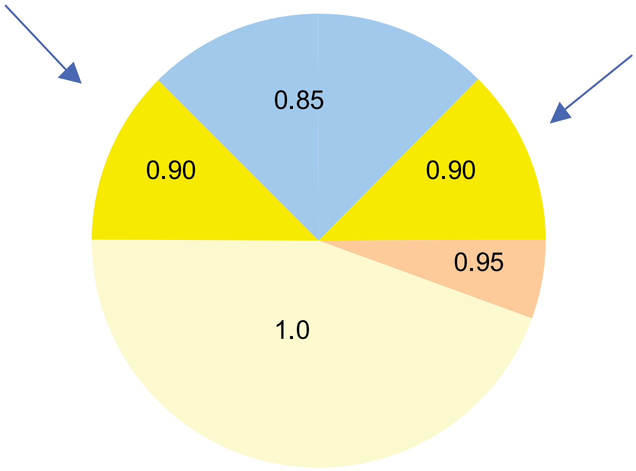

Figure (xvii). Topographic shielding reduction factors as a function of wind direction.

### 3.4.3 Small-scale Topographic Effects

The land elevations in Port Vila range between a few metres to about 100 metres, above sea level. In the north part of the city, some of the slopes can be quite steep, apparently rising 50 metres in a distance of 100 to 200 metres. The slope of the land upwind of a site is a major factor in determining the speed up effects on wind speeds. The maximum speed-up is achieved for an upwind slope of about 0.3. Above that slope, the flow separates and the magnitude of the speed-up is limited [5].

The following procedure was used to assess the small-scale topographic effects in Port Vila and Mele Bay :

- The matrix of 1 kilometre squares of the city and its environs were labelled 'A to E' running from west to east, and '1 to 10' from north to south. A smaller matrix labelled E-F/1-2 were created for the Mele Bay assets (Figure xviii);

- An average Topographic Multiplier, defined according to the Australian Standard for Wind Loads [5], was estimated for each designated square and for each of four principal wind directions. These are listed in Table 1 - Appendix A which relates the gust wind speed at a typical building height of 4 metres to that at the airport, representing flat, open terrain.

- The average gust speed in each square was related to the gust speed at the standard meteorological height of 10 metres at the airport, through a simple conversion factor for the height change. This also incorporated terrain roughness effects (Section 3.4.4).

- The average gust wind speed within each kilometer square was related to the mean (time-averaged) gradient wind speed at an elevation of 100 metres, or greater.

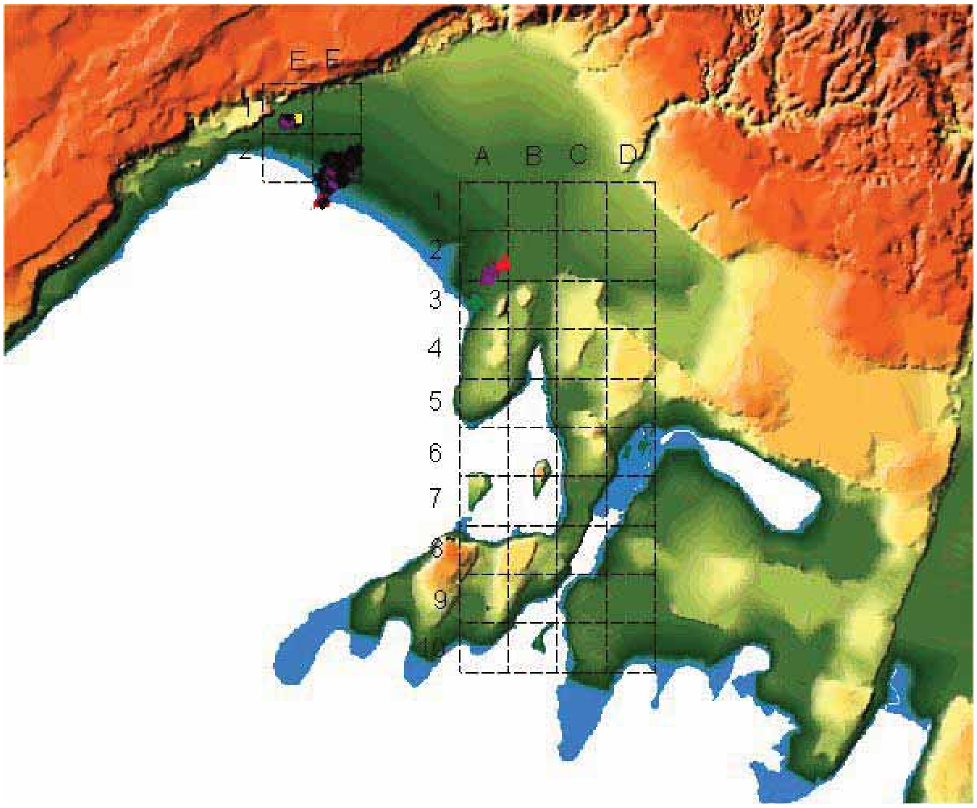

Figure (xviii) - Topography of Port Vila and designation of one kilometre squares.

Table 1 – Appendix A gives the basic Topographic Multipliers relating average gust speeds within each square at 4-metres height to that at the same height at the airport. It should be noted that, for any given wind direction, the wind speeds can vary considerably within any given square. For example, it will be highest near the crest of a hill or at the edge of a cliff or escarpment, and fall away both upwind and downwind. The values in Table I represent no more than estimated average values, with higher and lower values expected within any given square.

It should be noted that the non-dimensional multipliers for topography and height change are not sensitive to the general level of wind speed, and are applicable in all stages during the passage of a cyclone.

### 3.4.4 Correction For Terrain Roughness Effects

For the squares with the greatest building density within Port Vila, there will be a reduction in the expected peak gust due to the modification of the cyclonic boundary layer by the roughness of the terrain – i.e. the upwind buildings. This effect is greater the longer the 'fetch' length of rough terrain. In this case, there is a significant reduction due to this effect for north and south winds for squares C3 to C8 in Figure (xviii). Smaller effects have been assessed for other squares and wind directions.

The reduction is determined as follows. Interpolation of the terrain-height multipliers in the Australian Standard for Wind loads [5] for Terrain Categories 2 and 3 at 4 metres according to the distance was carried out according to an exponential adjustment with a distance constant of 2 kilometres. This adjustment rule was derived from wind-tunnel tests at Monash University and is reported in the Commentary to the Australian Standard [6]. The resulting multipliers for terrain effects are tabulated in Table II. These are given as 2-second gust multipliers at 4 metres within each square as a ratio to the 10 metre gust multiplier in Terrain Category 2 – assumed to be the appropriate one for the airport. The default value in this table for no terrain roughness effects is : 0.93.

### 3.4.5 Correction For Height Of Airport Gust

In Table III, the ratios of the average 2-second gust speeds in each kilometre square, incorporating both topographic and terrain effects, to the gust wind speed at 10 metres height at the airport have been calculated. These ratios are derived from the corresponding values in Table I, simply by multiplying by the values in Table II. For squares not affected by terrain roughness effects, the factor is 0.93, [5]. For squares and wind directions affected by terrain roughness effects, as discussed in Section 4, the multiplying factors are lower in Table II.

### 3.4.6 Gradient Wind Multipliers For Cyclones

To determine the multiplier to convert the gradient (mean) wind, $\overline{U}_\infty$ as calculated from numerical models of tropical cyclones, to airport wind speeds, it is first necessary to calculate the conversion factor for mean wind speeds over flat terrain at the surface.

The factor $\dfrac{\overline{U}_{60\text{min},\,10\text{m}}}{\overline{U}_\infty}$ can be obtained from AS1170.2-1989[5], which bases its profiles in tropical cyclones on measurements by Wilson [6] from a tower at the North-West Cape near Exmouth in Western Australia. AS1170.2 gives $\dfrac{\overline{U}_{60\text{min},10\text{m}}}{\overline{U}_\infty}$ as 0. 60. Krayer and Marshall [7] give $\dfrac{\overline{U}_{10\text{min},10\text{m}}}{\overline{U}_{60\text{min},10\text{m}}}$ as 1.10.

Thus,

$$\frac{\overline{U}_{10\text{min},10\text{m}}}{\overline{U}_\infty} \cong 0.60 \times 1.10 = 0.66$$

To determine the ratios of the maximum 3-second gust speed to the gradient wind speed, a value for the gust factor, $\dfrac{\hat{U}_{2\,\text{sec},10\text{m}}}{\overline{U}_{10\,\text{min},10\text{m}}}$, is required. A study by Krayer and Marshall [7] of four U.S. hurricanes gave the following value:

$$\frac{\hat{U}_{2\,\text{sec},10\,\text{m}}}{\overline{U}_{10\,\text{min},10\,\text{m}}} = 1.55 \qquad (1)$$

A value which appears to be based on measurements at higher wind speeds in hurricanes, from an analysis by Black [8], is :

$$\frac{\hat{U}_{2\,\mathrm{sec},10\,\mathrm{m}}}{\overline{\overline{U}}_{10\,\mathrm{min},10\,\mathrm{m}}} = 1.66 \qquad (2)$$

An average value of 1.60 for the gust factor, at 10 metres in standard flat terrain (airport), was used for the present calculations.

Thus to convert the gradient wind speed $U_\infty$ to a gust speed at 10 metres at the airport, a factor of (0.66)(1.60) = 1.056, should be applied. This factor has been applied to the values in Table V, to give the values in Table VI, representing the ratio of site gust wind speed at 4 metres, to the gradient wind.

### 3.4.7 Conclusions

The effects of the small-scale topography of Port Vila on cyclonic wind speeds for four directions has been investigated, in order to estimate multipliers to convert the gust wind speed at the airport, to equivalent conditions at each site within the city.

Multipliers to convert the gradient wind speed in tropical cyclones to the gust wind speeds at the airport, and at each site within the city of Port Vila have also been derived

The large-scale effects of the volcanic peaks to the north of Port Vila on cyclonic winds have been estimated approximately. More accurate determination of these effects can be achieved with small-scale wind tunnel tests, as has been done with Hong Kong and Hawaii, for example.

## 3.5 Economic Model

### 3.5.1 Asset Values

In order to estimate damage levels in monetary terms, it was necessary to develop an economic model for the value of assets in the study region. At this stage, the economic model is limited to the replacement value of buildings in the asset list supplied by SOPAC.

Replacement values have been computed for the 4976 buildings listed in the Port Vila and Mele Bay regions. These have been based on estimates of floor area for each building and estimates of the unit area replacement value for across the four building classes. In most cases, the floor area was provided as an estimated range and the mean value of the range was taken to estimate the replacement values.

Replacement cost estimates were provided by Risk Management Pty limited and Aon Insurance. The Risk Management estimates included the cost of demolition of damaged buildings; these values, expressed as cost per square metre for each of the four building classes were used as benchmarks for the modelling.

Table IV. Floor value (per square metre) estimates for the four building classes applied in the study.

| Building | Lowest | Best | Highest |
|---|---|---|---|
| Class A | 935 | 1,200 | 1,470 |
| Class B | 1,200 | 1,470 | 1,735 |
| Class C | 935 | 1,200 | 1,470 |
| Class D | 400 | 670 | 800 |

The number of individual buildings assigned to each Class A – D is given in Table V.

Table V. Number of buildings assigned to each building class.

| Building Class | Number |
|---|---|
| Class A | 254 |
| Class B | 2822 |
| Class C | 1629 |
| Class D | 98 |
| All | 4803 |

The computed total value of all buildings included in the study are given in Table VI.

Table VI. Aggregated dollar values for buildings included in the study.

| Building Class | Value ($A Million) |
|---|---|
| Class A | 49.230 |
| Class B | 459.301 |
| Class C | 161.670 |
| Class D | 5.075 |
| All | 675.276 |

### 3.5.2 Scenario Modelling

The economic modelling, though relatively simple, included a process to estimate the effectiveness of insurance. This was achieved by considering the behaviour of an "insurance" pool under varying scenarios and averaging over random samples of one hundred year periods.

The pool algorithm was defined as

$$\text{Pool} = \text{Pool} + \text{ROI} - \text{CapCost} - \text{DamLoss}$$

were ROI, Return on Investment is based on a designated investment rate,

Cap Cost, Capital Cost based on an interest rate on any capital borrowed to cover damage losses and DamLoss is the loss due to wind storm. This algorithm was computed in annual increments, based on random cyclone behaviour over 100 year periods.

The model allows for variations in premium rates (expressed as a percentage of replacement value), variation in capital cost (also expressed as a rate of interest); it also allows for changes to the vulnerability of assets through the vulnerability curves to allow for building upgrade or replacement.

## 3.6 Model Integration

### 3.6.1 Overview

The physical and economic models were integrated so as to provide estimates of damage (in percentage and dollar terms) for each building asset for any specified storm. The individual damage levels can also be integrated to provide total damage estimates.

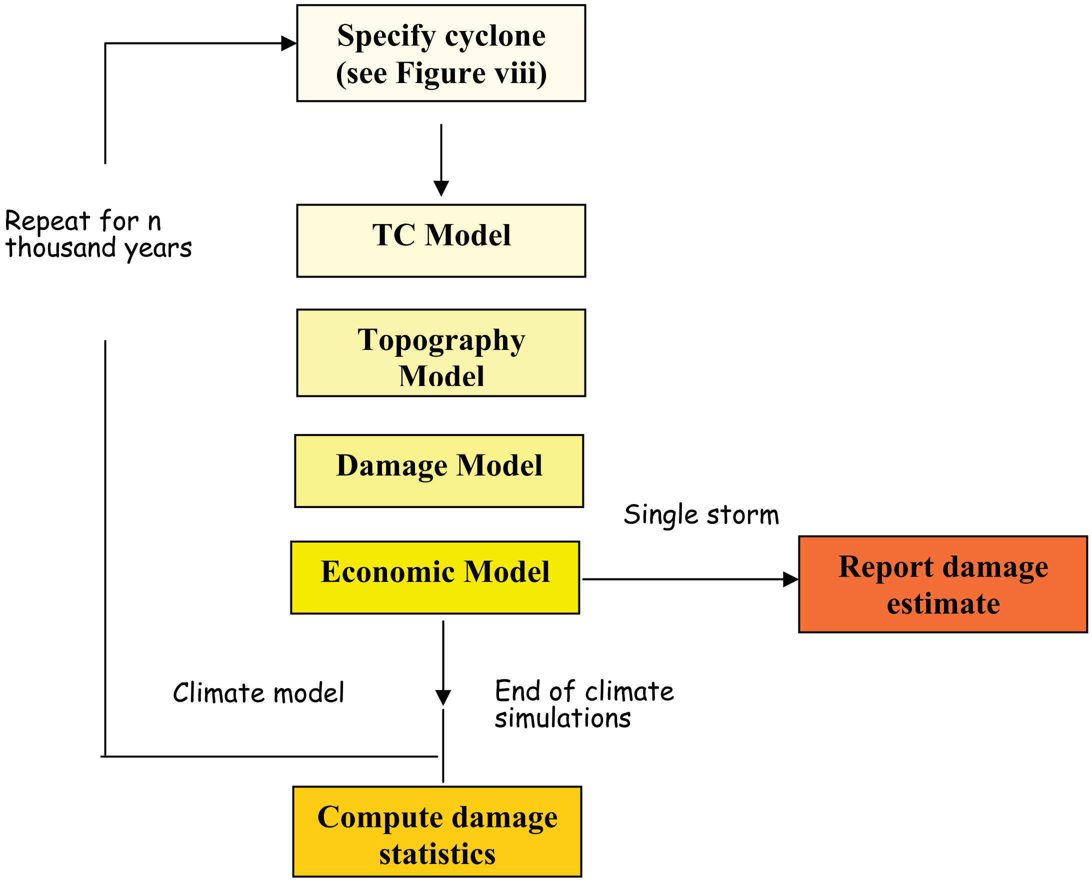

**Figure (xix) - Schematic of damage model system.**

The integrated model can be applied to actual storm events or for storms generated synthetically to represent the long term cyclone climatology of the region. The process is shown schematically in Figure (xix).

### 3.6.2 Verification – Tropical Cyclone 'Uma'

The integrated wind storm damage system was tested against Tropical Cyclone Uma which impacted Efate in February 1987.

Details of TC Uma are given in Table VII and the track is shown in Figure (xx). The storm passed just to the west of Efate, so that its region of maximum winds directly affected the island. Maximum wind gusts for the storm were estimated at 120 knots (60 m/s).

The lowest pressure recorded at Vila was 957 hPa and the maximum sustained wind was estimated at 75 knots – the anemometer at Vila was destroyed by the cyclone winds.

The GEMS cyclone model was run based on the track details given in Table VII with the radius of maximum winds set to 30 nautical miles. The 'B' parameter was adjusted so that minimum pressure obtained at Efate was close to the observed value of 957 hPa. Figure x (page 14) shows the wind field around the storm as it passed Efate. Figure xxi shows the spatial variation of modelled peak wind gust speed.

**Table VII. Track details – Tropical Cyclone 'Uma'.**

| Date (UTC) | Time (UTC) | Latitude ($^o$S) | Longitude ($^o$E) | Pressure (hPa) |
|---|---|---|---|---|
| 05/02/1987 | 0000 | 13.6 | 163.5 | 990 |
| 05/02/1987 | 0600 | 13.9 | 163.9 | 990 |
| 05/02/1987 | 1200 | 14.1 | 164.2 | 980 |
| 05/02/1987 | 1800 | 14.5 | 164.5 | 980 |
| 06/02/1987 | 0000 | 15.0 | 165.0 | 950 |
| 06/02/1987 | 0600 | 15.4 | 165.4 | 950 |
| 06/02/1987 | 1200 | 16.0 | 166.0 | 950 |
| 06/02/1987 | 1800 | 16.6 | 166.5 | 950 |
| 07/02/1987 | 0000 | 17.2 | 167.2 | 950 |
| 07/02/1987 | 0600 | 17.9 | 167.9 | 950 |
| 07/02/1987 | 1200 | 18.5 | 168.5 | 950 |
| 07/02/1987 | 1800 | 19.5 | 169.6 | 980 |
| 08/02/1987 | 0000 | 20.9 | 171.6 | 980 |
| 08/02/1987 | 0600 | 21.4 | 172.9 | 990 |
| 08/02/1987 | 1200 | 21.5 | 174.0 | 990 |

Table VIII gives the damage levels across the four building classes and in total in percentage and absolute dollar terms. The total estimate for the buildings included in the study, $A114.5 Million compares with the total estimated damage [6].

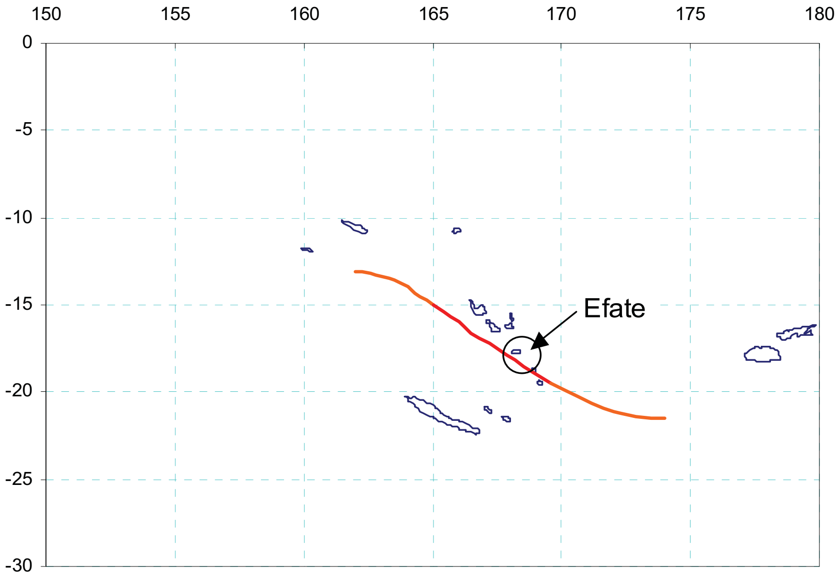

Figure (xx) - Track of Tropical cyclone 'Uma'.

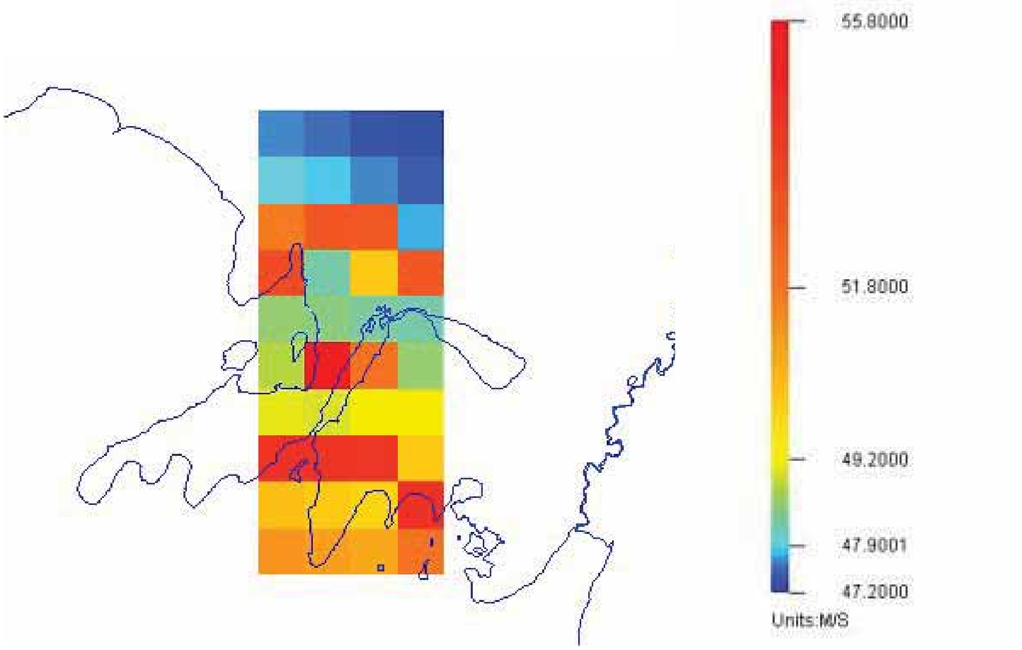

Figure (xxi) - Spatial variation of peak wind gust speed - Tropical Cyclone 'Uma'

Table VIII. Model damage estimates for Efate – TC 'Uma'.

| Building Class | Damage (%) | Damage ($A Million) |
|---|---|---|
| Class A | 8.1 | 5.7 |
| Class B | 13.4 | 63.6 |
| Class C | 23.9 | 41.5 |
| Class D | 70.6 | 3.6 |
| All | 15.8 | 114.9 |

The model was also tested against Tropical Cyclone 'Prema' which passed close to Efate in 1993. This storm was more intense than 'Uma' but appears to have been a much smaller cyclone, with a relatively small radius of maximum wind. The model predicts damage of the order of five per cent, but there was little observational (wind) data so that modelling the storm itself was somewhat problematic.

# 4 Results

## 4.1 Damage Frequency

The modelling system described in the previous sections was run for storms equivalent to 5000 years.

The results for each storm expressed in terms of both absolute dollars and percentage of total value were aggregated in terms of return periods. It should be noted that these results are subject to the accuracy of the estimates made for floor areas and relative replacement values.

Table IX gives the overall results for the Efate building data set included in the study. The model was re-run to measure the impact of upgrading Class B and Class C buildings with the results also shown in Table IX for comparison.

Table IX. Overall Efate damage estimates for current state of building assets and for upgraded assets (see Section 4.2).

| Recurrence Interval (Years) | Damage (%) Current | Damage (%) Upgraded |
|---|---|---|
| 10 | < 0.1 | < 0.1 |
| 25 | 1.1 | 0.7 |
| 50 | 8.2 | 5.9 |
| 100 | 28.5 | 21.6 |
| 1000 | 81.8 | 72.5 |

Damage levels were also computed for each of the topographic 42 wind zones described in Section 3.4.

Damage levels are shown for each building class for recurrence intervals of 50, 100, 450 and 1000 years in Table X(a) and (b). The relative differences between the cells largely reflect the topographic/terrain differences between locations.

The model was also used to estimate the frequency (recurrence interval) of levels of damage (expressed as percentage of buildings damaged to for that damage level). The results are shown for each building class in Tables XI to XIV respectively.

For example, Table XI shows that for Class A buildings, 10 per cent of buildings would be damaged to a level of 50% once every 455 years. In contrast, for Class C buildings, 10 per cent of buildings are predicted to suffer 50 per cent damage every 43 years.

Table X(a). Damage rates by building class and sub-region for Port Vila and Efate.

| **Ref** | **50 Year** | | | | **100 Year** | | | |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | A | B | C | D |
| **A1** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **A2** | 9.6 | 16.6 | 29.2 | 77.3 | 20.0 | 33.2 | 53.5 | 96.3 |
| **A3** | 11.6 | 20.0 | 34.6 | 83.9 | 22.4 | 36.7 | 58.1 | 97.6 |
| **A4** | 14.7 | 25.0 | 42.1 | 0.0 | 27.3 | 43.9 | 66.6 | 0.0 |
| **A5** | 17.2 | 28.9 | 47.7 | 0.0 | 35.5 | 54.8 | 77.8 | 0.0 |
| **A6** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **A7** | 9.8 | 17.0 | 29.7 | 78.1 | 20.7 | 34.2 | 54.8 | 96.7 |
| **A8** | 14.1 | 24.1 | 40.7 | 89.4 | 28.1 | 44.9 | 67.7 | 99.2 |
| **A9** | 0.0 | 26.1 | 43.6 | 0.0 | 0.0 | 45.6 | 68.5 | 0.0 |
| **A10** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **B1** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **B2** | 9.7 | 16.8 | 29.5 | 0.0 | 20.1 | 33.4 | 53.7 | 0.0 |
| **B3** | 15.1 | 25.7 | 43.1 | 91.1 | 28.5 | 45.5 | 68.4 | 99.3 |
| **B4** | 16.4 | 27.7 | 46.0 | 92.9 | 30.7 | 48.5 | 71.6 | 99.6 |
| **B5** | 9.5 | 16.6 | 29.1 | 77.2 | 20.5 | 33.9 | 54.5 | 96.6 |
| **B6** | 22.3 | 36.6 | 57.9 | 97.6 | 39.7 | 60.0 | 82.4 | 99.9 |
| **B7** | 0.0 | 24.0 | 40.5 | 89.3 | 0.0 | 43.2 | 65.8 | 99.0 |
| **B8** | 16.4 | 27.6 | 45.8 | 92.8 | 30.4 | 48.1 | 71.2 | 99.5 |
| **B9** | 16.0 | 27.1 | 45.1 | 92.4 | 25.9 | 41.8 | 64.2 | 98.8 |
| **B10** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **C1** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **C2** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **C3** | 17.3 | 29.1 | 47.9 | 93.9 | 31.3 | 49.3 | 72.4 | 99.6 |
| **C4** | 19.9 | 33.0 | 53.2 | 96.2 | 36.3 | 55.7 | 78.7 | 99.9 |
| **C5** | 13.9 | 23.8 | 40.2 | 89.1 | 24.0 | 39.1 | 60.9 | 98.2 |
| **C6** | 20.5 | 34.0 | 54.6 | 96.6 | 35.2 | 54.4 | 77.5 | 99.8 |
| **C7** | 17.4 | 29.2 | 48.0 | 94.0 | 29.7 | 47.2 | 70.2 | 99.5 |
| **C8** | 12.5 | 21.5 | 36.8 | 86.1 | 25.9 | 41.9 | 64.3 | 98.8 |
| **C9** | 0.0 | 17.9 | 0.0 | 0.0 | 0.0 | 33.8 | 0.0 | 0.0 |
| **C10** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D1** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D2** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D3** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D4** | 0.0 | 18.9 | 32.8 | 0.0 | 0.0 | 37.3 | 58.8 | 0.0 |
| **D5** | 0.0 | 23.0 | 39.1 | 0.0 | 0.0 | 40.1 | 62.2 | 0.0 |
| **D6** | 13.9 | 23.8 | 40.3 | 89.1 | 26.0 | 41.9 | 64.4 | 98.8 |
| **D7** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D8** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D9** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D10** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **E1** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **F2** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Table X(b). Damage rates by building class and sub-region for port Vila and Efate.

| **Ref.** | **450 Year** | | | | **1000 Year** | | | |
|---|---|---|---|---|---|---|---|---|
| | **A** | **B** | **C** | **D** | **A** | **B** | **C** | **D** |
| **A1** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **A2** | 45.1 | 66.2 | 87.2 | 100.0 | 47.5 | 68.8 | 89.0 | 100.0 |
| **A3** | 46.9 | 68.2 | 88.6 | 100.0 | 52.7 | 74.2 | 92.3 | 100.0 |
| **A4** | 52.5 | 74.0 | 92.2 | 0.0 | 63.6 | 83.9 | 96.9 | 0.0 |
| **A5** | 69.9 | 88.6 | 98.4 | 0.0 | 73.3 | 90.8 | 98.9 | 0.0 |
| **A6** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **A7** | 43.0 | 63.8 | 85.4 | 100.0 | 48.3 | 69.6 | 89.6 | 100.0 |
| **A8** | 56.2 | 77.5 | 94.1 | 100.0 | 64.1 | 84.3 | 97.0 | 100.0 |
| **A9** | 0.0 | 83.8 | 96.8 | 0.0 | 0.0 | 89.9 | 98.7 | 0.0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **A10** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **B1** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **B2** | 45.3 | 66.5 | 87.4 | 0.0 | 47.5 | 68.8 | 89.0 | 0.0 |
| **B3** | 64.9 | 85.0 | 97.3 | 100.0 | 69.0 | 88.0 | 98.2 | 100.0 |
| **B4** | 67.0 | 86.5 | 97.8 | 100.0 | 74.6 | 91.6 | 99.1 | 100.0 |
| **B5** | 43.5 | 64.4 | 85.9 | 100.0 | 48.0 | 69.3 | 89.4 | 100.0 |
| **B6** | 73.4 | 90.9 | 98.9 | 100.0 | 80.5 | 94.8 | 99.6 | 100.0 |
| **B7** | 0.0 | 83.7 | 96.8 | 100.0 | 0.0 | 89.3 | 98.6 | 100.0 |
| **B8** | 64.0 | 84.2 | 97.0 | 100.0 | 67.9 | 87.2 | 98.0 | 100.0 |
| **B9** | 63.9 | 84.1 | 97.0 | 100.0 | 71.1 | 89.4 | 98.6 | 100.0 |
| **B10** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **C1** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **C2** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **C3** | 68.0 | 87.3 | 98.0 | 100.0 | 71.6 | 89.7 | 98.7 | 100.0 |
| **C4** | 71.0 | 89.3 | 98.6 | 100.0 | 76.9 | 93.0 | 99.3 | 100.0 |
| **C5** | 53.4 | 74.8 | 92.7 | 100.0 | 63.9 | 84.1 | 97.0 | 100.0 |
| **C6** | 70.7 | 89.2 | 98.5 | 100.0 | 78.3 | 93.7 | 99.5 | 100.0 |
| **C7** | 67.6 | 87.0 | 97.9 | 100.0 | 71.9 | 90.0 | 98.7 | 100.0 |
| **C8** | 53.0 | 74.4 | 92.5 | 100.0 | 60.2 | 81.1 | 95.8 | 100.0 |
| **C9** | 0.0 | 60.4 | 0.0 | 0.0 | 0.0 | 70.1 | 0.0 | 0.0 |
| **C10** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D1** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D2** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D3** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D4** | 0.0 | 64.4 | 85.9 | 0.0 | 0.0 | 69.1 | 89.2 | 0.0 |
| **D5** | 0.0 | 84.3 | 97.0 | 0.0 | 0.0 | 87.9 | 98.2 | 0.0 |
| **D6** | 64.0 | 84.2 | 97.0 | 100.0 | 69.2 | 88.2 | 98.3 | 100.0 |
| **D7** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D8** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D9** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **D10** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **E1** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **F2** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Table XI. Recurrence intervals (years) for percentage of Class A buildings damaged to a given level.

| Level of Damage | Percentage of buildings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% |
| 10% | 60 | 65 | 66 | 67 | 69 | 70 | 83 | 93 | 111 |
| 20% | 91 | 94 | 104 | 111 | 114 | 122 | 167 | 227 | 294 |
| 30% | 139 | 147 | 152 | 185 | 185 | 227 | 417 | 455 | 556 |
| 40% | 208 | 238 | 278 | 313 | 333 | 333 | 714 | 714 | 1250 |
| 50% | 455 | 455 | 556 | 556 | 556 | 625 | 1667 | 5000 | |
| 60% | 625 | 625 | 714 | 714 | 714 | 714 | | | |
| 70% | 1000 | 1667 | 5000 | 5000 | 5000 | 5000 | | | |
| 80% | | | | | | | | | |
| 90% | | | | | | | | | |

Table XII. Recurrence intervals (years) for percentage of Class B buildings damaged to a given level.

| Level of Damage | Percentage of buildings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% |
| 10% | 20 | 20 | 23 | 24 | 24 | 25 | 28 | 33 | 35 |
| 20% | 31 | 32 | 37 | 38 | 40 | 40 | 46 | 57 | 65 |
| 30% | 44 | 44 | 52 | 56 | 57 | 60 | 67 | 85 | 100 |
| 40% | 59 | 62 | 76 | 80 | 80 | 92 | 107 | 141 | 161 |
| 50% | 88 | 92 | 110 | 118 | 122 | 122 | 141 | 196 | 265 |
| 60% | 113 | 125 | 136 | 150 | 155 | 167 | 225 | 321 | 375 |
| 70% | 173 | 173 | 196 | 214 | 214 | 237 | 300 | 900 | 1500 |
| 80% | 237 | 250 | 346 | 346 | 375 | 409 | 450 | 2250 | 0 |
| 90% | 643 | 643 | 900 | 1125 | 1125 | 4500 | 0 | 0 | 0 |

Table XIII. Recurrence intervals (years) for percentage of Class C buildings damaged to a given level.

| Level of Damage | Percentage of buildings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% |
| 10% | 14 | 15 | 15 | 16 | 17 | 17 | 18 | 21 | 23 |
| 20% | 21 | 23 | 24 | 25 | 26 | 26 | 28 | 33 | 39 |
| 30% | 28 | 30 | 31 | 32 | 33 | 34 | 38 | 47 | 58 |
| 40% | 33 | 39 | 40 | 42 | 43 | 44 | 48 | 60 | 80 |
| 50% | 43 | 50 | 52 | 54 | 57 | 60 | 62 | 79 | 100 |
| 60% | 56 | 64 | 65 | 70 | 73 | 80 | 96 | 115 | 167 |
| 70% | 73 | 83 | 94 | 100 | 110 | 113 | 132 | 150 | 281 |
| 80% | 96 | 115 | 118 | 132 | 136 | 145 | 173 | 265 | 375 |
| 90% | 173 | 205 | 205 | 205 | 214 | 237 | 300 | 500 | 4500 |

Table XIV. Recurrence intervals (years) for percentage of Class D buildings damaged to a given level.

| Level of Damage | Percentage of buildings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% |
| 10% | 8 | 8 | 9 | 9 | 9 | 10 | 10 | 11 | 11 |
| 20% | 11 | 11 | 12 | 12 | 12 | 13 | 13 | 14 | 16 |
| 30% | 13 | 13 | 14 | 14 | 15 | 15 | 16 | 18 | 19 |
| 40% | 15 | 15 | 16 | 17 | 18 | 19 | 20 | 22 | 24 |
| 50% | 18 | 18 | 19 | 20 | 21 | 23 | 23 | 26 | 29 |
| 60% | 20 | 21 | 23 | 24 | 25 | 27 | 28 | 34 | 37 |
| 70% | 24 | 25 | 27 | 27 | 28 | 31 | 33 | 38 | 43 |
| 80% | 28 | 28 | 32 | 34 | 35 | 38 | 42 | 51 | 57 |
| 90% | 35 | 37 | 42 | 45 | 48 | 50 | 52 | 65 | 78 |

As for Table XI (Class A) but for ‘upgraded’ buildings.

| Level of Damage | Percentage of buildings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% |
| 10% | 28 | 28 | 30 | 32 | 34 | 35 | 42 | 47 | 57 |
| 20% | 47 | 47 | 51 | 59 | 62 | 67 | 83 | 100 | 107 |
| 30% | 78 | 83 | 92 | 107 | 110 | 115 | 167 | 196 | 250 |
| 40% | 113 | 125 | 125 | 141 | 145 | 167 | 265 | 346 | 375 |
| 50% | 173 | 173 | 180 | 214 | 225 | 250 | 750 | 900 | 4500 |
| 60% | 250 | 250 | 265 | 375 | 375 | 409 | 1125 | 4500 | |
| 70% | 409 | 500 | 500 | 900 | 1125 | 1500 | 4500 | | |
| 80% | 1500 | 1500 | 2250 | 4500 | 4500 | 4500 | | | |
| 90% | 4500 | 4500 | 4500 | | | | | | |

As for Table XII (Class B) but for ‘upgraded’ buildings

| Level of Damage | Percentage of buildings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% |
| 10% | 23 | 24 | 26 | 27 | 28 | 29 | 34 | 37 | 42 |
| 20% | 39 | 39 | 45 | 48 | 49 | 51 | 58 | 74 | 87 |
| 30% | 54 | 58 | 70 | 74 | 75 | 82 | 102 | 132 | 145 |
| 40% | 88 | 92 | 110 | 118 | 122 | 122 | 141 | 196 | 265 |
| 50% | 115 | 125 | 145 | 150 | 167 | 173 | 237 | 321 | 450 |
| 60% | 173 | 173 | 205 | 214 | 214 | 265 | 321 | 900 | 4500 |
| 70% | 237 | 250 | 375 | 375 | 409 | 409 | 500 | 2250 | |
| 80% | 409 | 450 | 750 | 1125 | 1125 | 1500 | 4500 | | |
| 90% | 4500 | 4500 | 4500 | 4500 | 4500 | 4500 | | | |

As for Table XIII (Class C) but for ‘upgraded’ buildings.

| Level of Damage | Percentage of buildings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% |
| 10% | 19 | 21 | 22 | 23 | 24 | 25 | 27 | 31 | 36 |
| 20% | 31 | 35 | 36 | 38 | 38 | 39 | 45 | 54 | 68 |
| 30% | 42 | 49 | 51 | 53 | 56 | 59 | 62 | 76 | 100 |
| 40% | 59 | 69 | 69 | 76 | 82 | 85 | 105 | 118 | 188 |
| 50% | 83 | 98 | 102 | 113 | 122 | 122 | 136 | 173 | 281 |
| 60% | 105 | 132 | 141 | 155 | 155 | 155 | 196 | 281 | 500 |
| 70% | 173 | 196 | 205 | 205 | 214 | 237 | 300 | 450 | 4500 |
| 80% | 237 | 321 | 346 | 375 | 375 | 375 | 409 | 900 | |
| 90% | 563 | 900 | 1125 | 1125 | 1500 | 2250 | | | |

As for Table XIV (Class D) but for ‘upgraded’ buildings.

| Level of Damage | Percentage of buildings | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% |
| 10% | 14 | 15 | 15 | 17 | 17 | 18 | 18 | 21 | 22 |
| 20% | 21 | 22 | 24 | 25 | 26 | 27 | 29 | 35 | 38 |
| 30% | 28 | 28 | 30 | 32 | 34 | 37 | 39 | 47 | 55 |
| 40% | 33 | 34 | 40 | 42 | 43 | 46 | 49 | 63 | 73 |
| 50% | 44 | 44 | 49 | 55 | 59 | 61 | 66 | 83 | 100 |
| 60% | 54 | 57 | 65 | 71 | 76 | 87 | 100 | 115 | 141 |
| 70% | 74 | 75 | 92 | 110 | 115 | 122 | 132 | 188 | 250 |
| 80% | 102 | 102 | 122 | 132 | 136 | 161 | 180 | 281 | 321 |
| 90% | 167 | 173 | 214 | 214 | 237 | 281 | 300 | 900 | 1500 |

## 4.2 Scenario Modelling

Scenario modelling was undertaken to assess the cumulative economic impact of wind storm loss over time

The results of some specific scenarios are included in the current section, but the model is available for users to examine the effects of any combination of variables.

Table XIV summaries the model settings and results for the three cases chosen.

Table XIV. Summary of economic scenarios.

| Scenario | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Premium (%) | 0.5 | 1.0 | 1.5 | 1.0 | 1.0 |
| InvRet (%) | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| CapCost (%) | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Upgrade | No | No | No | Yes | Yes |
| Upgrade Cost (%) | | | | 0.0 | 10.0 |
| Mean ($Billion) | -0.82 | -0.48 | 4.60 | 0.36 | -0.05 |
| Std Dev ($Billion) | 1.38 | 2.77 | 4.53 | 3.09 | 1.76 |
| Median ($Billion) | -0.86 | -0.75 | 4.98 | -0.36 | -0.48 |
| Probability of break-even or better (%) | 0.20 | 0.30 | 0.75 | 0.42 | 0.36 |

The premium is the annual percentage of asset value. For these cases rate of investment return (applicable if the insurance pool value is greater that zero and the cost of capital (applicable where equivalent borrowings were required for asset/contents replacement) were set at the same rate (an arbitrary 4 per cent).

Upgrade refers to scenarios in which an upgrade in building readiness was applied. This was based on upgrading all B Class buildings to a vulnerability half way between Class A and Class B, All C Class buildings to B Class and all D class to C Class. No change was made to A Class.

The approach for quantifying the effects of building upgrades adopted in this study are quite rudimentary. It is intended that a more detailed assessment of the cost of upgrading buildings and the efficacy of such upgrading will be made in future wind storm work carried out for the region.

Results are based on the state of the pool for one hundred 100-year periods. Figure (XIX) shows the state of the pool for each sample period for Scenario 1. This shows a wide range of potential outcomes – the compounding nature of premiums versus borrowings is heavily dependent on how far into the period the first major loss occurs – where it is 'early' the cost of capital is such that the premium can never catch up. The mean over all samples was for a cumulative loss of $0.82 Billion and the probability of break-even or better (positive pool) was 20 per cent; in order to achieve even a seventy-five per cent break-even or better result, the premium had to be set to around 1.5 per cent).

The impact of so-called retro-fitting (structural improvement) and/or replacement of existing buildings is shown in Scenarios 4 and 5 which can be compared with the results of Scenario 2 (each based on a one per cent premium). In this case the vulnerability curves were adjusted from the current settings for each class as described above. The results (Scenario 4) show that that for otherwise equivalent settings, upgrading the buildings increases the break-even probability from 30 to 40 per cent and makes a mean 'saving' of 840 million dollars (-480 million to plus 360 million).

Scenario 4 did not however, include the cost of upgrading the buildings. Scenario 5 was a re-run of Scenario 4 but with a starting debt set to 10 per cent – an estimate for the cost of upgrading the buildings (this equates to a cost of around $70 Million). When compared with Scenario 1 the direct dollar benefit is reduced by about half but still points to the value in such an investment. Moreover, this comparison does not include the likely savings in injury and loss of life or benefits such as reductions in business interruption.

The scenarios shown here may be significantly refined based on better estimates of cost of building upgrades and a refinement of the damage curves.

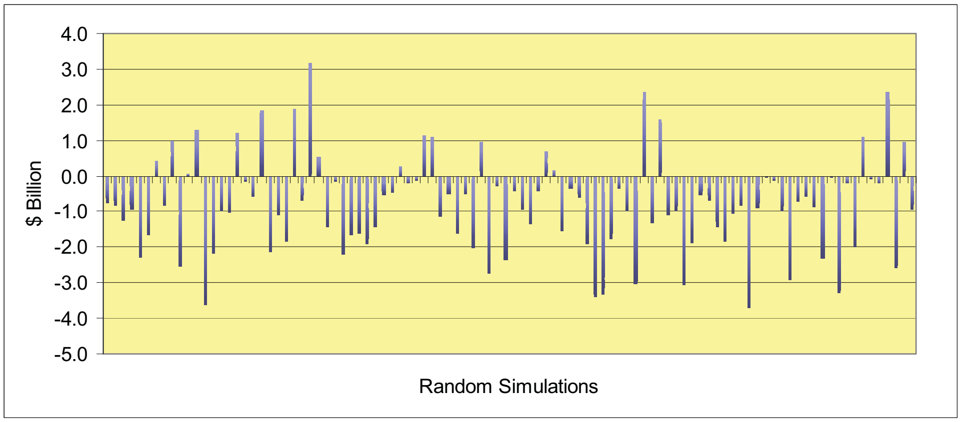

Figure (xxi) - Random event (sequence of 100 year period simulations) results for Scenario 1.

## 4.3 Conclusions

The results of this study have shown how modelling tools can be used to assess the potential long term impacts of cyclone wind storm. These tools may be further refined as more information becomes available and they are tested against detailed actual events.

The modelling techniques have the capacity to be extended to other locations throughout the region; the results could then be integrated to develop a detailed risk assessment for the region as a whole.

Because of the probabilistic nature of storm loss, it is clearly not possible to predict actual losses. However, by applying such tools appropriately, long term financial and social planning processes can be significantly enhanced.

# 5 References

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# 6 Appendix A – Wind Multiplier Tables

Table 1. Topographic Multipliers - Port Vila 2-second gust at site within square (4m height) / 2-second gust without topographic effects.

| Square | North | East | South | West |
|---|---|---|---|---|
| A1 | 1.00 | 1.00 | 1.00 | 1.00 |
| A2 | 1.00 | 1.00 | 1.00 | 1.00 |
| A3 | 1.05 | 1.00 | 1.00 | 1.05 |
| A4 | 1.10 | 1.00 | 1.00 | 1.10 |
| A5 | 1.00 | 1.10 | 1.10 | 1.10 |
| A6 | 1.00 | 1.00 | 1.00 | 1.00 |
| A7 | 1.00 | 1.00 | 1.00 | 1.00 |
| A8 | 1.10 | 1.00 | 1.00 | 1.10 |
| A9 | 1.00 | 1.00 | 1.10 | 1.05 |
| A10 | 1.00 | 1.00 | 1.00 | 1.00 |
| B1 | 1.00 | 1.00 | 1.00 | 1.00 |
| B2 | 1.00 | 1.00 | 1.00 | 1.00 |
| B3 | 1.10 | 1.10 | 1.00 | 0.90 |
| B4 | 1.00 | 1.10 | 1.05 | 1.10 |
| B5 | 1.00 | 1.00 | 1.00 | 1.00 |
| B6 | 1.15 | 1.10 | 1.10 | 1.15 |
| B7 | 1.00 | 1.00 | 1.10 | 1.00 |
| B8 | 1.10 | 1.10 | 1.05 | 0.90 |
| B9 | 1.00 | 1.10 | 1.10 | 0.90 |
| B10 | 1.00 | 1.00 | 1.00 | 1.00 |
| C1 | 1.00 | 1.00 | 1.00 | 1.00 |
| C2 | 1.00 | 1.00 | 1.00 | 1.00 |
| C3 | 1.10 | 1.10 | 1.00 | 1.10 |
| C4 | 1.00 | 1.10 | 1.05 | 1.15 |
| C5 | 1.00 | 1.00 | 1.00 | 1.10 |
| C6 | 1.00 | 1.10 | 1.00 | 1.15 |
| C7 | 1.00 | 1.10 | 1.00 | 1.10 |
| C8 | 1.10 | 1.00 | 1.05 | 0.90 |
| C9 | 1.00 | 1.00 | 1.00 | 1.00 |
| C10 | 1.00 | 1.00 | 1.00 | 1.00 |
| D1 | 1.00 | 1.00 | 1.00 | 1.00 |
| D2 | 1.00 | 1.00 | 1.00 | 1.00 |
| D3 | 1.00 | 1.00 | 1.00 | 0.90 |
| D4 | 1.10 | 1.00 | 1.00 | 1.00 |
| D5 | 1.00 | 1.00 | 1.10 | 1.00 |
| D6 | 1.00 | 1.10 | 1.00 | 1.00 |
| D7 | 1.00 | 1.00 | 1.00 | 1.10 |
| D8 | 1.00 | 1.00 | 1.00 | 1.10 |
| D9 | 1.10 | 1.05 | 1.00 | 1.10 |
| D10 | 1.00 | 1.10 | 1.05 | 1.10 |

Table 2. Rougness Multipliers - Port Vila 2-second gust at site within square (4m height) / 2-second gust at airport (10 m height).

| Square | North | East | South | West |
|---|---|---|---|---|
| A1 | 0.93 | 0.93 | 0.93 | 0.93 |
| A2 | 0.93 | 0.93 | 0.93 | 0.93 |
| A3 | 0.93 | 0.93 | 0.93 | 0.93 |
| A4 | 0.93 | 0.93 | 0.93 | 0.93 |
| A5 | 0.93 | 0.93 | 0.93 | 0.93 |
| A6 | 0.93 | 0.93 | 0.93 | 0.93 |
| A7 | 0.93 | 0.93 | 0.93 | 0.93 |
| A8 | 0.93 | 0.93 | 0.93 | 0.93 |
| A9 | 0.93 | 0.93 | 0.93 | 0.93 |
| A10 | 0.93 | 0.93 | 0.93 | 0.93 |
| B1 | 0.93 | 0.93 | 0.93 | 0.93 |
| B2 | 0.93 | 0.93 | 0.90 | 0.93 |
| B3 | 0.93 | 0.93 | 0.90 | 0.86 |
| B4 | 0.93 | 0.93 | 0.93 | 0.86 |
| B5 | 0.93 | 0.93 | 0.93 | 0.84 |
| B6 | 0.93 | 0.93 | 0.93 | 0.86 |
| B7 | 0.93 | 0.93 | 0.93 | 0.90 |
| B8 | 0.93 | 0.93 | 0.93 | 0.90 |
| B9 | 0.93 | 0.93 | 0.93 | 0.93 |
| B10 | 0.93 | 0.93 | 0.93 | 0.93 |
| C1 | 0.93 | 0.93 | 0.90 | 0.93 |
| C2 | 0.93 | 0.93 | 0.85 | 0.93 |
| C3 | 0.90 | 0.90 | 0.81 | 0.90 |
| C4 | 0.86 | 0.90 | 0.815 | 0.90 |
| C5 | 0.84 | 0.90 | 0.82 | 0.90 |
| C6 | 0.82 | 0.90 | 0.84 | 0.90 |
| C7 | 0.815 | 0.90 | 0.86 | 0.90 |
| C8 | 0.81 | 0.90 | 0.90 | 0.90 |
| C9 | 0.85 | 0.93 | 0.93 | 0.93 |
| C10 | 0.90 | 0.93 | 0.93 | 0.93 |
| D1 | 0.93 | 0.93 | 0.93 | 0.93 |
| D2 | 0.93 | 0.93 | 0.93 | 0.93 |
| D3 | 0.93 | 0.93 | 0.93 | 0.86 |
| D4 | 0.93 | 0.93 | 0.93 | 0.86 |
| D5 | 0.93 | 0.93 | 0.93 | 0.86 |
| D6 | 0.93 | 0.93 | 0.93 | 0.88 |
| D7 | 0.93 | 0.93 | 0.93 | 0.90 |
| D8 | 0.93 | 0.93 | 0.93 | 0.93 |
| D9 | 0.93 | 0.93 | 0.93 | 0.93 |
| D10 | 0.93 | 0.93 | 0.93 | 0.93 |

Table 3 Topographic & Roughness Multipliers - Port Vila 2-second gust at site within square (4m height) / 2-second gust at airport (10 metres).

| Square | North | East | South | West |
|---|---|---|---|---|
| A1 | 0.93 | 0.93 | 0.93 | 0.93 |
| A2 | 0.93 | 0.93 | 0.93 | 0.93 |
| A3 | 0.97 | 0.93 | 0.93 | 0.97 |
| A4 | 1.02 | 0.93 | 0.93 | 1.02 |
| A5 | 0.93 | 1.02 | 1.02 | 1.02 |
| A6 | 0.93 | 0.93 | 0.93 | 0.93 |
| A7 | 0.93 | 0.93 | 0.93 | 0.93 |
| A8 | 1.02 | 0.93 | 0.93 | 1.02 |
| A9 | 0.93 | 0.93 | 1.02 | 0.97 |
| A10 | 0.93 | 0.93 | 0.93 | 0.93 |
| B1 | 0.93 | 0.93 | 0.93 | 0.93 |
| B2 | 0.93 | 0.93 | 0.90 | 0.93 |
| B3 | 1.02 | 1.02 | 0.90 | 0.77 |
| B4 | 0.93 | 1.02 | 0.97 | 0.95 |
| B5 | 0.93 | 0.93 | 0.93 | 0.84 |
| B6 | 1.06 | 1.02 | 1.02 | 0.99 |
| B7 | 0.93 | 0.93 | 1.02 | 0.90 |
| B8 | 1.02 | 1.02 | 0.97 | 0.81 |
| B9 | 0.93 | 1.02 | 1.02 | 0.83 |
| B10 | 0.93 | 0.93 | 0.93 | 0.93 |
| C1 | 0.93 | 0.93 | 0.90 | 0.93 |
| C2 | 0.93 | 0.93 | 0.85 | 0.93 |
| C3 | 0.99 | 0.99 | 0.81 | 0.99 |
| C4 | 0.86 | 0.99 | 0.86 | 1.04 |
| C5 | 0.84 | 0.90 | 0.82 | 0.99 |
| C6 | 0.82 | 0.99 | 0.84 | 1.04 |
| C7 | 0.82 | 0.99 | 0.86 | 0.99 |
| C8 | 0.89 | 0.90 | 0.95 | 0.81 |
| C9 | 0.85 | 0.93 | 0.93 | 0.93 |
| C10 | 0.90 | 0.93 | 0.93 | 0.93 |
| D1 | 0.93 | 0.93 | 0.93 | 0.93 |
| D2 | 0.93 | 0.93 | 0.93 | 0.93 |
| D3 | 0.93 | 0.93 | 0.93 | 0.77 |
| D4 | 1.02 | 0.93 | 0.93 | 0.86 |
| D5 | 0.93 | 0.93 | 1.02 | 0.86 |
| D6 | 0.93 | 1.02 | 0.93 | 0.88 |
| D7 | 0.93 | 0.93 | 0.93 | 0.99 |
| D8 | 0.93 | 0.93 | 0.93 | 1.02 |
| D9 | 1.02 | 0.97 | 0.93 | 1.02 |
| D10 | 0.93 | 1.02 | 0.97 | 1.02 |

Table 4 Topographic and Roughness Multipliers - Port Vila 2-second gust at site within square (4m height) / 10-minute mean at gradient height.

| Square | North | East | South | West |
|---|---|---|---|---|
| A1 | 0.98 | 0.98 | 0.98 | 0.98 |
| A2 | 0.98 | 0.98 | 0.98 | 0.98 |
| A3 | 1.03 | 0.98 | 0.98 | 1.03 |
| A4 | 1.07 | 0.98 | 0.98 | 1.07 |
| A5 | 0.98 | 1.07 | 1.07 | 1.07 |
| A6 | 0.98 | 0.98 | 0.98 | 0.98 |
| A7 | 0.98 | 0.98 | 0.98 | 0.98 |
| A8 | 1.07 | 0.98 | 0.98 | 1.07 |
| A9 | 0.98 | 0.98 | 1.07 | 1.03 |
| A10 | 0.98 | 0.98 | 0.98 | 0.98 |
| B1 | 0.98 | 0.98 | 0.98 | 0.98 |
| B2 | 0.98 | 0.98 | 0.95 | 0.98 |
| B3 | 1.07 | 1.07 | 0.95 | 0.82 |
| B4 | 0.98 | 1.07 | 1.03 | 1.00 |
| B5 | 0.98 | 0.98 | 0.98 | 0.89 |
| B6 | 1.12 | 1.07 | 1.07 | 1.04 |
| B7 | 0.98 | 0.98 | 1.07 | 0.95 |
| B8 | 1.07 | 1.07 | 1.03 | 0.86 |
| B9 | 0.98 | 1.07 | 1.07 | 0.88 |
| B10 | 0.98 | 0.98 | 0.98 | 0.98 |
| C1 | 0.98 | 0.98 | 0.95 | 0.98 |
| C2 | 0.98 | 0.98 | 0.90 | 0.98 |
| C3 | 1.05 | 1.05 | 0.86 | 1.05 |
| C4 | 0.91 | 1.05 | 0.90 | 1.09 |
| C5 | 0.89 | 0.95 | 0.87 | 1.05 |
| C6 | 0.87 | 1.05 | 0.89 | 1.09 |
| C7 | 0.86 | 1.05 | 0.91 | 1.05 |
| C8 | 0.94 | 0.95 | 1.00 | 0.86 |
| C9 | 0.90 | 0.98 | 0.98 | 0.98 |
| C10 | 0.95 | 0.98 | 0.98 | 0.98 |
| D1 | 0.98 | 0.98 | 0.98 | 0.98 |
| D2 | 0.98 | 0.98 | 0.98 | 0.98 |
| D3 | 0.98 | 0.98 | 0.98 | 0.82 |
| D4 | 1.07 | 0.98 | 0.98 | 0.91 |
| D5 | 0.98 | 0.98 | 1.07 | 0.91 |
| D6 | 0.98 | 1.07 | 0.98 | 0.93 |
| D7 | 0.98 | 0.98 | 0.98 | 1.05 |
| D8 | 0.98 | 0.98 | 0.98 | 1.07 |
| D9 | 1.07 | 1.03 | 0.98 | 1.07 |
| D10 | 0.98 | 1.07 | 1.03 | 1.07 |

# Appendix 3b

# Disaster Risk Management in Marginal Communities of Port Vila, Vanuatu: Extreme Wave Risk

*by*

**Stephen Oliver**

Global Environmental Modelling Systems Pty Ltd, Melbourne, Australia

**SOPAC JOINT CONTRIBUTION REPORT 147**

*December, 2003*

**SOPAC**

# Disaster Risk Management in Marginal Communities of Port Vila, Vanuatu

## Extreme Wave Risk

**June 2003**

Global Environmental Modelling Systems Pty Ltd

PO Box 149 Warrandyte Victoria 3113 AUSTRALIA
Telephone 613 9712 0016 Facsimile 613 9712 0017
E-mail steve.oliver@gems-aus.com

GEMS

GLOBAL ENVIRONMENTAL MODELLING SYSTEMS PTY LTD

www.gems-aus.com

# 1 Introduction

## 1.1 Study Requirements

The current study has the following primary requirements:

- Establish a modelling system for assessing the impact of waves at Port Vila and adjacent locations in Mele Bay, with specific emphasis on Port Vila and the villages of Blacksands and Mele;
- Validate the modelling procedure by modelling the impacts of waves associated with Tropical Cyclone Beni, which occurred in January 2003, at these locations;
- Select a representative extreme wave – storm surge event, model waves in detail for such an event and assess their potential impact at the selected locations, and
- Make comment on the potential risk to Port Vila and Mele Bay communities from extreme wave events associated with tropical cyclones.

## 1.2 Acknowledgements

GEMS gratefully acknowledges the contributions of the following to this study:

Dr Matthew Elliot, Damara WA Pty Ltd, and

Dr Graham Shorten, Environmental & Community Risk International Pty Ltd.

# 2 Study Methodology

## 2.1 Overview

The first task to meet the objectives of this study was to establish and validate appropriate wave models to quantify the impacts of cyclone generated waves in the Mele Bay – Port Vila region. The models applied in the study are described in the next section of this report.

For validation purposes, the study focussed on the impact of Tropical Cyclone Beni which occurred early this year; this storm was selected because it produced unusually large waves in and around Port Vila and there was access to good data for the event. In addition, the track of the storm appears to correspond directly with that expected to produce extreme wave events. This aspect is discussed in more detail in Section 4 of this report. In order to establish how extreme this event was (in terms of waves) relative to overall storm frequency, the intensity of Beni and its track was compared with historical records of storm tracks over a period of thirty years.

Modelling of Tropical Cyclone 'Beni' was undertaken at a high level of detail. This involved firstly modelling the open ocean waves associated with the storm and then the detailed interaction of the waves with the shoreline at locations in Port Vila and near the Mele Bay villages. In particular, quantitative predictions of wave run-up and over-topping at these locations were made by applying a site specific one-dimensional shoreline model (also described in the next section).

Once the modelling system being applied was successfully validated, it was then applied to an extreme design cyclone–sea level event. Ideally, the selection of such an event would be based on applying the model to large range of such events and then selecting an event at a nominated return period. However, this process would involve a very large computational effort unable to met within time resource constraints. Accordingly, a representative event was selected on the basis of a desktop study of potential worst case storm tracks and previous analyses of storm behaviour [1].

This extreme cyclone event was then subjected to the validated modelling process and the results used to assess potential impacts of such extreme events. This included the mapping of risk in at-risk areas in Port Vila and Mele Bay.

Finally, conclusions were drawn on the implications of extreme wave events, for town planning and emergency response, both for the specific locations on which the modelling effort was centred and for other locations in the Port Vila - Mele Bay and the broader Vanuatu region.

# 3 Tropical Cyclone Beni

## 3.1 Description of Storm and Impacts

Tropical Cyclone Beni formed some 240 nautical miles south of the Solomon Islands on 24 January 2003. It initially tracked southwards and then deepened as it turned moves towards the southeast. The cyclone is estimated to have reached its maximum intensity of 920 hPa at or about 0600 UTC on 29 January. Beni's track is shown in Figure 1.

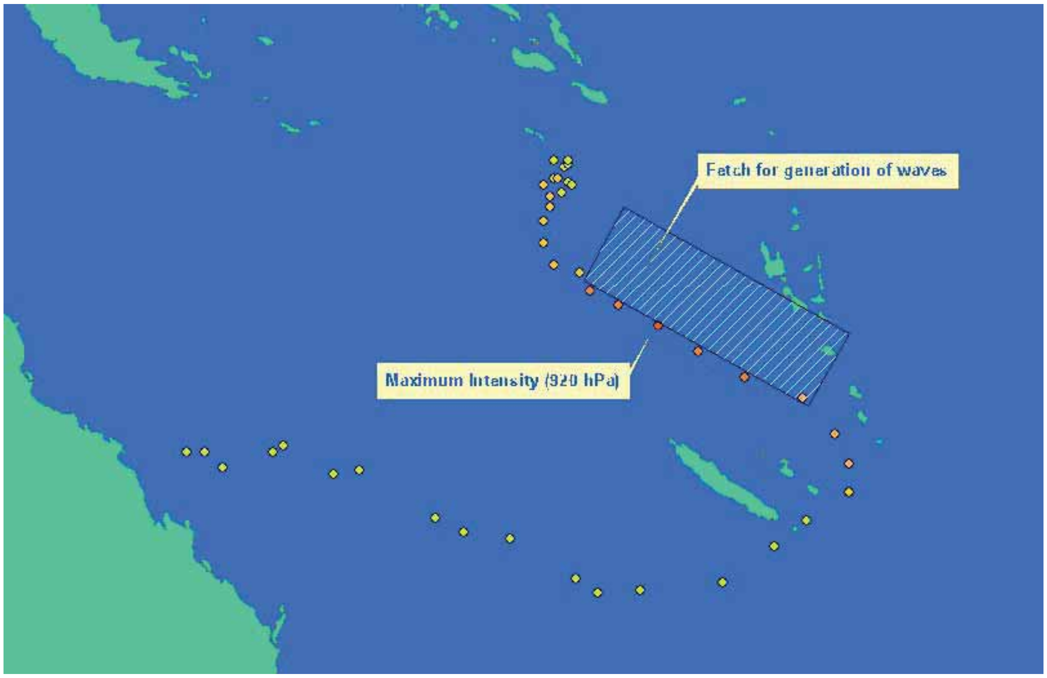


Figure 1: Track of Cyclone Beni

Table 1: Summary of some impacts of TC Beni

| Location ID | Location Description | Impact |
|---|---|---|
| 1 | Foreshore at northern edge of Port Vila township. | Low level inundation with significant coral debris spread over foreshore |
| 2 | Sea wall to south of Hotel Rossi | Over-topping of sea wall |
| 3 | Seawall near Port Vila market | Some over-topping |
| 4 | Blacksands village beach | Erosion of dune/berm and minor inundation over berm |
| 5 | Mele village beach | Minor inundation of foreshore near shoreline buildings |

Figure 2: Locations 1, 2 (Port Vila) and 3 (Blacksands).

Figure 3: Location 4 (Mele)

Beni passed to well to the west of Efate, causing notable inundation of exposed coastlines on 30 January. Reporting of the effects of Beni referred to significant inundation that was consistently described as resulting from a storm surge. Impacts at Port Vila were quite pronounced and some specific instances are summarised in Table 3 and geo-referenced in Figures 2 and 3. Corresponding photographs at affected sites are shown in Figures 4 to 7.

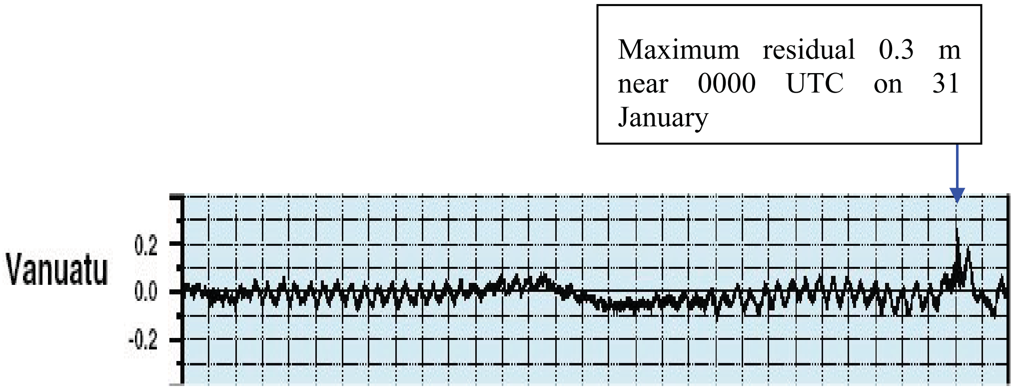
Closer examination of the event shows that any storm surge at Efate, associated with Beni, is likely to have been minimal. The maximum (10 minute mean) winds over Mele Bay are estimated to have peaked at about 50 km/h earlier on 30 January. An examination of records form the tide gauge located at the port, shows that the maximum sea level residual was only of the order 0.3 metres (at or about 0100 UTC on 30 January). Figure 8 shows a time series of residual for the month; these data are sourced from the Australian National Tidal Facility Web site.

Figure 4: Location 1. Debris strewn over the foreshore

Figure 5: Location 2.  Over-topping of the sea wall

Figure 6: Location 3.  Erosion of bank and over-topping

Figure 7: Location 3. Sea water run-up over floor level



Maximum residual 0.3 m near 0000 UTC on 31 January

Figure 8: National Tidal Facility tide gauge residuals for January 2003

Since the maximum steady water sea level in the port was well below Highest Astronomical Tide, it is clear that storm surge was not the major cause of the 'inundation' and it was, in fact wave run-up and overtopping from large storm waves that had the major impact.

This conclusion is supported by an initial examination of Beni's track. This shows that the radius of maximum winds would have been moving steadily south-eastwards with the storm, thereby maintaining extreme winds over waves propagating in the same direction, towards the southern islands of Vanuatu. The region of wave 'fetch' is shown in Figure 1. Some of the wave energy from waves initially generated well to the north-west would have propagated into Mele Bay; these waves would then have been accentuated by waves generated by west to south-westerly winds on the rear flank of the storm as it passed southwards of Efate.

The track of Beni appears to be ideal for maximising storm waves in Mele Bay; a more southerly track would cause the larger waves to propagate more southerly as well, with little chance of the waves entering Mele Bay, due to its orientation. Should the track have been shifted too much further to the east, the maximum winds and associated wave maximum would also shift eastwards and be able to enter Mele Bay. The latter case would be expected to result in much stronger, damaging winds to impact on Port Vila and may result in a larger storm surge effect.

To further investigate TC Beni and the potential for impacts of other (more severe storms) a modelling system was established and run for some specific events. The models and the results of results of the modelling program are described in the following sections.

# 4 Description of Models

## 4.1 Tropical Cyclone Model

The GEMS tropical cyclone model is based on the empirical model developed at the Australian Bureau of Meteorology [2]. The model treats the wind field as an asymmetric vortex.

Wind directions and speed are a function of the storm central pressure and the environmental pressure in which the storm is embedded. The spatial distribution of winds is controlled by the Radius of Maximum Winds (RMW), which defines the distance from the storm centre to the region of strongest winds. Physically, this region of strongest winds is found around the cyclone 'eye-wall'; the eye region is the calm centre of the storm. Typically the radius of maximum winds is of the order of 30-50 km.

Another parameter (the so-called 'B'- parameter) defines the extent to which the strongest winds are concentrated around the eye-wall or otherwise extend outwards from the storm centre. Figure 9 shows some profiles of wind strength as a function of distance from storm centre for arbitrary combinations of central pressure, RMW and the 'B'-parameter.

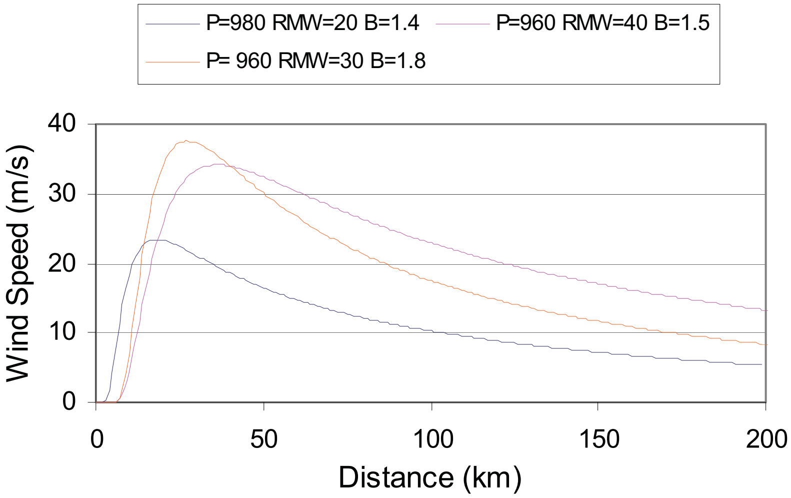


Figure 9: Profiles of cyclone wind speed for different storm parameters

## 4.2 Wave Model : SWAN

In order to model wave processes occurring in the near-shore zone, it is first necessary to establish the evolution of waves over the open ocean. Typically, significant tropical storm winds affect a region up to a few hundred kilometres from the storm centre, and this area changes with the movement of the storm.

Depending on the intensity of the cyclone, the winds in the affected area have the capacity to generate large ocean waves, which in turn propagate away from the generation region. In order to model these processes, it is necessary to establish a wave model over a regular grid, with a sufficiently large spatial extent to capture these processes.

Once these large-scale wind and wave generation processes are captured, the results can then be used to focus on the interaction of the ocean scale waves with coastlines. This latter task involves modelling the wave processes at higher spatial resolutions as the waves intersect shallower water depths.

GEMS has previously used two spectral wave models, WAM and SWAN [3] for tropical cyclone studies. Since WAM is essentially a deep water model, we have preferred to apply the third generation spectral model, SWAN which was originally developed to model near-shore processes. Later versions of SWAN have improved large scale /deep water algorithms and successfully predict tropical cyclone wave behaviour.

SWAN also incorporates a smooth nesting process in which model scales can be effectively "telescoped" from spatially coarse large scale grids to small high resolution grids established over particular areas of interest.

### 4.2.1 Model Grids

The SWAN grids were set-up on three scales. A coarse regional grid (spatial resolution 2km) was established to capture the broad scale wave development. The extent and bathymetry of this grid is shown in Figure 10.

Figure 11 shows the fine grid (resolution 200 m) and the three super-imposed micro grids (resolution 20m) referred to as MB1 (Mele Bay No.1, Mele Bay No.2 and Port Vila Harbour). Figure 12 shows a zoomed view of the three micro grids.

By modelling at higher resolution over the near shore zone, wave – bathymetry interaction processes such refraction and wave breaking are more precisely defined.

The dimensions and geographic locations of the grids are summarized in Table 2.

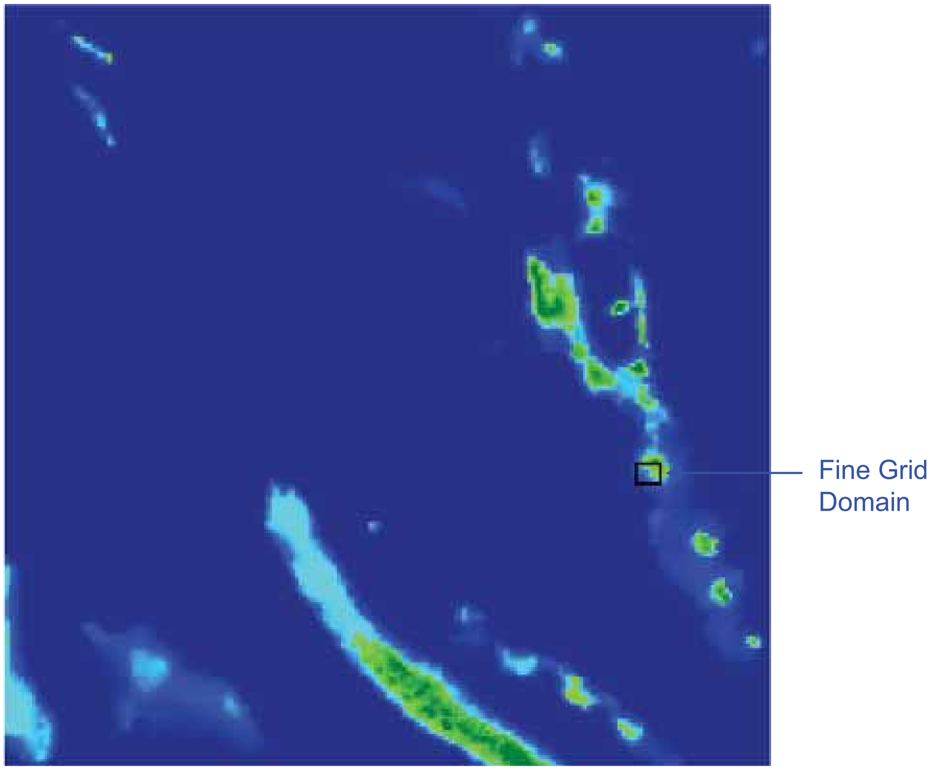


Figure 10: Coarse wave grid

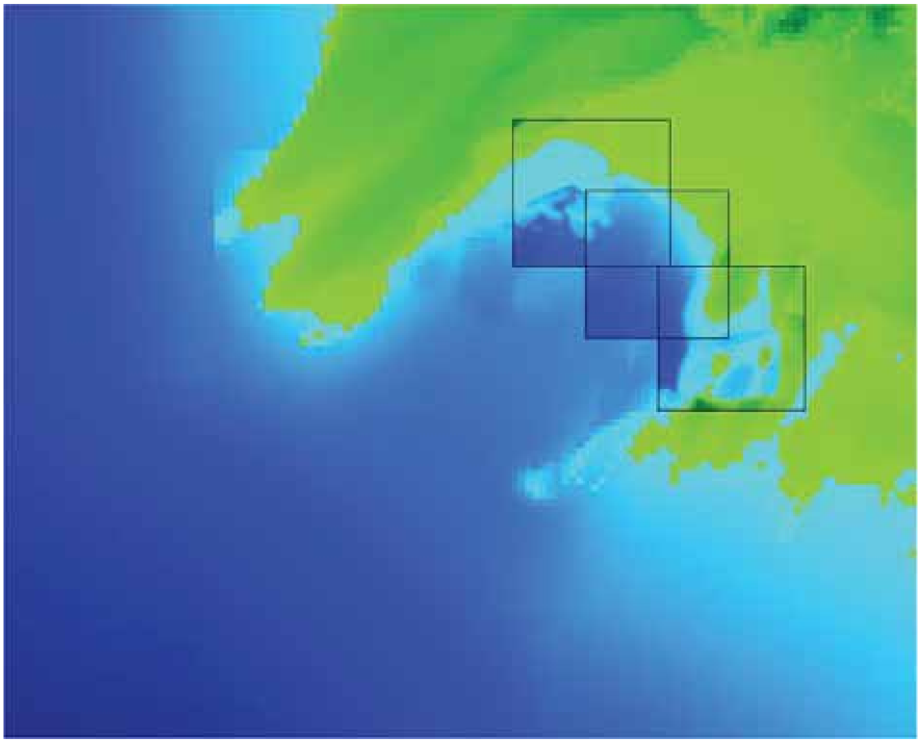


Figure 11: Fine Grid (0.02 degrees)

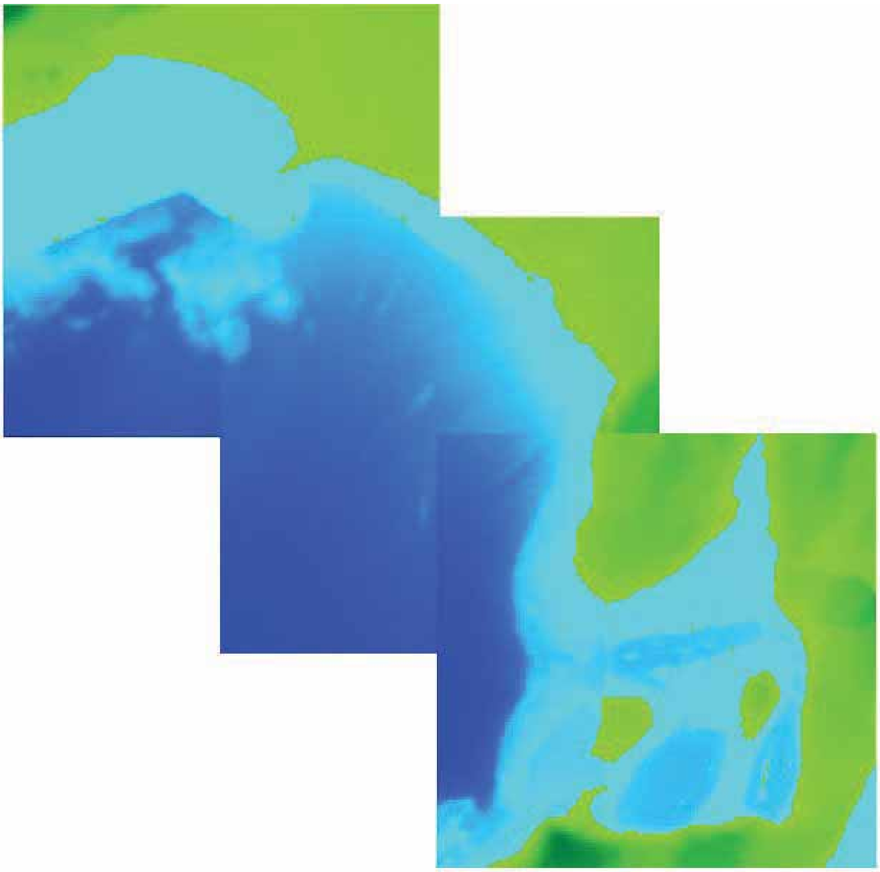


Figure 12: Micro wave grids – MB1, MB2 and PVH

Table 2: SWAN Grid Specifications

| Grid Name | Minimum Latitude | No. x points | Minimum Longitude | No. y points | Res. (deg) |
|---|---|---|---|---|---|
| Coarse | -22.0 | 221 | 159.0 | 221 | 0.05 |
| Fine | -17.85 | 126 | 168.1 | 101 | 0.002 |
| PVH | -17.76 | 201 | 168.28 | 201 | 0.0002 |
| MB1 | -17.74 | 201 | 18.24 | 201 | 0.0002 |
| MB2 | -17.72 | 201 | 168.26 | 201 | 0.0002 |

### 4.2.2 SWAN Set-up

Table 3 provides details of the SWAN parameter settings used for the modelling in the study.

Table 3: SWAN Model Settings

| | |
|---|---|
| Coordinate system | Spherical |
| Directional resolution, Δθ | $20^o$ |
| Frequency range | 0.04 to 1.0 Hz |
| Wave Breaking | On |
| Bottom Friction | On |
| Wave Spectrum | KOMEN |
| Set-up | Off |

## 4.3 Wave Run-up and Over-topping Model

### 4.3.1 One–Dimensional Wave Sections

Computation of wave run-up and over-topping effects at the shoreline is complex and requires treatment on a case-by-case basis for each location of interest.

To meet the requirements of this study, wave behaviour was considered along sections seawards from locations coinciding with the TC Beni impact locations, described in the last section. The location of the sections are shown in Figures 24, 25 and 26.

The following provides a brief description of the bathymetry of each section in the context of wave impacts. Sectional diagrams include the variation of topography (wave heights along the section for two storm events – Beni and a more extreme design storm - are also shown in these diagrams for convenience, and these will be discussed in the next section of the report).

### *Section A*

Section A is located on a relatively unprotected foreshore. A low relief revetment of approximately 0.5 m height was apparently present at the upper limit of a sand beach. Structural failure of the revetment has resulted in the extensive mass of debris shown in Figure X. The level of the roadway is estimated at 2.3 m above MSL.

The cross-sectional profile (Figure 13) is at a significant angle to the inshore bathymetric contours, distorting the apparent features. An extensive sub-aerial beach is present, with a grade of approximately 1 in 40, finishing at a depth of roughly 4.5 m below MSL, dropping rapidly into deeper water. The upper shore grade is estimated at 1 in 14.

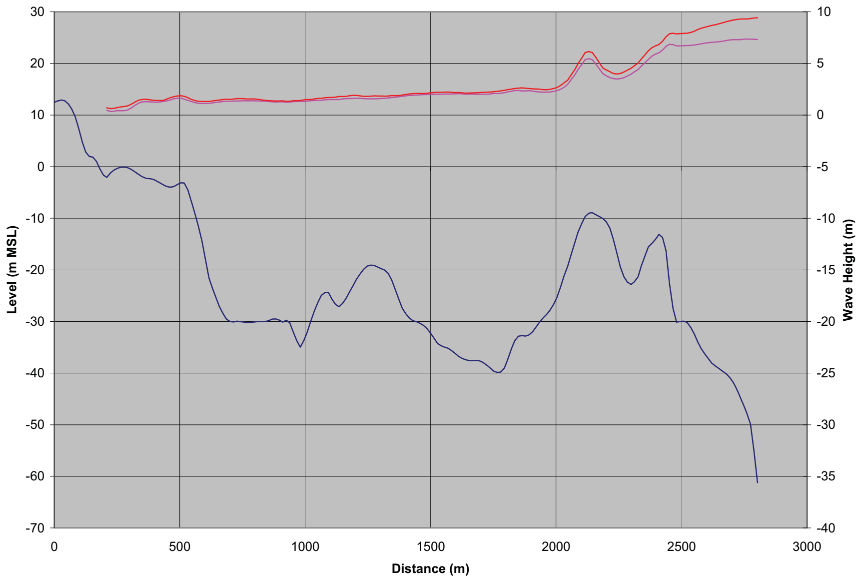


**Figure 13: Topography and wave height data along Section A – the higher wave curve is associated with a variation on TC Beni, discussed in Section 4.2 of this report.**

**Figure 14: Looking from just northwards of Section C (past Section B)**

### *Sections B and C*

Sections B and C are located adjacent to the harbour precinct, protected by a linear sheet pile wall, topped with a rail fence and backed with a bitumen pathway. The adjacent foreshore precinct is level up to buildings, some 40 metres from the pathway, as shown in Figure 15.

Section C passes across the submerged northern extent of Ifira island which appears on the section like a shoal. Wave conditions at the inshore terminus of Section C are actually generated by refraction around the headland, from the northwest.

Figure 15: Section B profile and modelled wave height.

Figure 16: Section C profile and modelled wave height

The top of the seawall is estimated to be 1.8 m above MSL, based upon the sections – this appears to be consistent with the top of the wall being a little above Highest Astronomical Tide.

## Section D

Section D is located at the southerly end of Mele Bay, which is controlled by an extensive rock headland. Emergent rock is also present offshore, as shown in Figure 17. This appears on the cross-section as an extensive shallow, flat coastal lagoon.

Figure 17: Blacksands village beach looking south-east

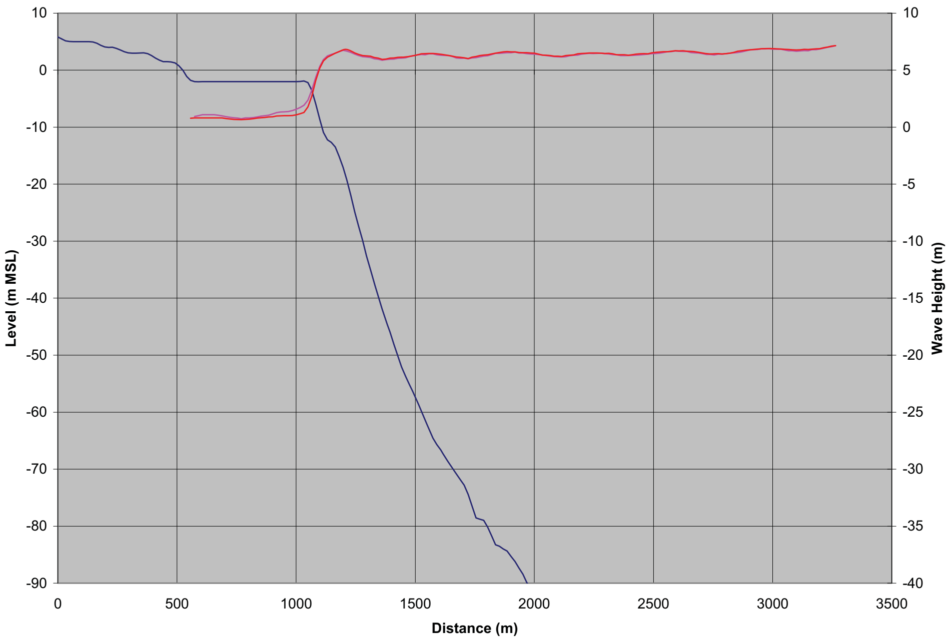


Figure 18: Section D profile and modelled wave height

The beach face of Section D is linear, truncated by a small scarp towards the top of the beach, roughly at 2.0 m above MSL. A beach grade of 1 in 40 has been estimated from the profile.

Section E

Section E is located towards the northern end of Mele Bay, intersecting with a tombola that extends almost to Hideaway Island. The presence of this feature might cause significant differences to alongshore beach response. Response will vary significantly according to the incident wave direction.

From the profile, the beach grade is very flat. However, the section has been drawn at a sharp angle relative to the beach face, and the beach grade is estimated at 1 in 60. There is an extended inshore lagoon developed through the presence of reef around Hideaway Island. From aerial photography, the land on the tombola is low profile. The cross-section suggests a level of approximately +1.0-m to MSL.

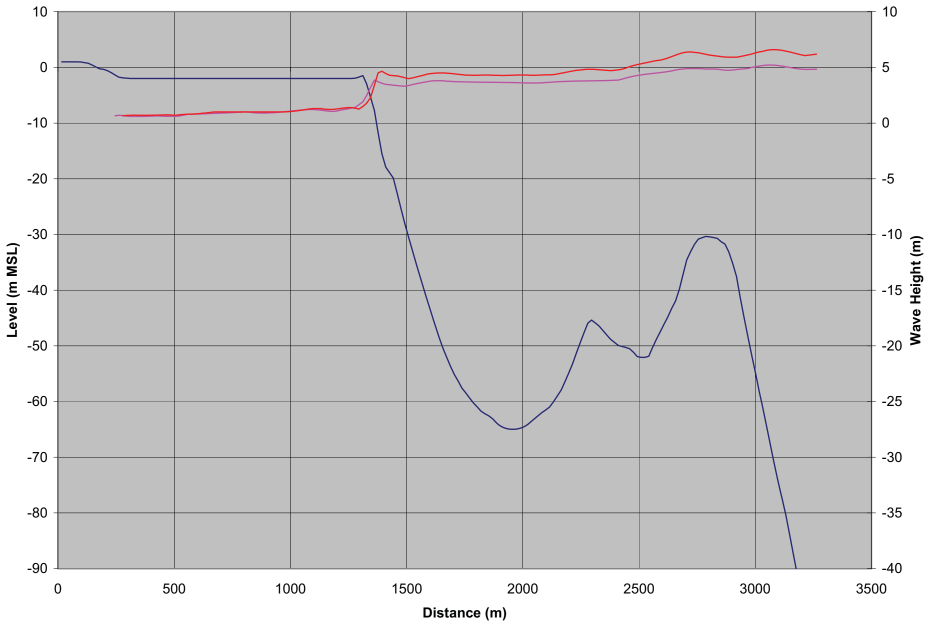


Figure 19: Section E profile and modelled wave height

### 4.3.2 Run-up on Beaches (Sections A, D and E)

Formulae for wave run-up estimation have generally been defined using wave tank testing. Consequently, the design is typically referenced to a uniform offshore wave condition. In this case however, the strong damping caused by friction, shoaling and breaking determines that wave conditions measured offshore may not be applied to the site.

Instead, the equivalent offshore wave height $H'_o$ is estimated using the wave height measured at the topographic rise nearest to the shore. This height is converted to the equivalent offshore wave height using linear wave theory, which effectively assumes only the process of shoaling.

Basic estimates of the wave run-up on Sections A, D and E have been prepared using the method of Mase [4]. Field observations suggest that this method may slightly exaggerate the run-up level. Like wave height, run-up may vary significantly between waves, forming a distribution of run-up levels. It is normally expressed in terms of $R_N$, where N is the fraction of observed wave run-up events that exceed the nominated level.

$$R_{max} / H_s = 2.32\ \xi_p^{0.77}$$

$$R_{2\%} / H_s = 1.87\ \xi_p^{0.71}$$

where $R_{max}$ is the estimated highest level of run-up. $R_{2\%}$ is the level that will be exceeded by less than 2% of individual waves. $\xi_p$ is the Iribarren surf similarity parameter:

$$\xi_p = \tan\alpha\ (L_p / H_s)^{0.5}$$

where $\alpha$ is the slope angle, $L_p$ and $H_s$ are the equivalent offshore wavelength and height.

As a wave runs further up a beach face, it reduces capacity to mobilise sediment. In general, the $R_{2\%}$ run-up level is a good estimator of the active beach-face zone.

**Beach Response to Increased Wave Conditions**

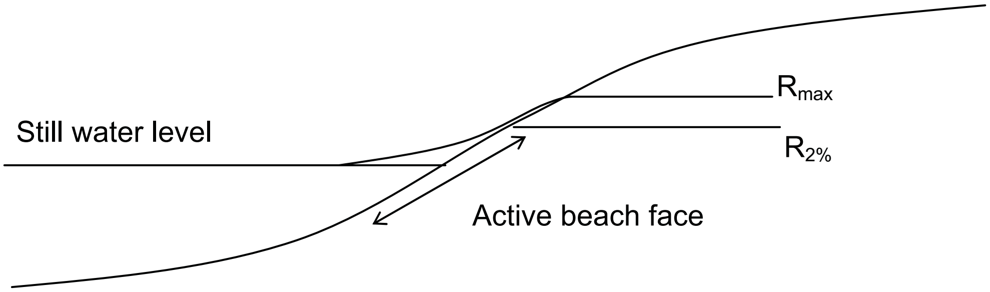


Figure 20: Active Beach Face

The active beach face is the zone in which wave action constantly produces sediment movement. In this zone, the slope of the beach is typically flat and smooth. The R2% run-up level approximately describes the upper limit of the active beach face.

During elevated wave conditions, higher wave energy increases the mobility of the beach sediments. This increases the width of the active beach face.

The beach naturally tends to move towards a flatter slope, which helps to dissipate wave energy. This is achieved by erosion of material from the upper beach face and deposition at the lower portion, possibly forming a storm bar

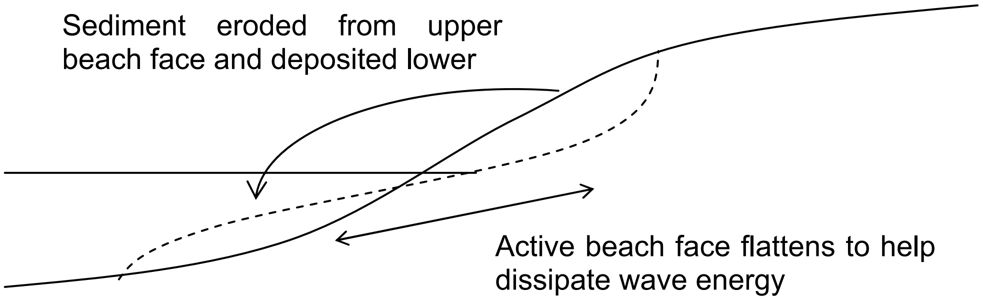


Figure 21: Flattening of Beach Face due to High Wave Energy

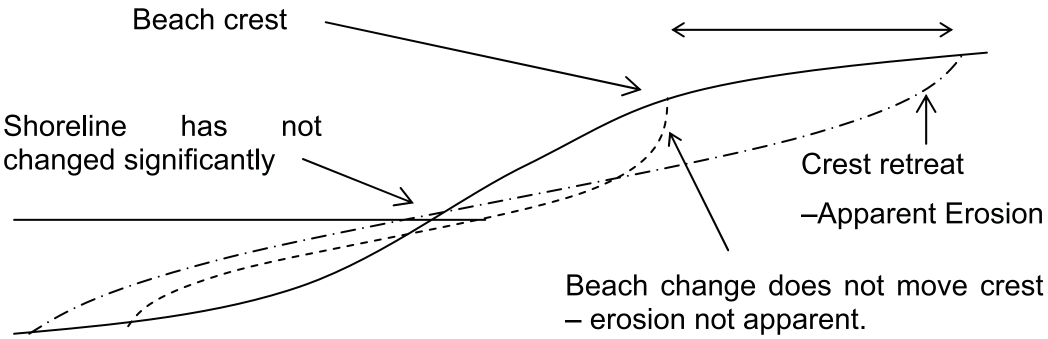


Figure 22: Apparent Erosion Associated With Beach Crest Movement

For many storm events, movement of the beach face occurs solely below the beach crest. The flattening of the beach face is therefore not considered as erosion.

For larger events, erosion of the upper beach face extends landwards of the beach crest. This produces apparent shoreward movement of the beach. However, in cases when there is no net offshore loss of sediment, the material eroded has merely moved from the upper beach face to the lower beach face.

### 4.3.3 Overtopping On Sea Wall (Sections B and C)

Basic estimates of the wave run-up on Sections B and C have been prepared combining the methods of Franco, de Gerloni & van der Meer [5] with model test results of Franco & Franco [6].

Estimation of overtopping discharge may be made using the formula:

$$Q = 0.082\ g^{0.5}\ H_s^{1.5}\ \exp(-\ 3.0\ R_*),$$

where dimensionless freeboard is given by $R_* = R_c / H_s\ 1/\gamma$. $\gamma$ is a coefficient based upon the bed slope, porosity and roughness of the face exposed to wave action. For the conditions at Port Vila Harbour $\gamma = 1.0$.

# 5 Modelling Results

## 5.1 Comparison of Tracks

In Section 3, consideration was given to comparing the relative impacts from waves associated with different cyclone tracks. The SWAN model was run on the Coarse Grid for TC Beni and for a storm of the same strength, on a track shifted approximately 2.5 degrees east. The tracks are shown in Figure 23 and the wave fields at a similar time in the storms' evolution are shown in Figure 24.

The wave field for Beni has a maximum of around 19.5 metres compared with 14.5 metres for the track shifted to the east – the main cause for the difference is the effect of northern islands of Vanuatu which reduce the effective fetch. The wave maximum is also shifted eastwards in accordance with the region maximum winds.

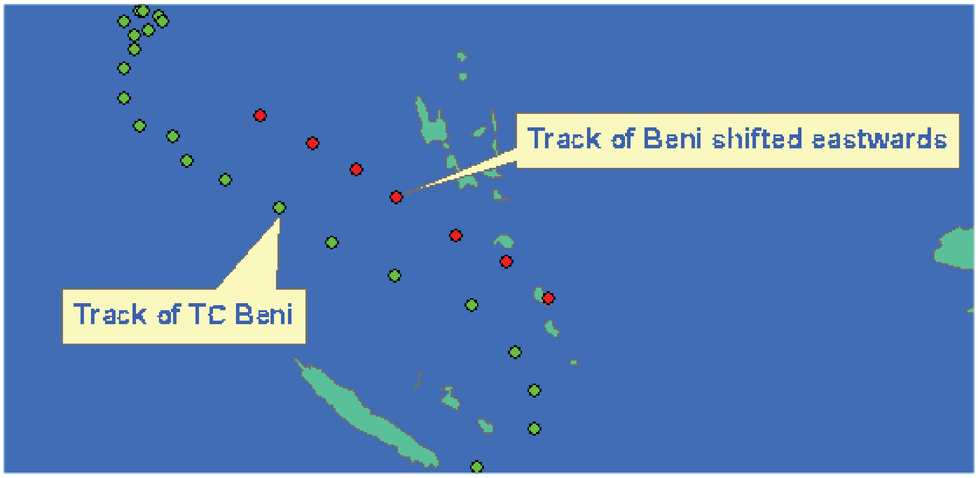


Figure 23: Tracks of TC Beni and Beni shifted approximately 250 km to the east

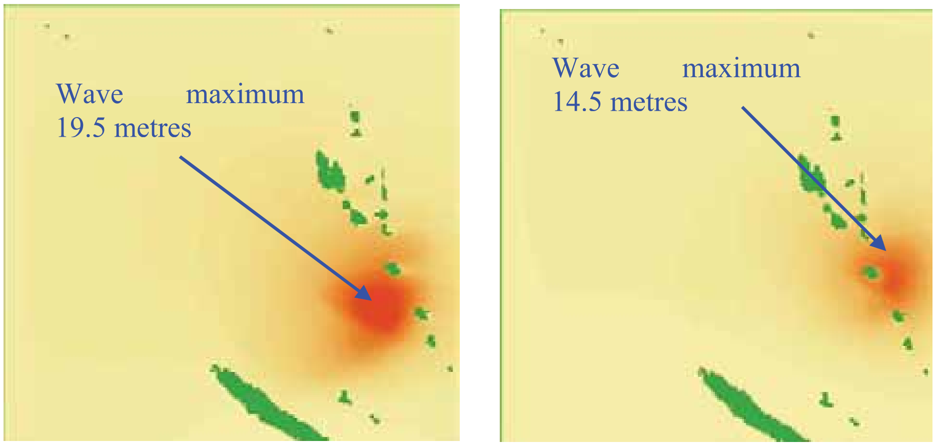


Figure 24: Wave height contours for the two tracks for storm locations nearest Efate – highest waves of Efate are for Beni, which is further away

## 5.2 Modelling TC Beni and an Extreme Event

### 5.2.1 Overview

Detailed, inshore wave modelling was undertaken for two storm events:

**Case 1 :** TC Beni with still water level set to 0.5 m

**Case 2** : TC Beni track, but intensity 910 hPa, which is the approximate 100 year storm central pressure for the Vanuatu region and still water level set to 1.0m.

The case approach is adopted since accurate specification of wave heights in the Port Vila – Mele Bay region at a range of return periods would require undertaking many hundreds of wave model runs for a wide range of cyclone events – varying intensity, speed of movement track – and a range of sea levels.

Since this is beyond the scope of the current project, in order to in provide quantitative estimates of an extreme wave event, a representative design storm was considered. The aim of this exercise was to establish wave heights and their potential impacts at the extreme end of cyclone events and to compare those impacts with that of Cyclone Beni.

To this end, a cyclone of intensity 910 hPa (which is approaching the extreme cyclone intensity in the vicinity of Vanuatu) was set up to run on the same track as Beni. Still Water Level at the time of maximum waves was set at 1.0 metres above mean sea level – this is well above that coinciding with Cyclone Beni (a maximum of 0.2 to 0.3 metres at the time of maximum waves). In a parallel study of storm surge risk [8], the 1000 sea level is estimated at about 1.2 metres above mean sea level – so that the selected event is extreme for both waves and sea level.

The coarse and fine grids SWAN runs for the two cases were used to generate boundary conditions for the three high resolution (20m) micro-grids described in Section 3.

Figure 25 shows the evolution of the cyclone scale wave fields over the coarse grid for Case 2, the extreme event. The wave fields for Beni are similar, except that the open ocean waves heights are commensurately less than for the extreme case.

Figure 26 shows the wave heights on the three micro wave grids for Case 2 at about the time of the maximum waves in Mele Bay. The reduction of waves heights as waves propagate into shallow water is clearly evident.

Bathymetry and wave conditions were extracted form these grids along five selected cross-sections terminating shorewards from specific points of interest. The locations of the cross sections are shown in Figures 27, 28 and 29 together with impact locations specified in the previous section of the report.

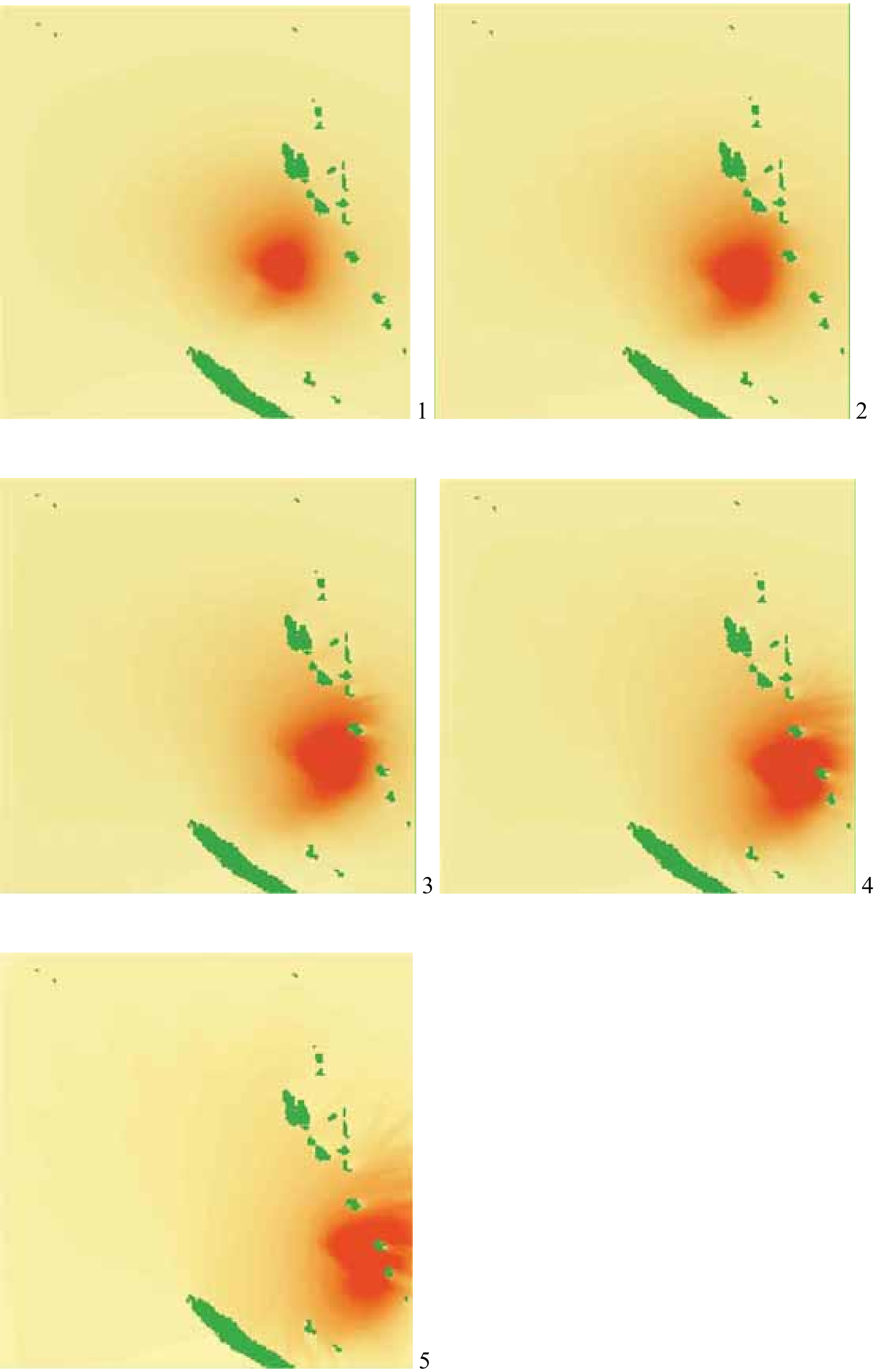


Figure 25: Evolution of wave field with design extreme cyclone (910 hPa).

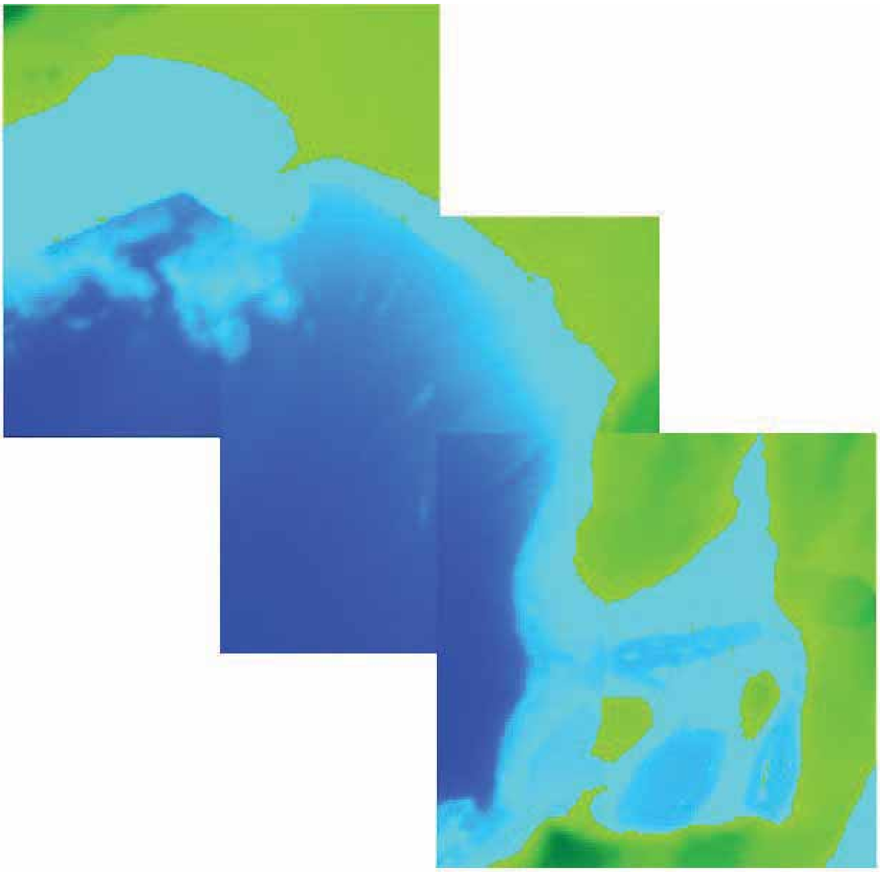


Figure 26: Contours of significant wave height for the extreme cyclone event across the three micro grids.

Figure 27: Sections A, B and C. Blue shading is of significant wave heights for TC Beni – the breaking zone over the steep bathymetric gradient outside the harbour is clearly evident

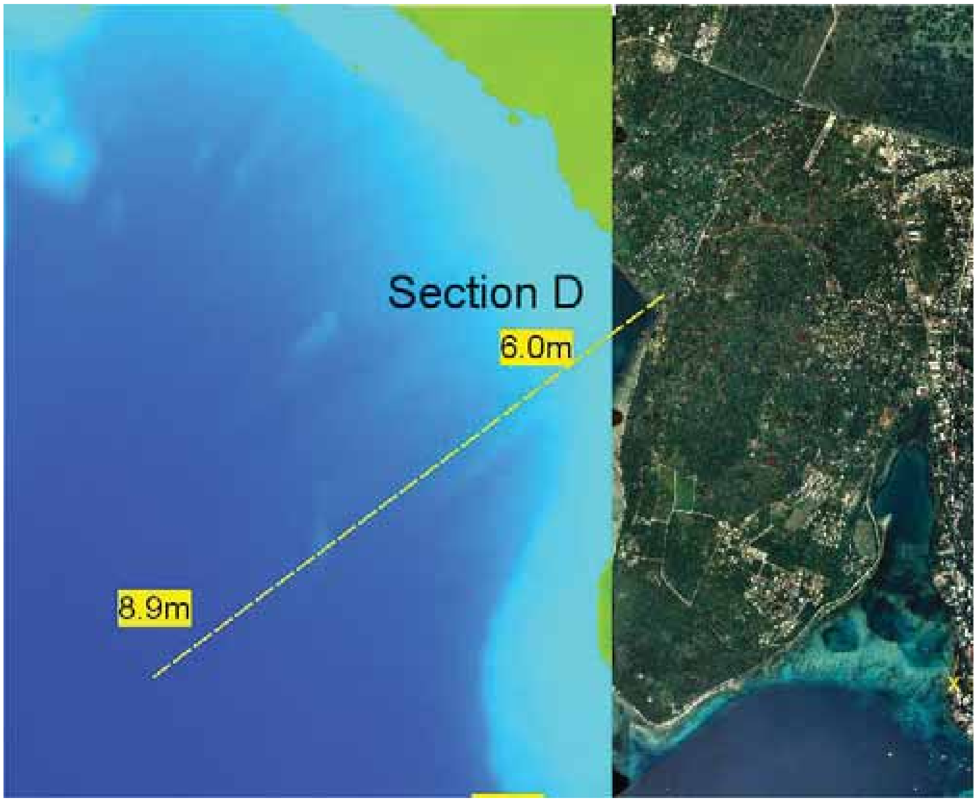


**Figure 28:**

Figure 28: As Figure 27, but Section D.

Figure 29: Section E.

Table 4 shows wave details for each section and case, comparing deeper and shallower waves. Offshore (that is, at the end of the cross sections) wave conditions up to 9.5 m height have been estimated. In general, the waves have long periods from 15 to 22 seconds. The resulting deep-water wavelength is 350 to 750 m, which determines that there will be strong wave-bed interaction from the shelf boundary.

Table 4: Modelled Wave Conditions for TC Beni

| **Case 1: Beni** | **Offshore Wave** | **Inner Shallow** |
|---|---|---|
| A | 7.32 m, 15.4 s in 61.2 m | 1.64 m, 15.4 s in 3.1 m |
| B | 7.37 m, 15.4 s in 44.5 m | 2.81 m, 18.1 s in 9.6 m |
| C | 7.33 m, 15.4 s in 20.3 m | 1.12 m, 18.1 s in 14.0 m |
| D | 8.89 m, 15.4 s in 184 m | 1.39 m, 25.0 s in 2.5 m |
| E | 4.84 m, 15.4 s in 107 m | 3.86 m, 18.1 s in 7.8 m |
| **Case 2: Extreme** | **Offshore Wave** | **Inner Shallow** |
| A | 9.42 m, 16.1 s in 61.7 m | 1.87 m, 18.1 s in 3.6 m |
| B | 9.46 m, 18.1 s in 45.0 m | 3.07 m, 18.1 s in 10.1 m |
| C | 9.03 m, 18.1 s in 20.8 m | 1.28 m, 18.1 s in 14.5 m |
| D | 8.99 m, 18.1 s in 185 m | 1.75 m, 21.3 s in 3.0 m |
| E | 6.18 m, 18.2 s in 108 m | 4.65, 18.1 s in 10.4 m |

Characteristics of the transition towards shore include shoaling, breaking and friction, with increasing effect for shallow water. The effect of shoaling and breaking is apparent at a number of sills and reef systems across the sections and there is significant damping of long-period waves as the wave approaches the shoreline.

### 5.2.2 Port Vila Harbour

Section A : Run-Up

Directly applying the formulae for run-up to the upper beach face grade, run-up has been estimated for each modelled cyclone condition. The run-up will occur on top of the notional Still Water Level (SWL) that includes both tide and surge components.

Table 5: Run-up Levels for Section A

| | $R_{max}$ | $R_{2\%}$ | $R_{max}$ + SWL | $R_{2\%}$ + SWL |
|---|---|---|---|---|
| **Case 1:**<br>**Beni** | 3.1 m | 2.5 m | 3.6 m | 3.0 m |
| **Case 2:**<br>**Extreme** | 3.8 m | 2.9 m | 4.8 m | 3.9 m |

The effect of beach face grade upon wave run-up is significant, and a relatively small flattening of the beach profile will result in a decline in the run-up level. This is a natural response of a beach system, where the beach face changes conditions from reflective during low-energy, to dissipative during high-energy. Typical adjustment is for the beach crest to match the $R_{2\%}$ level, which is near to the situation for Case 1.

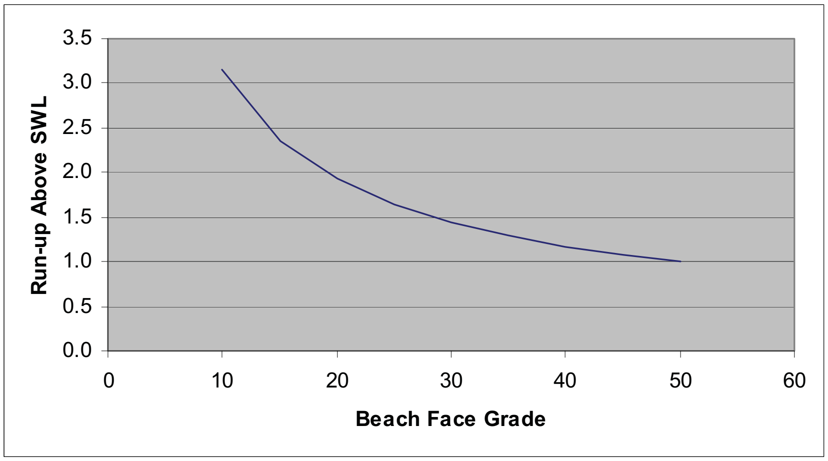


Figure 30: Effect of beach face grade on run-up for Section A.

Section B and C: Over-topping

Applying the wave overtopping formulae to the vertical wall at Sections B and C for the modelled wave conditions:

Table 6: Wave Breaking and Overtopping Conditions for Sections B & C

| | Breaking Wave (m) | Freeboard | Breaking Zone | Overtopping litre per second per metre |
|---|---|---|---|---|
| **Section B** | | | | |
| Case 1 | 2.65 | 1.3 | | 11 |
| Case 2 | 3.17 | 0.8 | | 58 |
| **Section C** | | | | |
| Case 1 | 1.82 | 1.3 | At wall | 0.3 |
| Case 2 | 2.11 | 0.8 | At wall | 9.1 |

Permissible levels for overtopping depend upon the level of access and use USACE, 2000 [9] For situations where there are pedestrians, vehicles or buildings the permissible level of overtopping is 0.1 l/s per m. Methods to estimate a safe distance behind the vertical wall are not well established, and can only be inferred from wave transmission tests such as Seelig [7]. Applying these methods to Section B, a 15-m setback is estimated for Case 1 and a 25-m setback for Case 2. However, it is necessary to recognise the uncertainty associated with these estimates, and for practical purposes, setback distances should be increased – potentially doubled.

The requirement for structural stability of the seawall is 50 l/s per m if the promenade is unpaved, and 200 l/s per m if the promenade is paved. Given the relatively narrow nature of the bituminous paving at the back of Port Vila Harbour seawall, it is likely that mild damage may be experienced in the event of Case 2 for Section B. Damage would be anticipated to include scour behind the bitumen and some potholing across the pavement.

### 5.2.3 Mele Bay

Section D : Run-Up

Applying the wave run-up formulae to Section D, a run-up of 1.5 m is estimated for Case 1 and 1.7 m for Case 2. This gives total run-up levels estimated as 2.0 m and 2.7 m above MSL.

The upper level of the beach face is estimated at 1.7 m above MSL with the roadway at 2.0 m above MSL. Consequently, the roadway at the northeast corner is expected to be safe under Case 1, although possibly washed by several individual waves. Under Case 2 conditions, the scarp would be flattened, extending at the same grade as the beach towards the roadway. For a 1 in 40 grade, a 0.4 m height difference extends the beach crest 15 m shorewards.

Table 7: Run-up Levels for Section D

| | $R_{max}$ (m) | $R_{2\%}$ (m) | $R_{max}$ + SWL (m) | $R_{2\%}$+ SWL (m) |
|---|---|---|---|---|
| **CASE 1: Beni** | 1.5 m | 1.2 m | 2.0 m | 1.7 m |
| **Case 2: Extreme** | 1.7 m | 1.4 m | 2.7 m | 2.4 m |

Section E : Run-Up

Applying the wave run-up formulae to Section E, a run-up of 1.4 m is estimated for Case 1 and 1.8 m for Case 2. This gives total run-up levels estimated as 1.9 m and 2.8 m above MSL.

Table 8: Run-up Levels for Section E

| | $R_{max}$ (m) | $R_{2\%}$ (m) | $R_{max}$ + SWL (m) | $R_{2\%}$+ SWL (m) |
|---|---|---|---|---|
| **CASE 1: Beni** | 1.4 m | 1.3 m | 1.9 m | 1.8 m |
| **Case 2: Extreme** | 1.7 m | 1.5 m | 2.7 m | 2.5 m |

Land levels corresponding to Section E are estimated to be roughly 1.0-m above MSL, which will be heavily washed during Case 1 and inundated during Case 2. As the profile flattens below the run-up levels, wave rush cannot continue upwards and the momentum produces horizontal wash instead. The extent of such wash depends on the drainage character of the inundated land.

Exceedance of the beach crest will tend to scour the upper part of the beach face, causing a flattening of the profile. Notionally, this may continue until the face is flat enough that it will not be over-crested, with a similar situation to Figure 28.

Theoretical shoreward extension under Case 1 conditions has been estimated; the results are shown in Table 9.

Table 9: Theoretical Erosion for Section E, Case 1 cyclone

| **Land Level** | +2.0-m MSL | +1.5 m MSL | +1.25 m MSL | +1.0 m MSL |
|---|---|---|---|---|
| **'Stable' Grade** | 1 in 95 | 1 in 160 | 1 in 235 | 1 in 400 |
| **'Erosion'** | None | 30-m | 75 m | 150 m |

It must be stressed that these theoretical 'erosion' condition requires sustained wave and water levels, which is unlikely during a cyclone event. For a short duration event, the observed retreat of the beach crest will be unaffected by the land level behind the crest.

Observed erosion will also include a significant component due to alongshore transport, as noted previously. As the still water level under Case 2 is the same as the estimated land level, the tombola will be fully inundated.

# 6 Summary & Conclusions

Waves associated with Tropical Cyclone Beni and an extreme cyclone have been modelled in detail, for specific locations around the Mele Bay – Port Vila area.

The results show that low level inundation that occurred during TC Beni were almost certainly associated with very large waves rather than storm surge per se. Wave run-up was found to have significant impact on beaches at the Mele sites and these results can probably be reasonably extrapolated to be applicable along the Mele Bay shoreline.

The extreme event case showed, as would be expected, higher levels of run-up and potential for beach erosion; some low level inundation could be expected to impact on building or other assets close to the shoreline. The results suggest that such wave events do not of themselves present a major safety danger to the village communities.

The results for Mele indicate that a impact line be established to at 3.0 m above mean sea level, and some further buffer for error, may be applied in addition to the computed 3.0 m level.

At Port Vila, the impact of Beni was to cause inundation of the 'beach front' to the north of the main township and over-topping of the main sea wall. Further southwards, towards the port, wave action is attenuated by the protective influence of Ifira island.

For the more extreme event, run-up and beach erosion are likely to cause some problems and overtopping would probably cause at least minor structural damage to the wall itself. More importantly, over-topping rates for the extreme event suggest the need for set-back constraints for buildings in this area. Reported incidences of impacts to the Hotel Rossi and Chantilly development during Beni would seem to confirm these calculations.

A setback of between 25 m and 50 m along the shore line in northern Port Vila has been suggested for extreme events.

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# Appendix 4a

# Tsunami Inundation Modelling for Pilot Project Harbour

*by*

**Vasily Titov**

Consultant, Seattle, USA

**SOPAC JOINT CONTRIBUTION REPORT 147**

*December, 2003*

# TSUNAMI INUNDATION MODELING FOR PORT VILA HARBOUR

## 1 Introduction

The report describes tsunami modeling for preliminary analysis of tsunami hazard for Port Vila Harbor. This study includes modeling of tsunami generation for several source scenarios, tsunami propagation and inundation at Port Vila Harbor. The initial plan for this pilot project had been limited to just one “worst case” scenario simulation of tsunami inundation in Port Vila. The January 2, 2002 Port Vila earthquake and consequent tsunami presented an unexpected opportunity to test the developed tsunami model against the field data collected after the event by the SOPAC team (G. Shorten, 2002). Hence, a tsunami with the 01/02/02 earthquake source scenario was simulated using the same numerical model and the same numerical grids as for the “worst case” model. The comparison of the model results with the field data showed general agreement with eyewitness observations and amplitude measurements, therefore, increasing the confidence level of the “worst case” modeling. Nevertheless, the modeling results of this study should be considered only as preliminary and one should use it for the tsunami risk analysis of Port Vila with caution. There are several factors that make this research a preliminary estimate, rather than a complete tsunami hazard mitigation study: (1) the quality of the bathymetry data used for the tsunami computations is very good in the Port Vila Harbor itself, but is very poor outside the harbor and in the immediate vicinity of the Efate Island, which can affect the model predictions; (2) only one source scenario is not sufficient to estimate the tsunami potential – it may require modeling several different source mechanisms and source locations.

The following additional research should be considered before the thorough tsunami risk assessment can be carried out for Port Vila in particular and Vanuatu Islands in general. The quality of all available bathymetry data should be assessed for the area and, possibly, additional surveys done for critical locations. The historical tsunami data should be analyzed to determine tsunami hazard priorities. All potential source mechanisms should be investigated (subduction zone megathrust events, intraplate ruptures, landslides etc.). Multiple tsunami simulation runs should be carried out to estimate potential tsunami inundation impact.

## 2 Tsunami Model

The tsunami propagation and inundation are simulated using the shallow water wave formulation by the MOST finite difference model (Titov and Synolakis, 1995, 1997, 1998). The MOST model uses spherical coordinates to account for the Earth curvature during tsunami propagation over long distances. The inundation boundary conditions are used to accurately simulate the process of tsunami inundation on land above the sea level. The nonlinear equations of the MOST model simulate complex wave dynamics near-shore including tsunami-induced strong currents and wave breaking. The model uses nested grids with three different grid resolutions to model tsunami evolution from deep water in the source area toward shallow depths of the Port Vila Harbor (Figure 1). The tsunami dynamics is computed simultaneously for all grids providing seamless transitions between nested grids. Different bathymetry data were used for different grids. The regional grid of 2min resolution covers the area 23ºS – 14º S; 162ºE – 171ºE and uses global digital bathymetry inferred from the gravimetric data constrained by the available ship-track data (Smith and Sandwell, 1994). The grid around Efate Island uses GEODAS data. The ship-track data were interpolated on a rectangular grid with 400m increment by Pacific Disaster Center (PDC). It should be noted that the data from GEODAS has very few tracks – some with questionable quality – in the vicinity of the Efate Island. Therefore, the resulted grid has low quality and only approximately reflects the bathymetry trends. The Port Vila merged bathy-topo grid (5m resolution) has highest quality. It consists of the high- resolution bathymetry survey and the LIDAR topography data of Port Vila merged together in GIS environment by PDC.

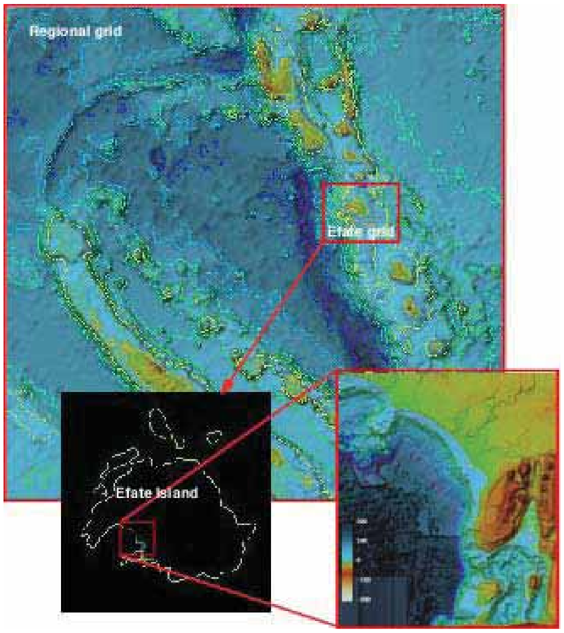

Figure 1: Bathymetric grids for tsunami simulation

# 3 “Worst Case” Scenario

## 3.1 Tsunami Source

The tsunami generation simulation is based on an elastic deformation model of the earthquake source (Okada, 1985; Gusiakov, 1978), which assumes an incompressible liquid layer on an underlying elastic halfspace to characterize the ocean and the Earth's crust. The implementation of this elastic fault plane model utilizes a formula for static sea-floor deformation to calculate the initial conditions required for subsequent computations of tsunami propagation and inundation.

Efate Island is located at the New Hybrid subduction zone, which is a part of the tectonically active system known to produce large earthquakes. The “worst case” scenario is assumed as an interplate inverse thrust event with the rupture under the continental slope in front of the Efate Island. The fault plane is placed at the interface between the subducting Australian plate and North Fiji Basin. The fault parameters are conformed to the inferred interface geometry (Jarrard, 1986;Pacheco et al.,1993): STRIKE = 343, DIP = 36, SLIP = 90. The magnitude of the earthquake scenario is specified to be the same as the strongest historical event $M_w = 8.1$ with the rupture area of 120x40km$^2$.

The computed bottom deformation has a typical pattern for the subduction zone earthquake with the subsidence near the coast and a larger uplift offshore. Maximum computed uplift is 3.2m, maximum subsidence is –0.3m.

## 3.2 Tsunami Simulation

The wave heights computed over the regional grid demonstrate the propagation pattern of the tsunami along the New Hebrides Arc (Figure 2). The wave reaches closest to the source Efate Island about 10 minutes after the earthquake.

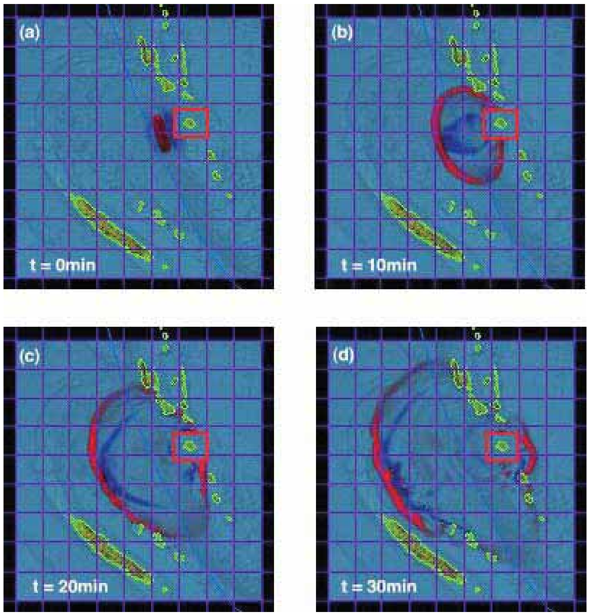

**Figure 2: Snapshots of computed tsunami propagation on a regional grid for the "worst-case" scenario. Positive amplitudes are red color, negative are dark blue**

In 20 minutes the wave arrives at Loyalty Islands and after 30 minutes it is near New Caledonia. The first wave to reach the Port Vila Harbor is a small negative wave, originated from the subsidence of the tsunami source. This is typical for earthquakes in subduction zones. As a result, the tsunami starts at Port Vila as a withdrawal of water from the harbor through a relatively narrow entrance. The first positive wave enters the Port Vila Harbor 14-15 minutes after the tsunami generation (Figure 3).

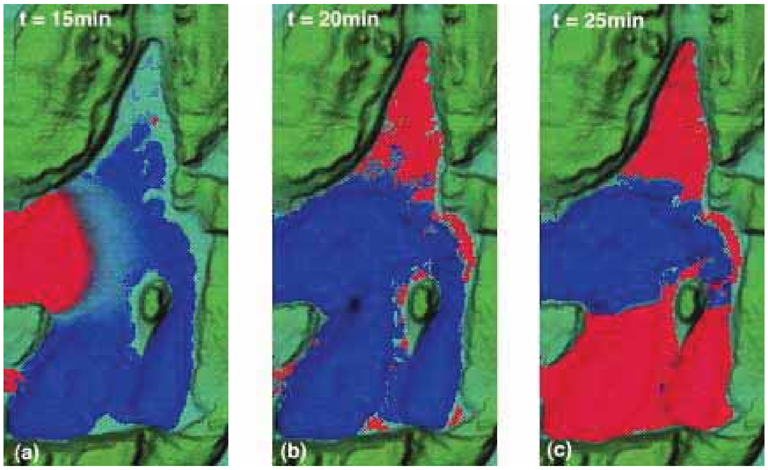

**Figure 3: Tsunami amplitudes during propagation inside the Port Vila Harbor for the "worst-case" scenario. Positive amplitudes are red color, negative are dark blue.**

A computer animation has been created to illustrate computed tsunami evolution in Port Vila Harbor from this moment on – 14 minutes through 25 minutes after generation. The simulation shows very strong currents at both entrances around the Ifara Island while the water flowing into the Port Vila Harbour. The main water flux occurs through the northern entrance; therefore the opposite waterfront on the east shore of the Harbor is struck with the highest amplitudes. The inundation of this shoreline starts 17 minutes after the earthquake. At the same time the simulation shows violent flooding of the shallow northern part of the Harbor, where extensive inundations are also computed. Another area of substantial flooding is at the Navy Base location on south-east part of the bay, where the inundation occurs 2 minutes later. Maximum computed inundation line is shown in Figure 4.

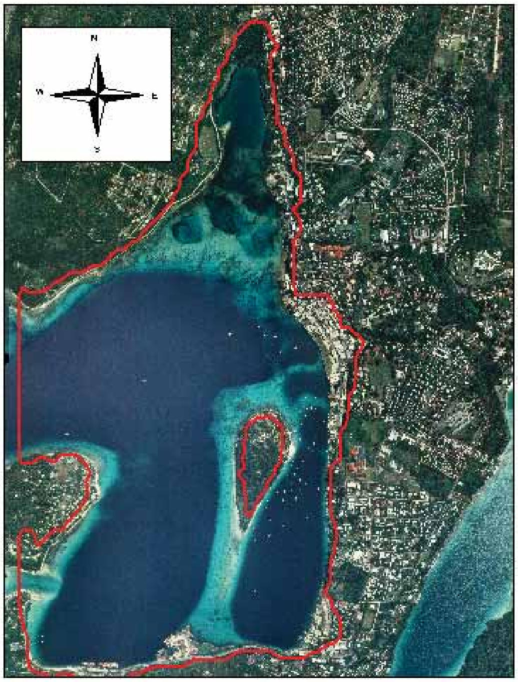

Figure 4: Maximum computed inundation line for Port Vila or “worst-case” scenario

After the first tsunami wave, which produces the largest inundation, the model shows continuous complex wave dynamic inside the Port Vila Harbor. The later tsunami waves continue to enter the harbor causing repeated floods of already inundated areas. Water masses of different parts of the Harbor separated by shallow bars interact with each other in a complicated resonant pattern creating strong currents over the shallow areas and whirlpool structures around the deeper part of the Harbor (Figure 5).

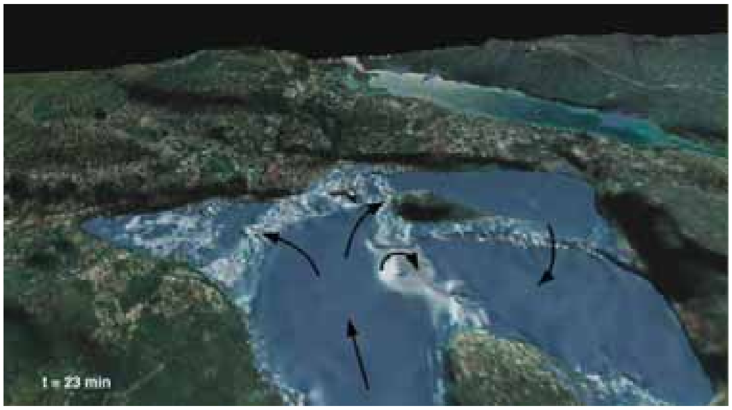

Figure 5: Computed flow patterns during tsunami inundation of Port Vila Harbor for worst-case scenario. Birds-eye view of computed wave amplitudes 23 minutes after tsunami generation are shown. Arrows indicate flow directions; white color indicates strong currents.

The model computed up to 9m maximum vertical inundation in Port Vila Harbor and maximum water penetration of about 200m beyond the shoreline (Figure 4).

# 4 Numerical model of January 2, 2002 tsunami at Port Vila

## 4.1 Background

At 17:22:49 on the 2nd of January 2002 (UTC) an earthquake magnitude 7.1 ($M_w$) shook the area near Port Vila in Vanuatu. The epicenter of the earthquake was located at the same general area as the proposed "worst case scenario" source for the Port Vila tsunami study described earlier. The earthquake caused widespread structural damage on the island of Efate with several people injured by falling debris. A number of landslides were observed in the area.

Several minutes after the earthquake a small tsunami was observed in Port Vila by several eyewitnesses and was recorded on the National Tidal Facility tide gauge. The tsunami did not produce any damage but was significant enough to create visible effects throughout the Port Vila Harbor. The eyewitness accounts recorded and quantified by Graham Shorten and the SOPAC survey team (Shorten, 2002a,b) have yielded important observation data to calibrate tsunami model for the Port Vila Harbor.

## 4.2 Source

The epicenter of this shallow earthquake was located directly offshore Vanuatu Island on the continental slope of the New Hebrides Trench at 17.590S, 167.829E. The associated tsunami could be generated by either a co-seismic elastic deformation of the ocean bottom, or an a-seismic ground failure (landslide or slump) on the ocean floor. The correlation between the earthquake magnitude and the observed size of the tsunami in the Port Vila Harbor suggests that the co-seismic deformation had been the most probable source of this wave. The elastic bottom deformation depends on the earthquake magnitude and the geometry of the fault. Both of these parameters are determined by the centroid moment tensor (CMT) solution for the seismic data. CMT solutions for this event published by USGS and Harvard are substantially different; therefore both solutions have been tested for the tsunami modeling. Each CMT solution produces two double couple fault models of the source that are not distinguishable from the seismic records alone. Other considerations – including, sometimes, tsunami evidence – have to be applied to choose the right fault geometry. Hence, both double-couples were considered for tsunami modeling for completeness.

Consequently, the following four double couple source parameters have been used for the tsunami simulations:

1) USGS CMT
   NP1: STRIKE = 1; DIP = 32; SLIP = 81
   NP2: STRIKE = 192; DIP = 59; SLIP = 96
2) Harvard CMT
   NP1: STRIKE = 298; DIP = 14; SLIP = 20
   NP2: STRIKE = 189; DIP = 85; SLIP = 104

All model faults have been assigned the same spatial dimensions (80 x 40 km) and the same slip amount of 0.9m. The epicenter of each fault plane is the same. Assuming rigidity value of $3 \times 10^{11}$ N/m$^2$, all these sources correspond to $M_w = 7.2$ earthquake (Harvard estimate of this event).

Each set of parameters is used as input for the elastic deformation model to produce the static earth crust deformation due to the corresponding fault rupture (Okada, 1985). The bottom deformations corresponding to these fault models are shown in Figure 6 (uplift in red, subsidence in dark blue).

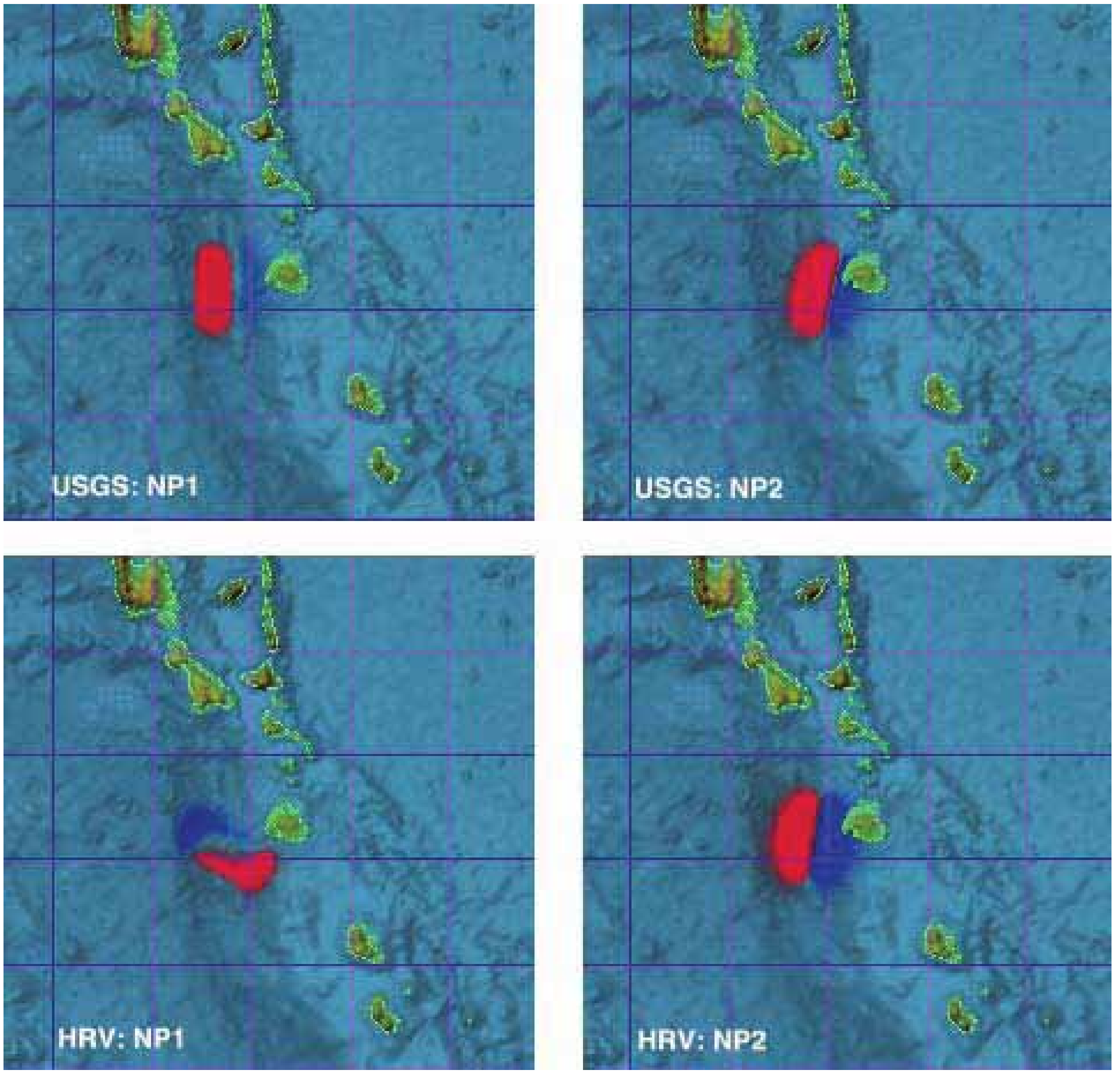

**Figure 6: Static bottom deformations computed for four different source mechanisms of the 01/02/02 tsunami. Uplift shown in red color, subsidence is dark blue.**

## 4.3 Results

The MOST model was used to compute tsunami propagation from each model source and wave evolution inside the Port Vila Harbor. The model uses the same computational grids as for the "worst-case" scenario simulation. For three of the computed source scenarios, the first wave that arrives at Port Vila is a negative wave. The Harvard's NP1 scenario – the only CMT solution with substantial strike-slip component – produces first positive wave at the Harbor with much smaller amplitudes than the rest of the sources. The computed arrival time of the first positive wave in the Harbor varies from 9 to 14 minutes after the earthquake for different sources (Figure 7).

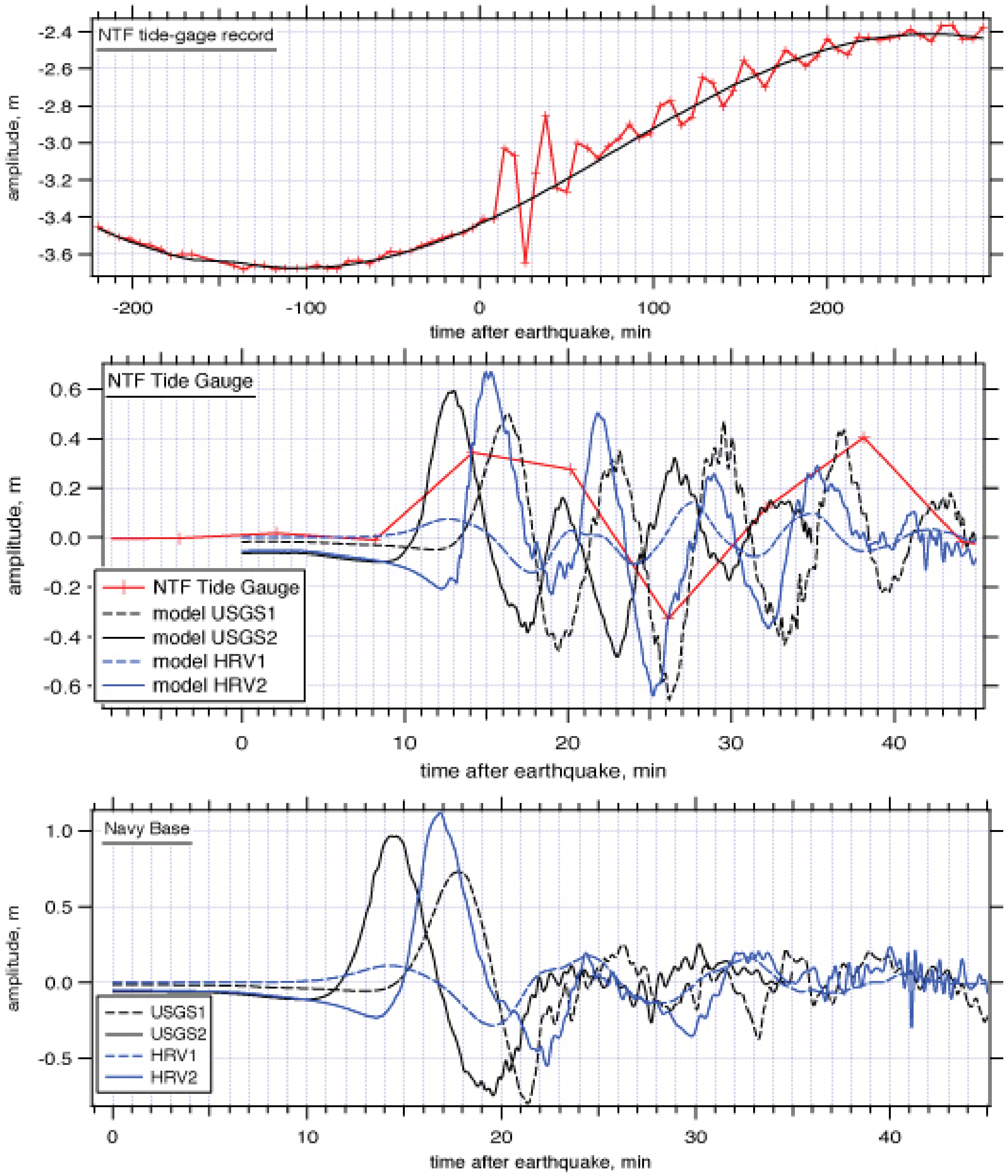

**Figure 7: (a) NTF tide gauge record, (b). compared with computed waveforms from four model sources of 01/02/02 tsunami. (c).Computed waveforms at Navy Base location is also shown**

The wave dynamics after the first positive arrival is fairly similar for the three non strike-slip scenarios (HRV:NP2, USGS:NP1,NP2). The wave arrives at the waterfront of east coast and the NTF tide gage at approximately the same time (Figure 8); the shore of the Navy Base is reached about 2 minutes later. The model did not compute substantial inundation for any of the simulated source dislocations. The maximum computed wave heights along the Port Vila coasts do not exceed 1.5 m (Figure 9), which is consistent with the eyewitness accounts.

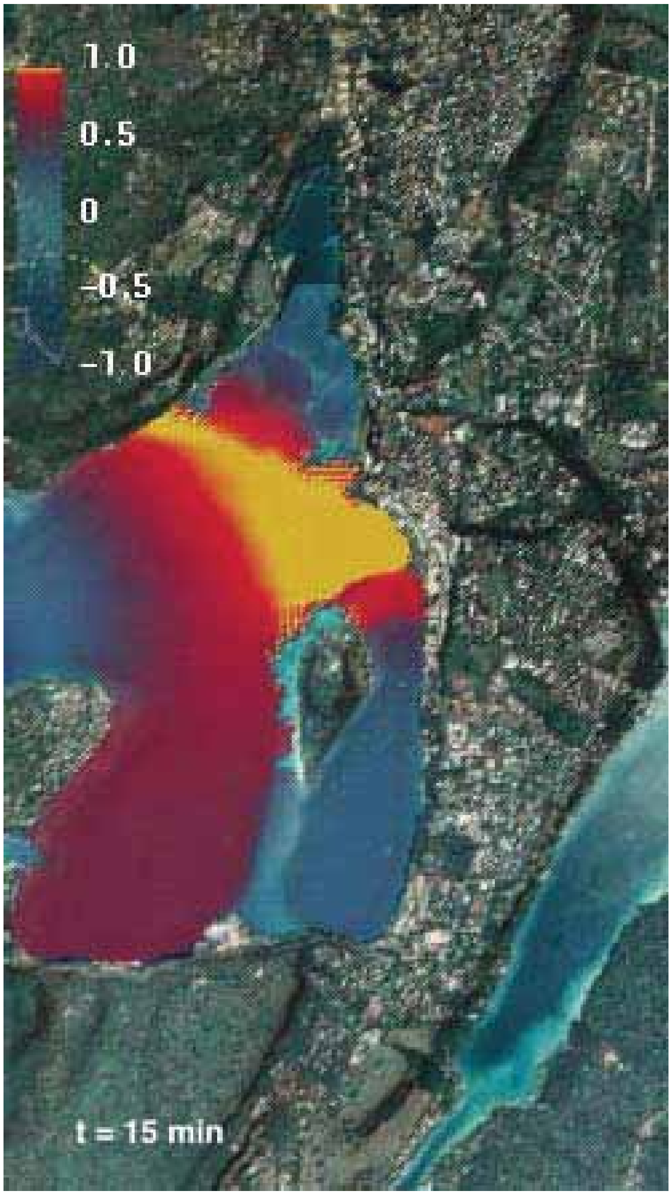

**Figure 8: Computed tsunami amplitudes inside Port Vila Harbor for HRV:NP2 source scenario 15 minutes after generation.**

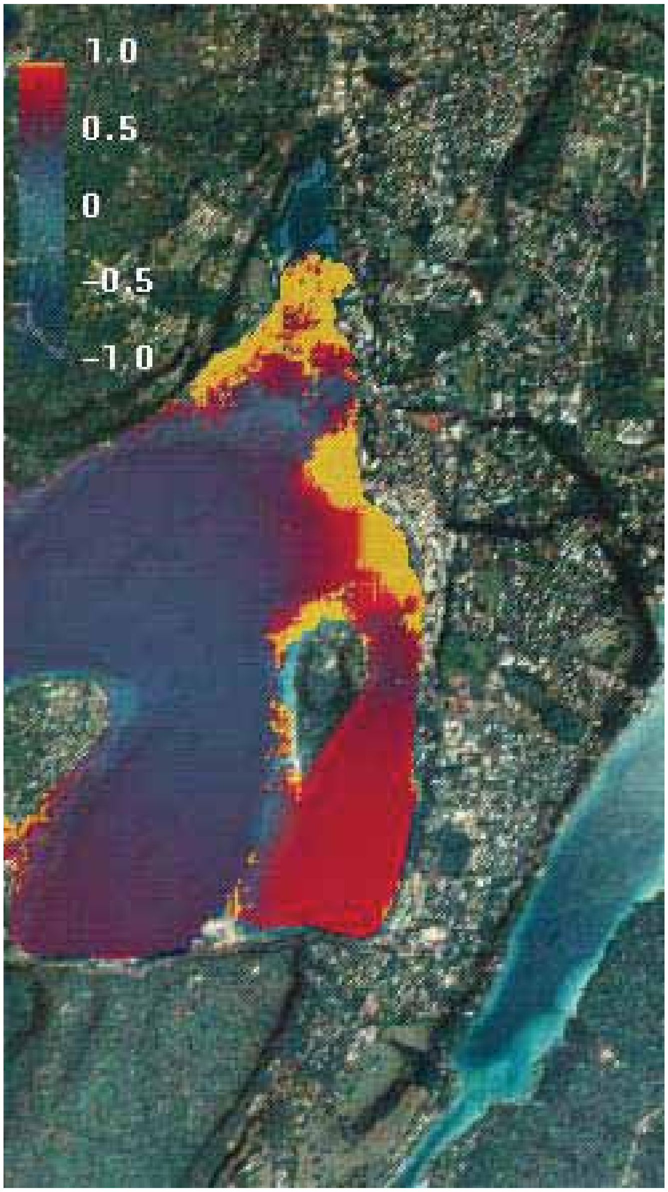

**Figure 9: Maximum computed tsunami amplitudes in Port Vila Harbor for HRV:NP2 source scenario.**

## 4.4 Discussion

### 4.4.1 Model results vs. observations

The observations for this event consist of the instrumental record of the tsunami at the NTF tide-gage and eyewitness accounts collected by the SOPAC team (G. Shorten, 2002).

The model comparison with the tide gage record is shown in Figure 7b. The computed waves for all sources have substantially smaller periods than the recorded signal. The computed waves show 6 to 7-minute period of water oscillation at gage location, while the record indicates 15 to 20-minute period. Interestingly, all the eyewitness accounts indicate much higher frequency oscillations (periods of 3-5 minute) in the Harbor than recorded at the tide-gage. Several explanations can be put forth to explain the observation discrepancy: (1) The tide gage record is highly aliased due to the law-sampling rate (~6minutes), does not catch all the peaks of actual water oscillations, therefore distort the period of the tsunami. (2) The tide gage construction can induce distortion of high frequency waves (compared with tide periods) if the intake pipes have small diameter. This problem of tide-gage tsunami records is well known and has been address in the literature (Satake et al, 1988; Noye, B,J., 1976). (3) All the eyewitnesses exaggerated the frequency of water level oscillations, since none of them had actually timed the period. This study favors the combination of (1) and (2) to explain the long periods of recorded tsunami. The model predictions combined with the eyewitness accounts are strong evidences suggesting 3 to 7-minute periods of the tsunami inside the harbor. However, since the model prediction can be affected by less then perfect bathymetry outside of the Port Vila Harbor, the final answer can be obtain only after inspecting the tide gage frequency response characteristics.

The computed amplitudes correspond well to the recorded signal for the three no-strike-slip sources and are much smaller for the HRV:NP1 strike-slip source. The computed maximum amplitudes for these three sources are similar and qualitatively agree with eyewitness observations around the harbor.

### 4.4.2 Source mechanism

The four considered fault plane solutions produce four different initial deformations (Figure 6), therefore produced different tsunamis in Port Vila Harbor. Figure 7 shows modeled tsunamis for all computed fault solutions. While all three dip-slip sources have similar signals at the gage, the observations seem to favor the normal fault mechanism with steeper dipping fault plane ( HRV and USGS: NP2): it produces the wave with earlier arrival time, first withdrawal with relatively larger amplitude and higher positive amplitudes. All these are consistent with eyewitness observations. This mechanism appears to suggest an intra-plate earthquake within the North Fiji basin. The thrust mechanism with shallower dipping plane (NP1) would suggest an inter-plate event at the subducting Australian plate interface. That mechanism (inter-plate event) assumed for the “worst case scenario” simulation (but for a larger magnitude earthquake). Tsunami observations suggest that the 01/02/02 earthquake did not rupture the plate interface, therefore, did not release accumulating stress there, leaving the potential for large inter-plate event in the future.

## 5 Conclusions

This study has performed numerical modeling of tsunami inundation inside Port Vila Harbor for the purpose of evaluating tsunami risk. Several source scenarios have been simulated. The “worst case” tsunami simulation provided estimates of maximum tsunami inundation possible inside the Port Vila Harbor. The simulation of the 02.01.02 tsunami tested the tsunami model predictions against tsunami observations in Port Vila. The comparison confirmed the credibility of the MOST model estimates for Port Vila. The results of this project lay ground for a full-scale tsunami risk assessment study for Port Vila and other Vanuatu sites.

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# Appendix 4b

# Tsunami Inundation Model of Mele Bay

*by*

**Vasily Titov**

Consultant, Seattle, USA

**SOPAC JOINT CONTRIBUTION REPORT 147**

*December, 2003*

# TSUNAMI INUNDATION MODEL OF MELE BAY

## 1 Introduction

Simulation of tsunami inundation in the Mele Bay is an extension of the Port Vila tsunami-modeling project (Titov, 2002). The goal of the project is to provide preliminary estimate of tsunami inundation pattern for Mele Bay using numerical model of tsunami generated by an earthquake at the New Hebrides Subduction Zone (NHSZ).

## 2 Tsunami Model and Data

### 2.1 Bathymetry

The regional grid and the grid around Efate Island are the same as for the Port Vila model. The Pacific Disaster Center (PDC) has developed 10m-grid for Mele Bay by merging high-resolution bathymetry survey data with topography derived from aerial survey (Figure 1). The grid boundaries are chosen to maximize use of limited coverage of the topography data and use as much of the surveyed coastline as possible (Figure 2).

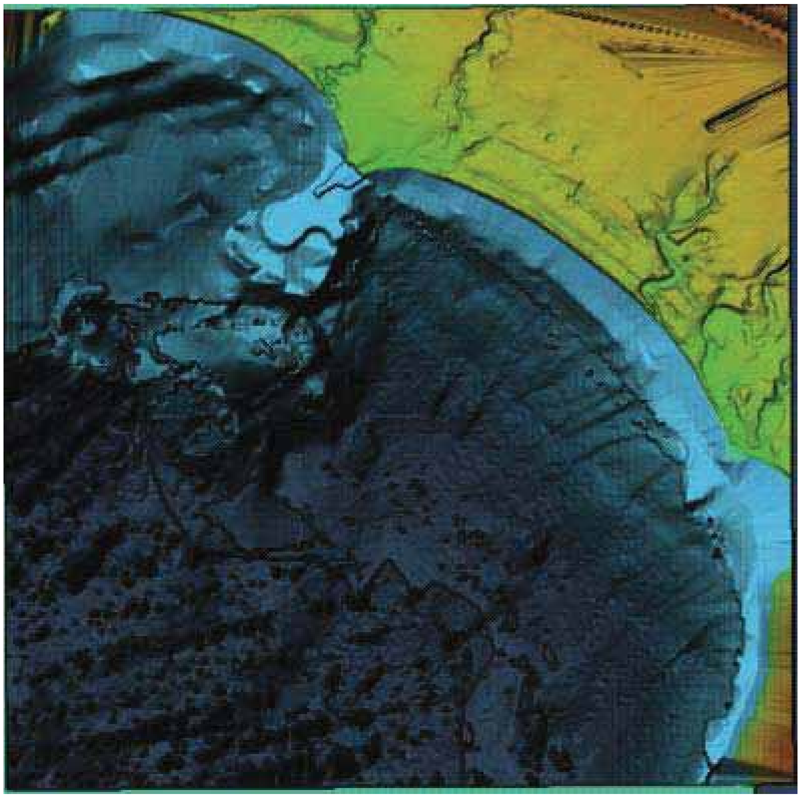

Figure 1. High-resolution 10-meter topography-bathymetry grid for the Mele Bay.

### 2.2 Source

The source of the modeled tsunami wave is the bottom deformation due to $M_w$ 8.1 earthquake at NHSZ. The same source scenario is used for tsunami inundation model of Port Vila (Titov, 2002). Therefore, the Port Vila inundation model and the Mele Bay inundation model simulate inundation effects of the same tsunami event at different locations.

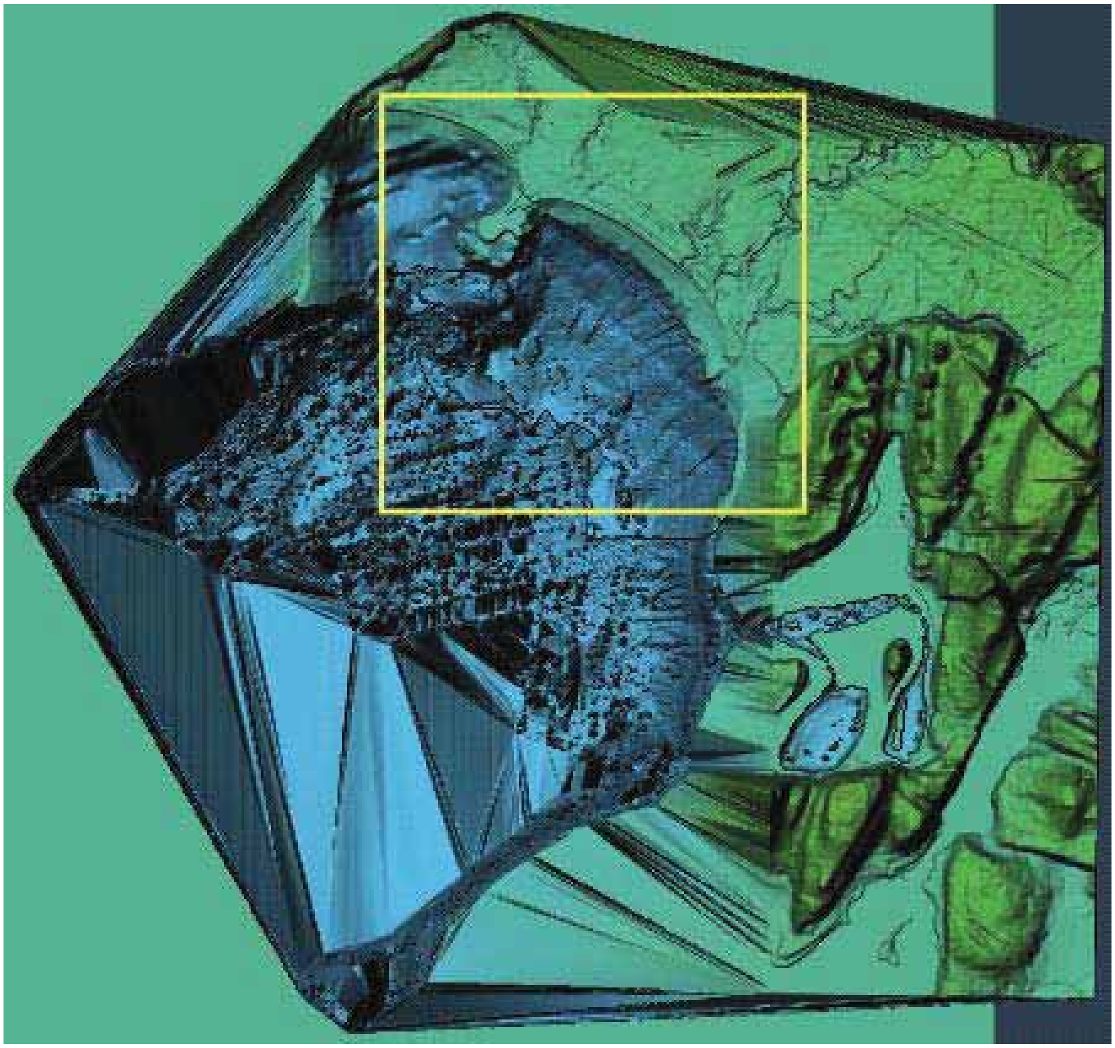

Figure 2. Bathymetry and topography data interpolated on 10-meter grid used for the high-resolution nested grid. Yellow rectangle shows the portion of the data used for the computation.

## 2.3 Tsunami Model

Tsunami propagation and inundation are simulated using the same numerical model and same technique as for the Port Vila simulation, as described by Titov (2002). The MOST finite difference model is used (Titov and Synolakis, 1995, 1997, 1998) with three nested grids of different spatial resolution. The topography of the Mele Bay coast is very flat when compared with steeper slopes of the Port Vila Harbour. Hence, the inundation distances are much larger for a tsunami with the same amplitude. For shallow water flow over long inundation distances, the bottom friction becomes an important factor that cannot be ignored. The Manning formula for bottom friction is used for the inundation computation in Mele Bay. The Manning coefficient is not calibrated for the specific features of the Mele Bay topography. A generic value of n = 0.1 is used to account for the bottom roughness and also for the form drag of large-scale obstacles. This value has been used for tsunami inundation studies for the West Coast of US. The proper value of the bottom roughness for the Mele Bay needs to be developed. For smaller roughness, extend of the inundation can be larger and, therefore, larger topography coverage is needed for the simulation.

# 3 Simulation Results

Tsunami starts at Mele Bay as a small withdrawal of water from the shoreline, down to about –0.5m. The first positive tsunami wave reaches the Mele Bay coast about 14 minutes after the earthquake. The model animation does not show the approaching wave to be breaking until it reaches the shoreline. The inundation starts as a relatively slow flooding. However, when the crest of the tsunami approaches the shoreline at around 16 minutes, the flow velocities increase substantially and breaking tip of the wave rushes up to 8 meter above sea level, penetrating more than 1km inland. The maximum inundation occurred at around 18 minutes after the earthquake. Figure 3 shows the area of maximum computed water inundation in the computational area (contours of land elevation are also shown). It should be noted that south and east on-land computational boundaries act as reflective barriers for the water reaching these points, therefore, reflecting the flow back inside the computational area. This may artificially increase the computed wave elevation near those boundaries. In general, the results are consistent with both, the Port Vila simulation and historical tsunamis of the same magnitude. Port Vila model shows similar vertical amplitudes but smaller horizontal penetration due to steeper topography near shoreline. The $M_w$ 8.2 June 23, 2001 Camana tsunami in Peru was generated by a subduction zone earthquake similar to the considered scenario (E. Okal et al, 2002). It demonstrated similar inundation amplitudes (from 5 to 9 meters near the source) and penetration distances (up to 1.5 km) at places with similar flat topography.

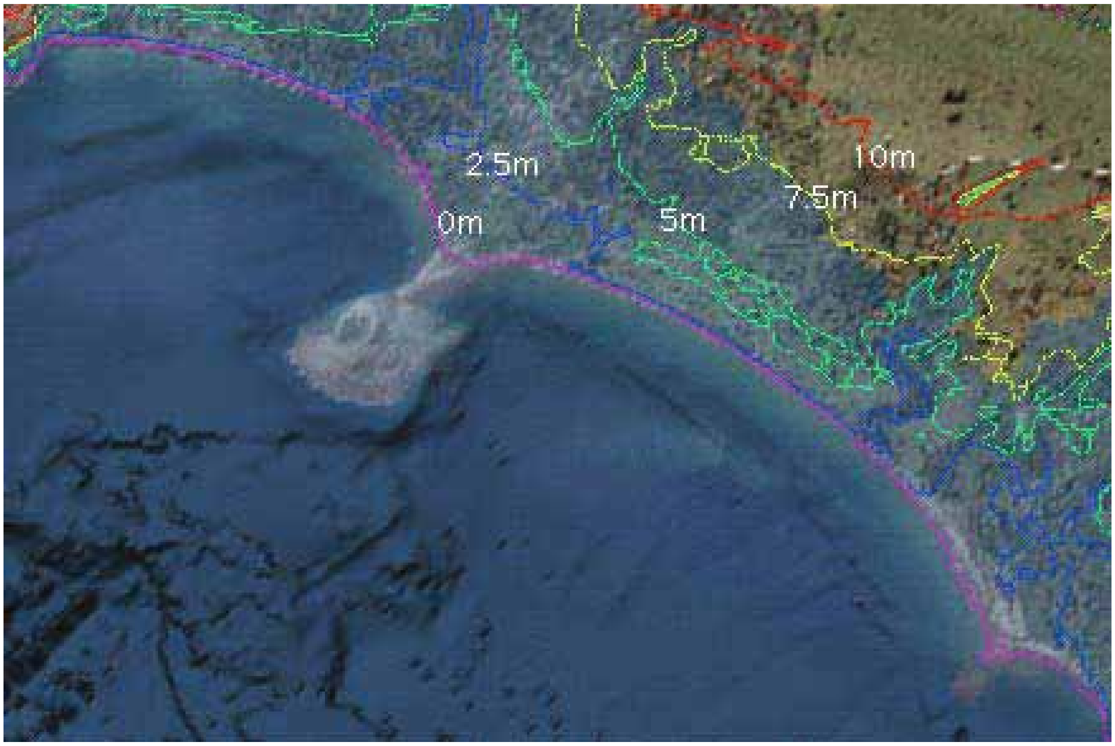

**Figure 3. Maximum computed inundation area is shown as a transparent blue fill. Contours of land elevation are shown for reference as colored lines.**

# 4 Conclusions

This study has performed numerical modeling of tsunami inundation at Mele Bay area of Efate Island. The Mw 8.1 earthquake is considered as a “worst case” tsunami generation scenario. The model produces up to 9 meters of vertical inundation and water penetration of up to 1km inland, which is consistent with similar historical events at similar settings. The results of this project lay ground for a full-scale tsunami risk assessment study for Port Vila and other Vanuatu sites.

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# Appendix 5a

# Risk and Vulnerability Assessment for Selected Building Types on the Island of Efate, Vanuatu

*by*

**Stan Goosby**

Pacific Disaster Center, Hawaii, USA

**SOPAC JOINT CONTRIBUTION REPORT 147**

*December, 2003*

Pacific Disaster Center

# Risk and Vulnerability Assessment for Selected Building Types on the Island of Efate, Vanuatu

**Prepared January 2003**

# Risk and Vulnerability Assessment for Selected Building Types on the Island of Efate, Vanuatu

## 1 Introduction

In an attempt to quantify the impacts of catastrophes in Pacific Island countries, the South Pacific Applied Geoscience Commission (SOPAC) has chosen Port Vila and Mele on the Island of Efate in Vanuatu as pilot study areas for investigating methodologies to support the development of a realistic mechanism for providing catastrophe insurance in the Pacific region.

The Pacific Disaster Center (PDC) has been collaborating with SOPAC to demonstrate a methodology for assessing the flood losses to selected buildings in the Port Vila and Mele areas from an earthquake-generated tsunami. The PDC has provided SOPAC an initial demonstration of its methodology, which is the basis of this report, through the application of its predictive modeling capabilities, data and information resources, analytical tools, and by engaging an expert in tsunami modeling as a consulting scientist.

In order to anticipate the impact of the tsunami hazard, the PDC team has implemented a Risk and Vulnerability Assessment (RVA) methodology, which is applicable to a variety of natural and human-induced hazards for providing quantitative assessments of potential impacts of disasters. This methodology can contribute significantly to mitigation and response planning thereby avoiding and/or offsetting the effects of potential disasters. In order for this methodology to be successful:

- A comprehensive understanding of the risk is required.
- Knowledge of appropriate physical models must be applied.
- Robust and applicable data and information resources appropriate to predictive models and analytical methods must be acquired.

Applications of predictive modeling, high performance computing, Geographic Information System (GIS) resources, scientific visualization and animation provide a very powerful capability for assessing the potential impact of hazards on built environments.

To fully address the range of tsunami inundation scenarios would require access to higher resolution data than was available during this project. The additional data needed to assess the impacts of tsunami-based inundation would include near-shore bathymetry, a high-resolution digital elevation model, and building inventory information.

The section that follows will provide background information on tsunamis, including a definition, causes and characteristics.

# 2 Background Information

On November 26,1999, an undersea earthquake of magnitude ($M_w$) 7.3 struck the Vanuatu archipelago. The epicenter was 200 kilometers east of Pentecost Island. A tsunami of 1 to 5 meters struck Pentecost Island 30 minutes after the earthquake and destroyed homes in villages along the island's southern coast killing at least 5 people.

On January 3, 2002, an undersea earthquake of magnitude ($M_w$) 7.1 struck the Vanuatu archipelago and generated a tsunami, which reached the Port Vila Harbor some 15 minutes later. The tsunami recorded a water height (amplitude) of 0.8m on the tide gauge located at the Port Vila Wharf. Several eyewitnesses observing different parts of the harbor placed the water height at around 1.5m above the tides. Fortunately, the tsunami occurred during some of the lowest tides of the year.

Since 1990, there have been 82 tsunamis worldwide, of which 10 were destructive, claiming more than 4,000 lives. One of the most destructive of these occurred on July 17, 1998 in Papua New Guinea (PNG) when an earthquake of magnitude ($M_w$) 7 struck the north central coast of PNG. Shortly after the earthquake, a tsunami of 7 to 15 meters destroyed the villages of Sissano, Warupu, Arop and Malol, killing at least 2,100 people and displacing over 5,000.

## 1.1. Definition

Tsunami (soo-NAH-mee) is a Japanese word, which translates in English as "harbor wave," and is now used internationally to describe a series of waves of extremely long wavelength and long period traveling across the ocean. The public sometimes refers to tsunamis as "tidal waves," which is a misnomer; although a tsunami's impact upon a coastline is dependent upon the tidal level at the time of impact, tsunamis are unrelated to the tides. Tides result from the gravitational influences of the moon, sun, and planets on the earth's oceans. The scientific community once referred to tsunamis as "seismic sea waves," which is also misleading. "Seismic" implies an earthquake-related generation mechanism, but a non-seismic event such as a landslide, meteorite impact, or sub-marine volcanic eruption can generate a tsunami as well.

## 1.2. Causes of Tsunamis

In fact, any disturbance that displaces a large volume of water from its equilibrium position can generate a tsunami. In the case of earthquake-generated tsunamis, the earthquake causes the sea floor to abruptly uplift or subside. This abrupt change or deformation of the sea floor disturbs the overlaying water column from its equilibrium position resulting in the generation of a tsunami.

Submarine landslides, which often accompany large earthquakes, can also generate tsunamis from the sudden down slope movement and redistribution of sediment and rocks across the sea floor. Similarly, a violent submarine volcanic eruption can create an impulsive force that uplifts the water column from its equilibrium position thereby generating a tsunami. In 1883, Indonesia's Mt. Krakatoa violently erupted and generated a tsunami that killed over thirty thousand people. Conversely, supermarine (above water) landslides and space born impacts can disturb the water column by the transfer of momentum from falling debris to the water into which the debris falls. In 1958, a huge landslide generated a 1,722-foot (525 meter) tsunami in Lituya Bay, Alaska. In general, tsunamis generated by these non-seismic mechanisms usually dissipate quickly and rarely affect coastlines far from the source area.

## 1.3. Characteristics of Tsunamis

Tsunamis are shallow-water waves, but are different from the wind-generated waves many have observed from the beach. Wind-generated waves usually have a period (the time between two successive waves) of five to twenty seconds and a wavelength (the distance between two successive waves) of about 330 to 660 feet (100 to 200 meters). Tsunamis in deep water can have a wavelength greater than 300 miles (482 kilometers) and a period of about an hour. This is very different from the normal California type tube wave, which generally has a wavelength of about 330 feet (100 meters) and a period of about ten seconds, as depicted in ***Figure 2.1***.

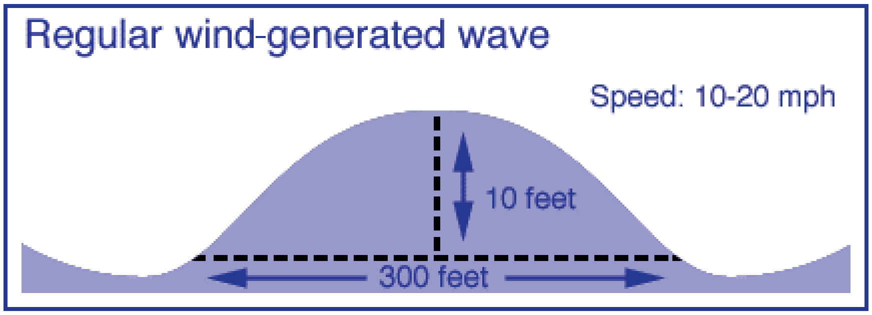

***Figure 2.1: Regular Wind-generated Wave***

As mentioned above, tsunamis are shallow-water waves, which means that the ratio between water depth and wavelength is very small. These shallow-water waves move at a speed equal to the square root of the product of the acceleration of gravity ($9.8 m/s^2$) and the water depth, so the deeper the water, the faster and shorter the wave. For example, when the ocean is 20,000 feet deep, a tsunami travels at the speed of a jet airplane, 550 miles per hour, shown in ***Figure 2.2.***

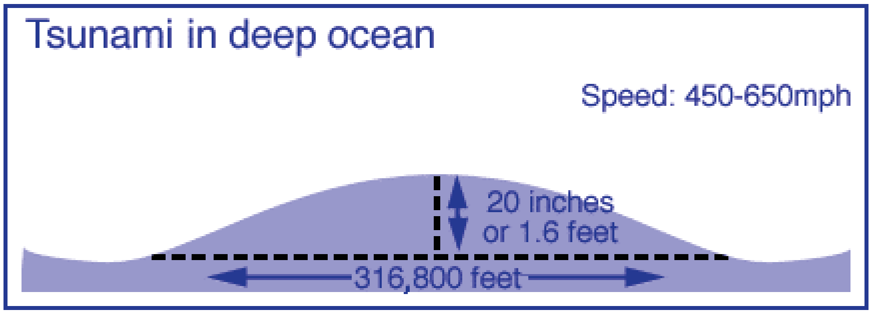

***Figure 2.2: Tsunami in Deep Ocean***

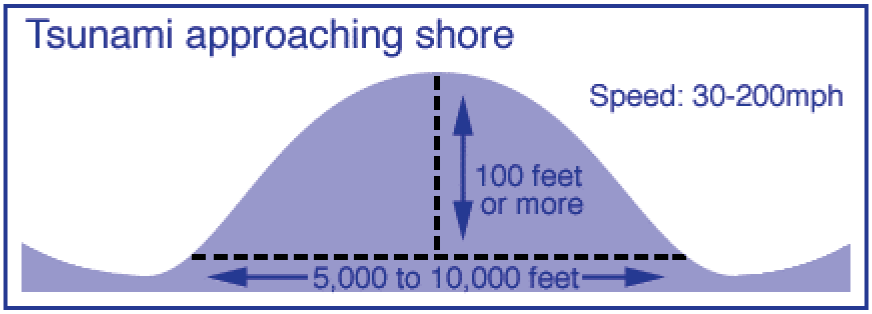

*Figure 2.3: Tsunami Approaching Shore*

Tsunami waves have a very long reach, and may transport destructive energy from the initial source location to coastlines thousands of miles or kilometers away. As a tsunami approaches the shore, its speed decreases, and its height increases as depicted in **Figure 2.3**. It may appear as a rapidly rising or falling tide, or a series of breaking waves. Coastal features, such as reefs, bays, and harbor entrances, as well as the slope of the beach, all help to modify the tsunami as it approaches the shore.

# 3 Methodology

This section highlights the methodology used by the PDC in the assessment of tsunami flood losses to selected building types located within the Port Villa and Mele areas on the Island of Efate.

## 1.4. Scenario Development

Develop a hypothetical, but plausible earthquake-generated tsunami event based on seismicity for the Island of Efate.

## 1.5. Predictive Tsunami inundation

Utilize the Method of Splitting Tsunami Mofjeld (MOST) model to estimate the maximum tsunami inundation resulting from a hypothetical earthquake scenario.

## 1.6. Flood Loss Analysis

Use Geographic Information System (GIS) tools to assess the impact of flood losses to selected building types.

# 4 Flood Loss Assessment

This section details the flood loss assessment process, which resulted in the creation of a series of maps and information products that can be used in planning for, or mitigating against, tsunami induced flooding.

## 1.7. Scenario Development

The scenario developed for this assessment depicts a tsunami generated by an inverse thrust earthquake that ruptures at the interface between the subducting Australian plate and North Fiji Basin. The parameters used to characterize the earthquake included a Strike angle of 343 degrees, Dip angle of 36 degrees, and Slip angle of 90 degrees. The epicenter was located directly offshore of the Island of Efate at 17.590S and 167.829E. The magnitude ($M_w$) of the earthquake was 8.1, with a rupture area of $120x40km^2$. The magnitude was chosen to be the same as the strongest recorded earthquake in the region.

## 1.8. Predictive Tsunami Inundation

The Method of Splitting Tsunami Mofjeld (MOST) model was used to simulate tsunami evolution in both the Port Vila Harbor, and Mele Bay, and to estimate the maximum inundation based upon a hypothetical earthquake event. The model uses the shallow water wave formulation, as well as three nested grids of different resolutions (i.e., 10km, 4km, and 5m) to simulate the tsunami evolution from the deep-water tsunami source area to the shallow water depths of the Port Vila Harbor and Mele Bay. The narrative that follows describes tsunami wave behavior for the Port Vila Harbor only.

Based on the analysis of the model output, the tsunami begins to evolve shortly after the earthquake and reaches Port Vila Harbor about 10 minutes later. The first wave to reach the harbor is a small negative wave, originated from the subsidence of the tsunami source. This is typical for earthquakes in subduction zones. As a result, the tsunami starts at Port Vila as a withdrawal of water from the harbor through a relatively narrow entrance. The first positive wave enters the Port Vila Harbor approximately 14 minutes after the generation of tsunami. A computer animation created for this project illustrates the computed tsunami evolution in Port Vila Harbor. The simulation shows very strong currents at both entrances around the Island of Ifara while the water is flowing into the Port Vila Harbor. The inundation of this shoreline starts 17 minutes after the earthquake. At the same time, the simulation shows violent flooding of the shallow northern part of the harbor. The maximum computed inundation is about 200 meters beyond the shoreline, as shown in ***Figure 4.1***.

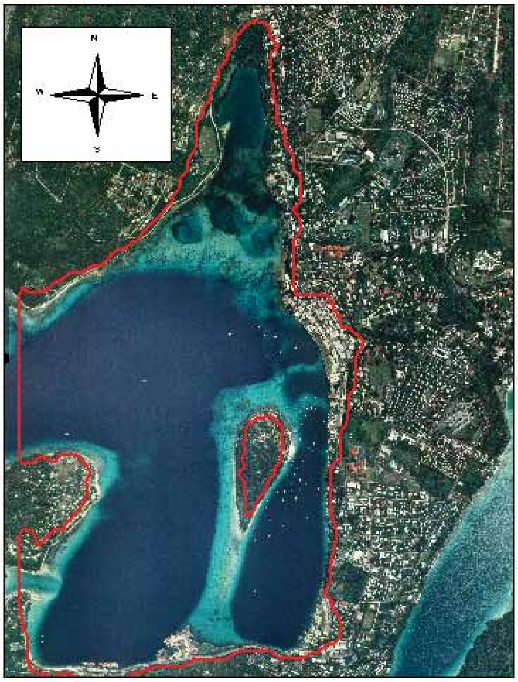

***Figure 4.1: Maximum computed inundation line for Port Vila***

Courtesy of Vasily Titov and the Pacific Disaster Center

After the first tsunami wave, which produces the largest inundation, the model shows continuous complex wave dynamics inside the Port Vila Harbor. The later tsunami waves continue to enter the harbor causing repeated flooding of already inundated areas. Water masses of different parts of the harbor separated by shallow bars interact with each other in a complicated resonant pattern creating strong currents over the shallow areas and whirlpool structures around the deeper part of the harbor, as shown in ***Figure 4.2.***

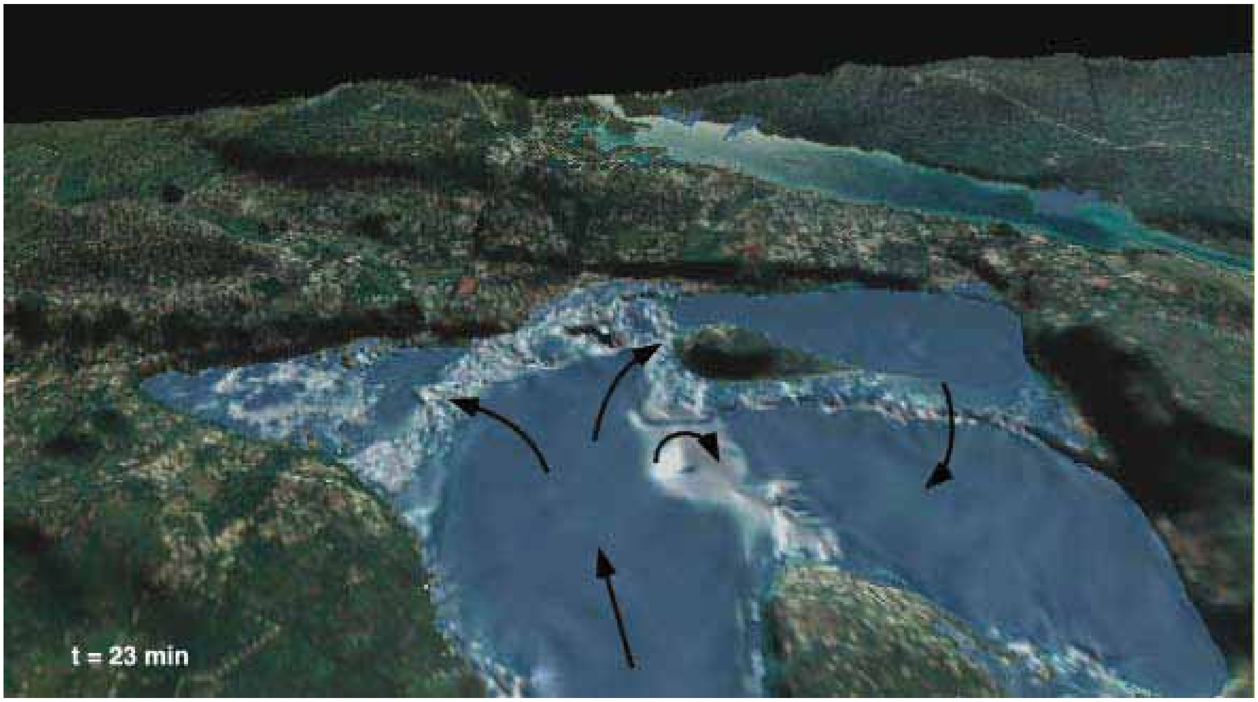

***Figure 4.2: Inundation of Port Vila at t=23 minutes after the generation of the tsunami***

Courtesy of Vasily Titov

## 1.9. Flood Loss Analysis

The flood loss analysis utilized the model generated inundation results, the SOPAC supplied building inventory data, and the building replacement cost to determine the numbers of selected building types (A, B, C, and D) within the Port Vila and Mele inundation zones, and to estimate the flood losses and flood states for those building types. **Table 4.1** provides a brief description of the building types used.

### Table 4.1: Description of the Building Types

| Building Types | Description |
|---|---|
| **A** | Well-engineered structures such as schools, hospitals |
| **B** | Concrete or concrete block structures |
| **C** | Wooden bungalows |
| **D** | Poor quality shacks and sheds |

Flood states represent the level of flooding (e.g. low, medium, and high) and are specified for each selected building within the inundation zone. The low flood state represents water heights of 0.25 meters to 2.75 meters, the medium flood state represents water heights of 2.76 meters to 4.25 meters, and the high flood state represents water heights in excess of 4.25 meters.

Additionally, the analysis makes three assumptions: 1) any A, B, C, and D buildings within the inundation zone are destroyed; 2) the building replacement cost includes the cost of demolition and debris removal; and 3) replacement cost is based on the building type and floor area, shown in **Table 4.2.** The replacement costs are based on best estimates by Kevin Lindsay of Riskman Ltd., New Zealand.

### Table 4.2: Replacement Cost Per Floor Area by Building Types

| **Building Types** | **Cost per Floor Area**<br>**Australian dollars per $m^2$** |
|---|---|
| **A** | 1,200 |
| **B** | 1,470 |
| **C** | 1,200 |
| **D** | 670 |

**Figure 4.3** identifies the A, B, C, and D buildings within the Port Vila inundation zone. The dark blue line denotes the maximum tsunami run-up, which extends 200m beyond the shoreline. Water height rose 6m above mean sea level.

*Figure 4.3: Port Vila Building Class Distribution*

Courtesy of Vasily Titov and the Pacific Disaster Center

**Tables 4.3** through **4.5** display the building count information, building floor area, and loss estimates for the Port Vila areas. **Tables 4.6** through **4.8** display building count information, building floor area, and loss estimates for the Mele area.

**Table 4.3** shows the number of A, B, C, and D buildings located within the Port Vila tsunami inundation zone in each of the three flood states. In addition, this table shows the percentage of A, B, C, and D building types for each flood state. Based on the table, there are a total of 212 buildings within the inundation zone of which 34 (16%) are A buildings, 103 (49%) are B buildings, 68 (32%) are C buildings, and 7 (3%) are D buildings. The B and C buildings account for 81% of the buildings.

**Table 4.3: Port Vila Flood State by Building Type**

| Building Type | Low Flood State | | Medium Flood State | | High Flood State | | |
|---|---|---|---|---|---|---|---|
| | Count | Count (%) | Count | Count (%) | Count | Count (%) | Total Count |
| A | **6** | 8.2 | **19** | 20.0 | **9** | 20.5 | **34** |
| B | **44** | 60.3 | **47** | 49.5 | **12** | 27.3 | **103** |
| C | **19** | 26.0 | **26** | 27.4 | **23** | 52.3 | **68** |
| D | **4** | 5.5 | **3** | 3.2 | **0** | 0 | **7** |
| Total | **73** | 100.0 | **95** | 100.0 | **44** | 100.0 | **212** |

**Table 4.4** shows the number and flood area of type A, B, C, and D buildings located within the tsunami inundation zone by flood state. In addition, this table provides the total area for each building type in square meters. According to the table, the 212 buildings occupy a total floor area of 27,750m$^2$ of which 5,700m$^2$ (21%) are A buildings, 13,125m$^2$ (47%) are B buildings, 8,450m$^2$ (30%) are C buildings, and 475m$^2$ (2%) are D buildings. The B and C buildings account for 77% of the total floor area.

**Table 4.4: Port Vila Flood Area by Building Type**

| Building Type | Low Flood State | | Medium Flood State | | High Flood State | | |
|---|---|---|---|---|---|---|---|
| | Count | Area | Count | Area | Count | Area | Total Area m2 |
| A | 6 | **1,650** | 19 | **3,100** | 9 | **950** | **5,700** |
| B | 44 | **5,300** | 47 | **6,200** | 12 | **1,625** | **13,125** |
| C | 19 | **1,775** | 26 | **4,075** | 23 | **2,600** | **8,450** |
| D | 4 | **275** | 3 | **200** | 0 | **0** | **475** |
| Total | 73 | **9,000** | 95 | **13,575** | 44 | **5,175** | **27,750** |

**Table 4.5** shows the flood losses in Australian (AU) dollars by building type count and flood state. The loss values were calculated by simply multiplying the respective areas listed in **Table 4.4**, by the replacement cost estimates in **Table 4.2**. From the table, losses total

36,592,000 AU dollars and of the losses 19% are building type A, 53% are building type B, 27% are building type C, and 1% are building type D. The B and C buildings account for 80% of the losses.

### Table 4.5: Port Vila Flood Losses in AU Dollars by Building Type

| Building Type | Building Count | Total Losses |
|---|---|---|
| A | 34 | 6,840,000 |
| B | 103 | 19,293,750 |
| C | 68 | 10,140,000 |
| D | 7 | 318,250 |
| Total | 212 | 36,592,000 |

**Figure 4.4** shows the A, B, and C buildings within the Mele inundation zone (there are no type D buildings in Mele). The dark blue line denotes the maximum tsunami run-up, which extends 2000m beyond the shoreline. Water height rose 7m above mean sea level.

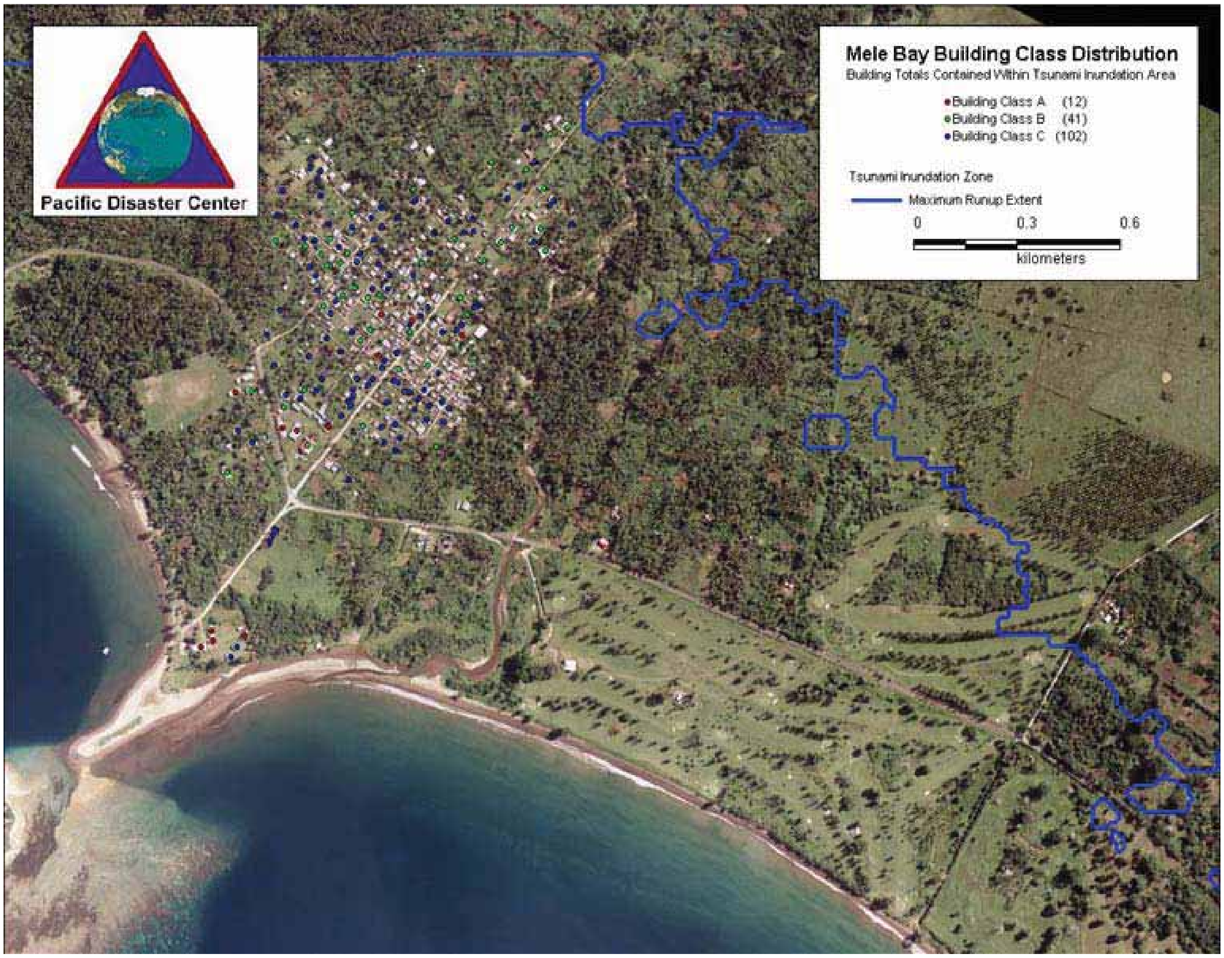

*Figure 4.4: Mele Building Class Distribution*

Courtesy of Vasily Titov and the Pacific Disaster Center

**Tables 4.6** through **4.8** display the building count information, building floor area, and loss estimates for the Mele area. **Table 4.6** shows the number of A, B, C, and D buildings located within the Mele tsunami inundation zone in each of the three flood states. Again, the low flood state equals water heights of 0.25 meters to 2.75 meters, the medium flood state denotes water heights of 2.76 meters to 4.25 meters, and the high flood state represents water heights in excess of 4.25 meters. This table also shows the percentage of A, B, C, and D building types in each flood state. As indicated in the table, a total of 155 buildings are located within the Mele inundation zone, 12 (8%) of which are building type A, 41 (26%) are building type B, 102 (66%) are building type C, and 0 (0%) are building type D. The B and C buildings account for 92% of the total number of buildings.

**Table 4.6: Mele Flood State by Building Type**

| Building Type | Low Flood State | | Medium Flood State | | High Flood State | | |
|---|---|---|---|---|---|---|---|
| | Count | Count (%) | Count | Count (%) | Count | Count (%) | Total Count |
| A | **0** | 0 | **4** | 4.2 | **8** | 25.0 | **12** |
| B | **13** | 48.1 | **23** | 24.0 | **5** | 15.6 | **41** |
| C | **14** | 51.9 | **69** | 71.8 | **19** | 59.4 | **102** |
| D | **0** | 0 | **0** | 0 | **0** | 0 | **0** |
| Total | **27** | 100.0 | **96** | 100.0 | **32** | 100.0 | **155** |

**Table 4.7** shows the number and flood area of type A, B, C, and D buildings located within the Mele tsunami inundation zone by flood state. In addition, this table provides the total area for each building type. The table shows that 155 buildings occupy a total area of 21,672m$^2$, of which 2,788m$^2$ (13%) are A buildings, 6,917m$^2$ (32%) are B buildings, 11,967m$^2$ (55%) are C buildings, and 0m$^2$ (0%) are D buildings. The B and C buildings account for 87% of the total floor area.

**Table 4.7: Mele Flood Area by Building Type**

| Building Type | Low Flood State | | Medium Flood State | | High Flood State | | |
|---|---|---|---|---|---|---|---|
| | Count | Area | Count | Area | Count | Area | Total Area m2 |
| A | 0 | **0** | 4 | **662** | 8 | **2,126** | **2,788** |
| B | 13 | **2,078** | 23 | **3,392** | 5 | **1,447** | **6,917** |
| C | 14 | **1,568** | 96 | **8,366** | 0 | **2,033** | **11,967** |
| D | 0 | **0** | 0 | **0** | 0 | **0** | **0** |
| Total | 27 | **3,646** | 96 | **12,420** | 32 | **5,606** | **21,672** |

**Table 4.8** shows the Mele flood losses in Australian (AU) dollars by building type and flood level. The loss values were calculated by multiplying the respective areas listed in **Table 4.7**, by the replacement cost estimates in **Table 4.2**. As indicated in **Table 4.8**, total losses are 27,873,990 AU dollars, and of the losses 12% are building type A, 36% are building type B, 52% are building type C, and 0% are building type D. The B and C buildings account for 88% of the losses.

**Table 4.8: Mele Flood Losses in AU Dollars by Building Type**

| Building Type | Building Count | Total Losses |
|---|---|---|
| A | 12 | 3,345,600 |
| B | 41 | 10,167,990 |
| C | 102 | 14,360,400 |
| D | 0 | 0 |
| Total | 155 | 27,873,990 |

# 5 Summary of Results

There are 212 type A, B, C, and D buildings within the Port Vila inundation zone, which extends 200m beyond the shoreline. In this case, water heights rose to 6m above mean sea level. The estimated losses or cost of replacing these buildings is 36,592,000 AU dollars. Of the losses, 19% are the A buildings, 53% are the B buildings, 27% are the C buildings, and 1% are the D buildings. The B and C buildings account for 80% of the losses.

Similarly, there are 155 type A, B, and C buildings within the Mele inundation zone, which extends 2000m beyond the shoreline. In this instance, water heights rose to 7m above mean sea level. The estimated losses or cost of replacing these buildings is 27,873,990 AU dollars and of the losses 12% are the A buildings, 36% are the B buildings, and 52% are the C buildings. The B and C buildings account for 88% of the losses.

# 6 Concluding Thoughts

In conclusion, this report demonstrates a methodology for assessing the flood losses to selected buildings in the Port Vila and Mele areas from an earthquake-generated tsunami. It also illustrates the expertise and resources required to do a quantitative risk and vulnerability assessment. The assessment undertaken here resulted in the creation of a series of maps and information products depicting the estimated flood losses to various building types within the Port Vila and Mele inundation zones from a hypothetical tsunamigenic earthquake.

# Appendix 5b

# Tsunami Inundation Modeling for Port Vila Harbour and Mele Bay, Efate Island, Vanuatu

*by*

**Stan Goosby**

Pacific Disaster Center, Hawaii, USA

**SOPAC JOINT CONTRIBUTION REPORT 147**

*December, 2003*

PACIFIC
DISASTER
CENTER
Managing Partner: EAST-WEST CENTER

# Tsunami Inundation Modeling for Port Vila Harbour and Mele Bay

## Efate Island, Vanuatu

July 3, 2003

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Special thanks to Dr. Vasily Titov for his contribution and expertise in tsunami modeling.

# 1 Tsunami Inundation Modeling

## 1.1 Introduction

The following report describes tsunami modeling for preliminary analysis of tsunami hazards for Port Vila Harbor and Mele Bay on the island of Efate, Vanuatu. This study includes modeling of tsunami generation for a hypothetical worst-case source scenario, tsunami propagation, and inundation at Port Vila Harbor and Mele Bay. The source scenario was developed based on historical seismicity of the area, historical tsunami records, and characteristics of the tectonic setting of the New Hebrides subduction zone. The results of the simulation have been analyzed and processed to produce a maximum inundation map and maximum computed wave heights for the computational area. Computer animations have been created to assess the tsunami inundation dynamics.

## 1.2 Tsunami Model

The tsunami propagation and inundation are simulated using the shallow water wave formulation by the MOST finite difference model (Titov and Synolakis, 1995, 1997, 1998). The MOST model uses spherical coordinates to account for the earth's curvature during tsunami propagation over long distances. The inundation boundary conditions are used to accurately simulate the process of tsunami inundation on land above sea level. The numerical dispersion is utilized to account for frequency dispersion during tsunami propagation. The nonlinear equations of the MOST model simulate complex wave dynamics near-shore including tsunami-induced strong currents and wave breaking. The model uses nested grids with three different grid resolutions to model tsunami evolution from deep water in the source area toward shallow depths of the Port Vila Harbor **(Figure 1).**

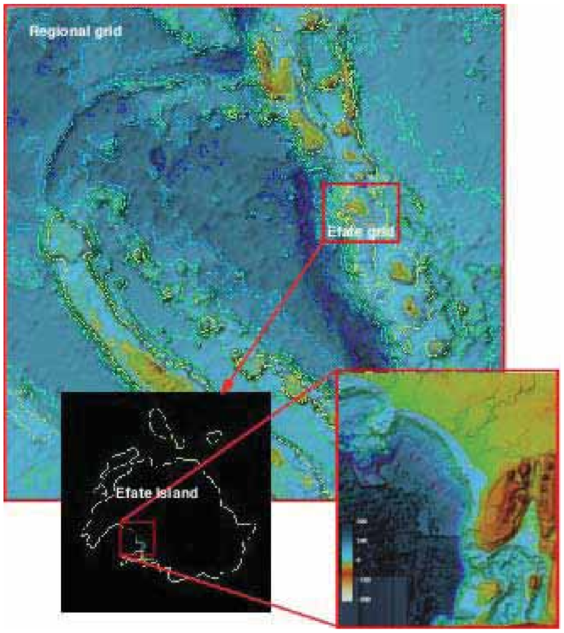

Figure 3:  Bathymetric grids for tsunami simulation

The tsunami dynamics are computed simultaneously for all grids providing seamless transitions between nested grids. Different bathymetry data were used for different grids. The regional grid of 2min resolution covers the area 23ºS – 14º S; 162ºE – 171ºE and uses global digital bathymetry inferred from the gravimetric data constrained by the available ship-track data (Smith and Sandwell, 1994). The grid around Efate Island uses GEODAS data. The ship-track data have been interpolated on a rectangular grid with 400m increments by the Pacific Disaster Center (PDC). It should be noted that the data from GEODAS has very few tracks – some with questionable quality – in the vicinity of Efate Island. Therefore, the resulted grid has low quality and only approximately reflects the bathymetry trends. The merged bathy-topo grid that covers areas of Port Vila and Mele Bay has the highest quality. It consists of the high-resolution bathymetry survey and the LIDAR topography data merged together in a GIS environment by the Pacific Disaster Center. Tsunami inundation onto land above Mean Water Level (MWL), a.k.a. tsunami run up, is computed only for the best quality finest resolution grid of Port Vila and Mele Bay. Titov and Synolakis (1997) have shown that the inundation computations may under-predict the run up values if the computational grid is coarser than 30m; while the 50m- and better- resolution grids provide adequate prediction even for extreme run up values of above 30m-elevation. Therefore, the resolution of 20 meters has been accepted for the run up computation of the Port Vila – Mele Bay area to ensure accuracy of the inundation predictions.

# 2 Worst-Case Scenario Simulation

## 2.1 Tsunami Source

Efate Island is part of the New Hebrides archipelago that forms an island arc along the New Hebrides trench. Along this trench, the Australian plate is subducting under the Pacific plate with the convergence rate estimates varying from 86 to 96 mm/yr (Calmant et al, 1997; Jarrard, 1986). The New Hebrides subduction zone is a part of the tectonically active system known to produce large earthquakes and tsunamis. The historical seismicity has a relatively short record for this area; nevertheless, it includes 19 earthquakes of magnitude 7 and greater that have generated tsunamis in the New Hebrides since 1863, including 4 earthquakes of magnitude 8.0 to 8.3 (Soloviev & Go, 1984; NGDC tsunami database http://www.ngdc.noaa.gov/seg/hazard/tsudb.shtml ).

The worst-case scenario is assumed as a typical tsunamigenic earthquake in a subduction zone, namely, an interplate inverse-thrust event that ruptures the interface between the subducting plates. There is not enough geological evidence to assign different seismic intensity along the New Hebrides subduction zone (or any subduction zone). Therefore, the probability of occurrence of such an event can be presumed uniform along the trench. It is logical, then, to assume that the worst-case scenario source be located under the continental slope in front of Efate Island. The magnitude of the earthquake scenario is $M_w = 8.1$ with the rupture area of $120x40km^2$. The fault plane is placed at the interface between the subducting Australian plate and the North Fiji Basin. The fault parameters are conformed to the inferred interface geometry (Jarrard, 1986; Pacheco et al., 1993): STRIKE = 343, DIP = 36, SLIP = 90. Based on historical seismicity, the repeat period of such an event in the New Hebrides subduction zone is not more than 100 years. A more precise evaluation of the probability of such an earthquake and estimates of the maximum possible magnitude can be done only after paleo-seismic studies in Efate Island, including paleo-tsunami investigations.

The tsunami generation simulation is based on an elastic deformation model of the earthquake source (Okada, 1985; Gusiakov, 1978), which assumes an incompressible liquid layer on underlying elastic half-space to characterize the ocean and the Earth's crust. The implementation of this elastic fault plane model utilizes a formula for static sea-floor deformation to calculate the initial conditions required for subsequent computations of tsunami propagation and inundation.

The computed bottom deformation has a typical pattern for a subduction zone earthquake with the subsidence near the coast and a larger uplift offshore **(Figure 2a).** Maximum computed uplift is 3.2m, maximum subsidence is –0.3m.

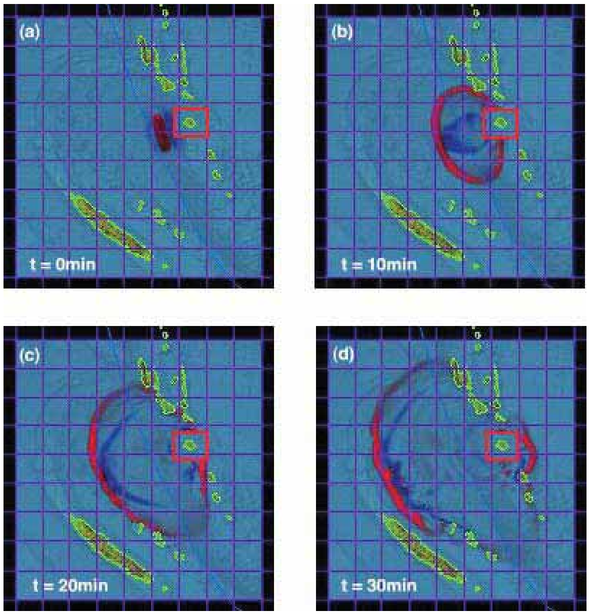

**Figure 4: Snapshots of computed tsunami propagation on a regional grid for the worst-case scenario. Positive amplitudes are red color, negative are dark blue**

## 2.2 Tsunami Simulation

Tsunami propagation over the regional grid is computed without inundation simulation. A reflective boundary is set along the shorelines. The wave heights computed over the regional grid demonstrate the propagation pattern of the tsunami along the New Hebrides Arc **(Figure 2).** The wave reaches Efate Island about 10 minutes after the earthquake. In 20 minutes the wave arrives at Loyalty Islands and after 30 minutes it is near New Caledonia.

Tsunami impact on south shores of Efate Island is computed with the inundation model that performs computations of the run up over the topography above MWL. The inundation heights are computed for the whole Mele – Port Vila grid.

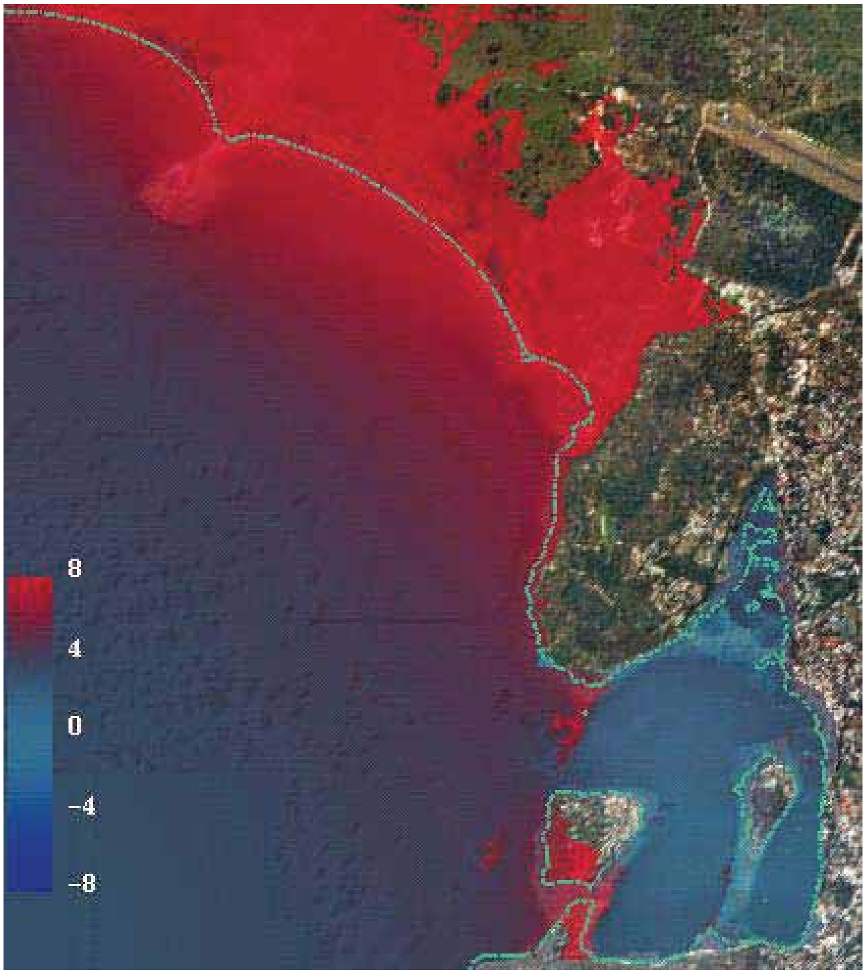

**Figure 3: Maximum computed wave heights and inundation for the high-resolution computational grid of Mele Bay and Port Vila Harbor for worst-case source scenario. The initial shoreline is shown as a blue contour line.**

**Figure 3** shows maximum computed wave heights over the inundation grid including run up values. The figure demonstrates substantial vertical run up values (up to 10 meters) and inundation distances (over 1 kilometer) computed for the relatively unprotected Mele Bay. The Port Vila Harbor shows relatively smaller run up and inundation distances in comparison with Mele Bay. However, the absolute values inside the Harbor are high (up to 6 meters run up and 200 meters inundation) making the modeled tsunami very destructive at the Port Vila waterfront. The economical and social impact in densely populated Port Vila may be even larger than in mostly unoccupied Mele Bay. The following sections describe the dynamic of the tsunami inundation in the Mele Bay and Port Vila.

### 2.2.1 Tsunami at Port Vila

The first wave to reach the Port Vila Harbor is a small negative wave, originated from the subsidence of the tsunami source. This is common for earthquakes in subduction zones due to the shape of the earthquake bottom deformation. As a result, the tsunami starts at Port Vila as a withdrawal of water from the harbor through a relatively narrow entrance. The first positive wave enters the Port Vila Harbor 14 - 15 minutes after the tsunami generation **(Figure 4a).**

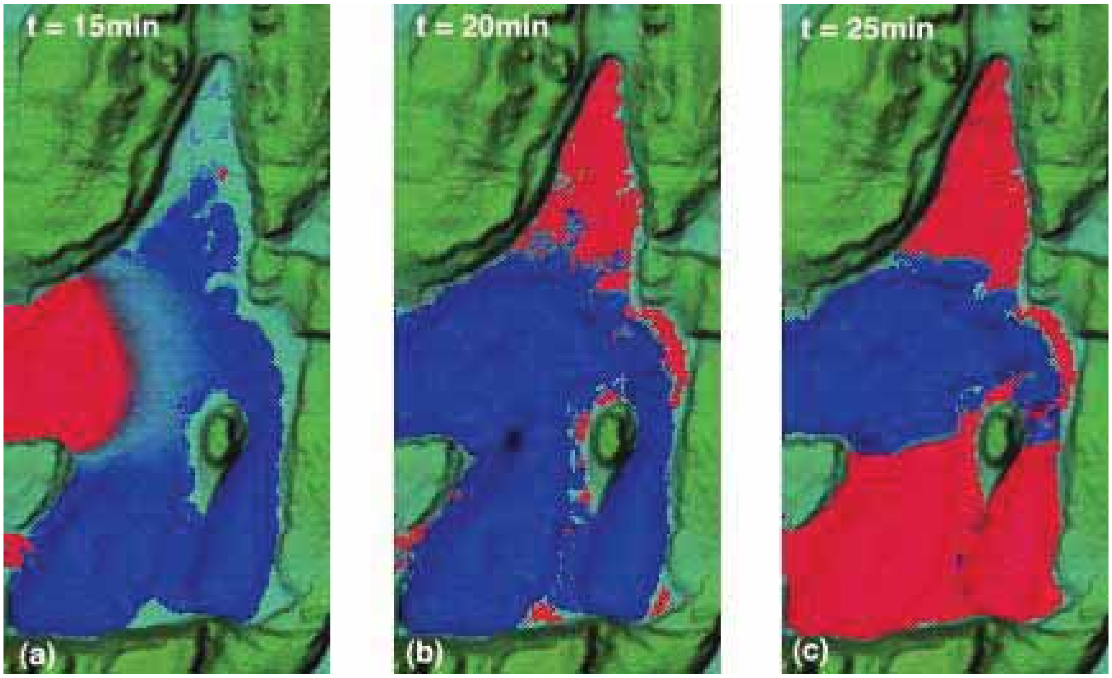

**Figure 4. Tsunami amplitudes during propagation inside the Port Vila Harbor for the worst-case scenario. Positive amplitudes are red color, negative are dark blue.**

A computer animation has been created to demonstrate tsunami evolution in Port Vila Harbor from this moment on – 14.5 minutes through 24.5 minutes after generation. The simulation shows very strong currents at both entrances around Ifara Island while the water is flowing into the Port Vila Harbor. The main water flux occurs through the northern entrance; therefore the opposite waterfront on the east shore of the Harbor is struck with the highest amplitudes. The inundation of this shoreline starts 17 minutes after the earthquake. At the same time the simulation shows violent flooding of the shallow northern part of the Harbor, where extensive inundations are also computed. Another area of substantial flooding is at the Navy Base located on the southeast part of the bay, where the inundation occurs 2 minutes later. The maximum computed inundation line for Port Vila Harbor is shown in **Figure 5**. The model computed up to 6m maximum vertical inundations inside the Port Vila Harbor and maximum water penetration of about 200m beyond the shoreline.

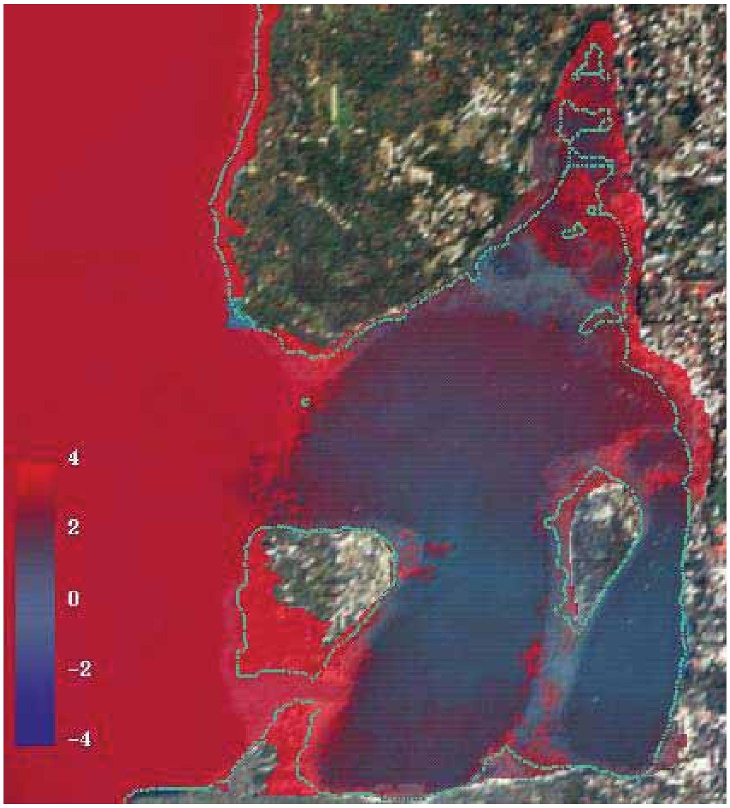

**Figure 5. Maximum computed wave heights and inundation in the Port Vila Harbor for worst-case source scenario. The initial shoreline is shown as a blue contour line.**

After the first tsunami wave, which produces the largest inundation, the model shows continuous complex wave action inside the Port Vila Harbor. The later tsunami waves continue to enter the harbor, causing repeated floods of already inundated areas. Water masses of different parts of the Harbor separated by shallow bars interact with each other in a complicated resonant pattern creating strong currents over the shallow barriers and whirlpool structures around the deeper part of the Harbor **(Figure 6).**

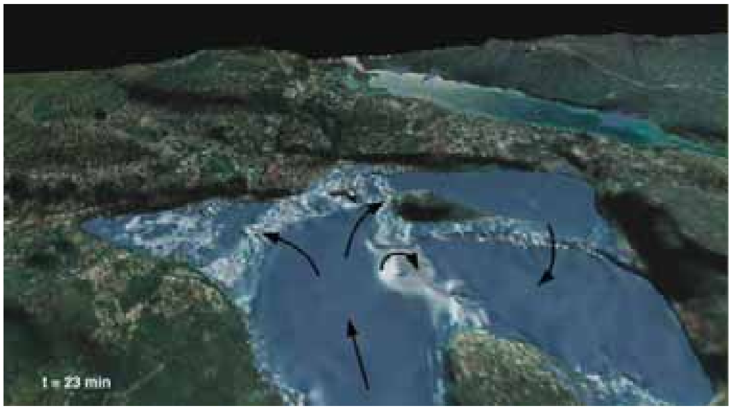

**Figure 6. Computed flow patterns during tsunami inundation of Port Vila Harbor for worst-case scenario. Birds-eye view of computed wave amplitudes 23 minutes after tsunami generation are shown. Arrows indicate flow directions; white color indicates strong currents.**

### 2.2.2 Tsunami at Mele Bay

The tsunami starts at Mele Bay also as a small withdrawal of water from the shoreline, down to 0.5m below MWL. The first positive tsunami wave reaches the Mele Bay coast about 14 minutes after the earthquake -- the same time that water starts to flow into Port Vila Harbor. However, at Mele Bay the inundation begins immediately. The model animation shows the approaching wave remaining intact until it reaches the shoreline. The inundation starts as a relatively slow flooding. However, when the crest of the tsunami comes up to the shoreline at around 16 minutes, the flow velocities increase substantially and the breaking tip of the wave rushes up to 9 meters above sea level, penetrating more than 1 kilometer inland.

The tsunami inundation at Port Vila shows smaller vertical amplitudes and horizontal penetration since it is protected by a shallow, narrow entrance and has topography near the shoreline. Inspection of the topography data near Mele Bay reveals that it has a very flat and low profile, with vast areas of the coast not more than 5-7 meters above the coastline. The maximum inundation occurred at around 18 minutes after the earthquake. **Figure 3** shows the area of maximum computed water inundation in the computational area (contours of land elevation are also shown). It should be noted that south and east on-land computational boundaries act as reflective barriers for the water reaching these points, therefore, reflecting the flow back inside the computational area. This may artificially increase the computed wave elevation near those boundaries. In general, the results are consistent with historical tsunamis of similar magnitude.

The $M_w$ 8.2 June 23, 2001 Camana tsunami in Peru was generated by a subduction zone earthquake similar to the considered scenario (E. Okal et al, 2002). It demonstrated similar inundation amplitudes (from 5 to 9 meters near the source) and penetration distances (up to 1.5 km) at places with similar flat topography.

The January 2, 2002 Port Vila earthquake and consequent tsunami has provided an opportunity to test the developed tsunami model against the field data collected after the event by the SOPAC team (G. Shorten, 2002). The comparison of the model results with the field data showed general agreement with eyewitness observations and amplitude measurements, therefore, increasing the confidence level of the worst-case modeling. Results of the model comparison are described in the previous reports.

# 3 Flood Loss Analysis

The flood loss analysis utilized the model generated inundation results, the SOPAC supplied building inventory data, and the building replacement cost to determine the numbers of selected building types (A, B, C, and D) within the Port Vila and Mele Bay inundation zones, and to estimate the flood losses and flood states for those building types. **Table 1** provides a brief description of the building types used.

Table 1: Description of the Building Types

| Building Types | Description |
|---|---|
| **A** | Well-engineered structures such as schools, hospitals |
| **B** | Concrete or concrete block structures |
| **C** | Wooden bungalows |
| **D** | Poor quality shacks and sheds |

Flood states representing three levels of flooding are specified for each selected building within the inundation zone. The Level I flood state is assigned to structures prone to less than

3 meters of flooding. Level II represents structures prone to 3 to 6 meters flooding. The Level III flood state refers to those structures prone to >6 meters of flooding.

Table 2: Flood Loss Estimation Criteria

| Flood State | Description |
|---|---|
| **Level I** | Structures prone to less than 3 meters flooding. |
| **Level II** | Structures prone to 3 to 6 meters flooding. |
| **Level III** | Structures prone to >6 meters flooding. |

Additionally, the analysis makes three assumptions: 1) any A, B, C, and D buildings within the inundation zone are destroyed; 2) the building replacement cost includes the cost of demolition and debris removal; and 3) replacement cost is based on the building type and floor area, shown in **Table 3.** The replacement costs are based on best estimates developed by Kevin Lindsay of Riskman Ltd., New Zealand. These assumptions should be considered simplified and preliminary, and can be improved on the basis of tsunami survey and engineering data. They are used here as a proof of concept study and to give the upper limit of the losses.

Table 3: Replacement Cost Per Floor Area by Building Types

| Building Types | Cost per Floor Area Australian dollars per $m^2$ |
|---|---|
| **A** | 1,200 |
| **B** | 1,470 |
| **C** | 1,200 |
| **D** | 670 |

**Figure 7** identifies 389 flooded buildings within the Port Vila – Mele Bay inundation zone. The buildings are color-coded as red, yellow, or green according to the flood state or level of flooding. **Table 2** (above) describes each flood state. The dark blue line denotes the maximum tsunami run-up, which extends 200m beyond the shoreline. Water height rose to 6m above mean sea level.

Figure 7: Spatial distribution of 389 inundated buildings within Port Vila – Mele Bay region. Courtesy the Pacific Disaster Center

**Table 4** through **Table 6** display building count information, building floor area, and loss estimates for the Port Vila – Mele Bay areas.

**Table 4** shows the number of A, B, C, and D buildings located within the Port Vila tsunami inundation zone in each of the three flood states. In addition, this table shows the percentage of A, B, C, and D building types for each flood state. Based on the table, there are a total of 389 buildings within the inundation zone of which 60 (15%) are A buildings, 137 (35%) are B buildings, 181 (47%) are C buildings, and 11 (3%) are D buildings. The B and C buildings account for 82% of the buildings.

Table 4: Port Vila – Mele Bay Flood State by Building Type

| Building Type | Level I Flood State | | Level II Flood State | | Level III Flood State | | |
|---|---|---|---|---|---|---|---|
| | Count | Count (%) | Count | Count (%) | Count | Count (%) | Total Count |
| A | **44** | 22.0 | **10** | 6.5 | **6** | 16.2 | **60** |
| B | **84** | 42.0 | **48** | 31.5 | **5** | 13.5 | **137** |
| C | **65** | 32.5 | **92** | 60.5 | **24** | 64.8 | **181** |
| D | **7** | 3.5 | **2** | 1.3 | **2** | 5.4 | **11** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Total** | **200** | 100.0 | **152** | 100.0 | **37** | 100.0 | **389** |

**Table 5** shows the number and flood area of type A, B, C, and D buildings located within the tsunami inundation zone by flood state. In addition, this table provides the total area for each building type in square meters. According to the table, the 389 buildings occupy a total floor area of 51,362m$^2$ of which 9,137m$^2$ (18%) are A buildings, 19,408m$^2$ (38%) are B buildings, 22,092m$^2$ (43%) are C buildings, and 725m$^2$ (1%) are D buildings. The B and C buildings account for 81% of the total floor area.

Table 5: Port Vila – Mele Bay Area by Building Type

| | **Level I Flood State** | | **Level II Flood State** | | **Level III Flood State** | | |
|---|---|---|---|---|---|---|---|
| | **Count** | **Area** | **Count** | **Area** | **Count** | **Area** | **Total Area m2** |
| **A** | **44** | 5,932 | **10** | 1,468 | **6** | 1,737 | 9,137 |
| **B** | **84** | 10,432 | **48** | 7,190 | **5** | 1,786 | 19,408 |
| **C** | **65** | 9,539 | **92** | 10,557 | **24** | 1,996 | 22,092 |
| **D** | **7** | 475 | **2** | 150 | **2** | 100 | 725 |
| **Total** | **200** | 26,378 | **152** | 19,365 | **37** | 5,619 | **51,362** |

Table 6: Port Vila – Mele Bay Flood Losses in AU Dollars by Building Type

| **Building Type** | **Building Count** | **Total Losses** |
|---|---|---|
| **A** | **60** | **10,964,400** |
| **B** | **137** | **28,529,760** |
| **C** | **181** | **26,510,400** |
| **D** | **11** | **485,750** |
| **Total** | **389** | **66,490,310** |

# 4 Conclusion

This study has performed numerical modeling of tsunami inundation at Mele Bay and Port Vila Harbor for the purpose of evaluating tsunami risk. The hypothetical worst-case tsunami simulation provides estimates of maximum tsunami inundation at Mele Bay and inside Port Vila Harbor. The model demonstrated much higher inundation at Mele Bay than at relatively protected Port Vila Harbor. However, the computed inundation values at Port Vila are still high and the model predicts a destructive tsunami inside the Harbor. This assessment has been partially confirmed by the January, 2002, Port Vila tsunami, which was generated by a much smaller source but demonstrated relatively high intensity inside the Port Vila Harbor (Shorten, 2002a,b). The results of this project lay the groundwork for a full-scale tsunami risk assessment study for Port Vila and other Vanuatu sites.

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# Appendix 6

## Preliminary Report and Vanuatu Government Risk Management System

*by*

**Kevin Lindsay**

Risk Management International Consulting (Riskman) Ltd, Port Vila, Vanuatu

**SOPAC JOINT CONTRIBUTION REPORT 147**

*December, 2003*

# 1 Report structure

## Expected Outputs

**1.** In addition to the table of building replacement costs already provided by Riskman, develop a complementary table of the relative value of typical loss of contents and business interruption costs in the context of Port Vila-Mele.

**2.** Prediction of the relative levels of loss to Vanuatu due to consequential risks following on from catastrophes such as temporary loss of tourism opportunities and damage to seaport or airport facilities in the Port Vila-Mele area, based on the current economic figures for Vanuatu.

**3.** Assessment of the extent to which people living in peri-urban communities such as Mele, Blacksands, Ifira and Malapoa are engaged in the Port Vila city economy, and the extent to which a disaster that affects these communities is reflected in the national economy.

**4.** Actual and relative figures for losses of all kinds, particularly in housing, public buildings and infrastructure, associated with TC Uma in February 1987

**5.** Actual and relative figures for losses of all kinds, particularly in housing, public buildings and infrastructure, associated with the Port Vila earthquake of January 2002.

**6.** Summary of the current requirements of the Vanuatu insurance industry for cyclone-readiness inspections and engineering certificates to be issued for private housing and public buildings.

**7.** Tabulation of the degree to which people from various communities and levels of society carry their own private/business insurance cover, and the amounts of cover adopted for various insured areas.

**8.** Assessment of the value of Government assets that are at risk in the Port Vila-Mele area given that a significant proportion of infrastructure is now in the hands of private organisations, and typical losses that might be faced in the event of catastrophic earthquake r cyclone events

**9.** Short history of the development of the Government Risk Management System (GRMS) together with a description of its importance in developing and instituting any national catastrophe insurance scheme, as well as an assessment of the success of the GRMS to date, and the factors affecting that success or otherwise

**10.** Analysis of the capacity of the Vanuatu Government to institute and support any catastrophe insurance scheme through either an insurance pool or a national disaster fund, or a combination of both.

# 2 Contents, Stock and Business Interruption Losses

**Output 1: In addition to the table of building replacement costs already provided by Riskman, develop a complementary table of the relative value of typical loss of contents and business interruption costs in the context of Port Vila- Mele**

Profile of building cost, rental income and the value of the contents (tenants) and tenants revenue/business interruption

**Calculate per Square metre**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Class A.** | **Repl** | **Rent** | **Contents** | **Stock** | **BI/Revenues** |
| Lower limit | 60,000 | 1,050 | 17,636 | 25,337 | 30,903 |
| Best estimate | 80,000 | 1,200 | 22,045 | 31,671 | 38,628 |
| Upper limit | 100,000 | 1,500 | 26,455 | 38,005 | 46,354 |
| **Class B.** | | | | | |
| Lower limit | 80,000 | 8,727 | 36,000 | Domestic | |
| Best estimate | 100,000 | 9,500 | 47,500 | modelling only | |
| Upper limit | 120,000 | 10,000 | 50,000 | | |
| **Class C.** | | | | | |
| Lower limit | 60,000 | 8,727 | 36,000 | 0 | |
| Best estimate | 80,000 | 9,500 | 47,500 | 0 | |
| Upper limit | 100,000 | 10,000 | 50,000 | 0 | |
| **Class D.** | | | | | |
| Lower limit | 20,000 | | | | |
| Best estimate | 40,000 | | | | |
| Upper limit | 50,000 | | | | |

Class A - the cost is about right for 1 or 2 storey buildings (no air con) but add 20% for commercial 3 storeys plus (no air-con).

All based on gross floor area.

**1. Replacement cost including all professional fees such as Architects & Engineers**
**2. Estimated revenue from rent including insurance claim preparation fees**
**3.1 Estimated replacement value of all commercial contents including additional costs**
**3.2 Estimated replacement value of all domestic contents including additional accommodation**
**4. Estimated commercial stock**
**5. Estimated revenue stream earned by the occupier business**

**Class A Notes**

Commercial rent calculation assumptions upper average

| | P/sq m | |
|---|---|---|
| On the main street | 2,000 | ground floor |
| On the main street over looking bay | 1,500 | second floor |
| Second street | 1,500 | ground floor |
| Second street no view of bay | 1,000 | second floor |
| | 1,500 | Upper average |

Estimated replacement value of all commercial contents

Based on a typical office business -
real estate, accountant, solicitor, insurance, small business

| | | |
|---|---|---|
| Contents - ffe, computers etc. | 4,409,097 | |
| | 200 | sq. meters average area |
| | 22,045 | |
| Stock | 6,334,146 | |
| | 200 | sq. meters average area |
| | 31,671 | |
| Business Interruption | | |
| Average sum insured | 7,725,688 | |
| | 200 | sq. meters average area |
| | 38,628 | |

***Not included in the above modelling***
Special higher values for commercial businesses
Estimated replacement value of all commercial contents

| | | |
|---|---|---|
| Contents - ffe, computers etc. | 48,798,667 | |
| | 500 | sq. meters average area |
| | 97,597 | |

Based on a typical business -
Merchandising, duty free

| | | |
|---|---|---|
| Stock | 42,750,000 | |
| | 500 | sq. meters average area |
| | 85,500 | |
| Business Interruption | | |
| Average sum insured | 76,608,729 | |
| | 500 | sq. meters average area |
| | 153,217 | |

***Not included in the above modelling***
Big ticket items such as Government, Unelco, Telecom

**Strictly confidential source**

| | |
|---|---|
| **SAMPLE** | 98 insured business clients |
| **CLASS** | Buildings, Contents, Stock, Business Interruption |
| **CURRENCY** | Vatu |

| **RANGE** | | **NO OF CLIENTS** | **TOTAL SUM INSURED** | **AVERAGE SUM INSURED** |
|---|---|---|---|---|
| 0 | 5,000,000 | **10** | 25,576,964 | 2,557,696 |
| 5,000,001 | 10,000,000 | **6** | 48,300,000 | 8,050,000 |
| 10,000,001 | 15,000,000 | **15** | 119,517,000 | 7,967,800 |
| 15,000,001 | 20,000,000 | **10** | 168,953,000 | 16,895,300 |
| 20,000,001 | 30,000,000 | **13** | 328,799,000 | 25,292,231 |
| 30,000,001 | 45,000,000 | **13** | 475,918,000 | 36,609,077 |
| 45,000,001 | 80,000,000 | **14** | 796,480,000 | 56,891,429 |
| 80,000,001 | 100,000,000 | **6** | 539,860,000 | 89,976,667 |
| 100,000,001 | 200,000,000 | **6** | 850,122,200 | 141,687,033 |
| OVER | 200,000,001 | **5** | 2,234,210,000 | 446,842,000 |
| | | **98** | 5,587,736,164 | |

| **Comments** | | |
|---|---|---|
| **Clients including business Interruption** | **31** | **32%** |
| **Clients including building cover** | **69** | **70%** |
| **Clients excluding buildings** | **21** | **21%** |

# 3 Consequential Risks

**Output 2: Prediction of the relative levels of loss to Vanuatu due to consequential risks following on from catastrophes such as temporary loss of tourism opportunities and damage to seaport or airport facilities in the Port Vila-Mele area, based on the current economic figures for Vanuatu**

The most representative example to study that may give a clue to the above is Tropical Cyclone UMA which hit Tafea, Shepherds and Efate in February 1987. Also the recent earthquake in January 2002 is a glimpse into what could be a devastating outcome.

Uma had a destructive effect on agricultural crops and infrastructure. In the Port Vila-Mele area certain sectors, for example Government infrastructure and tourism, suffered major physical and business interruption [7] loss. For some 12 months tourist arrivals were down. Other sectors such as construction and some professional sectors e.g. accountants, activities increased significantly.

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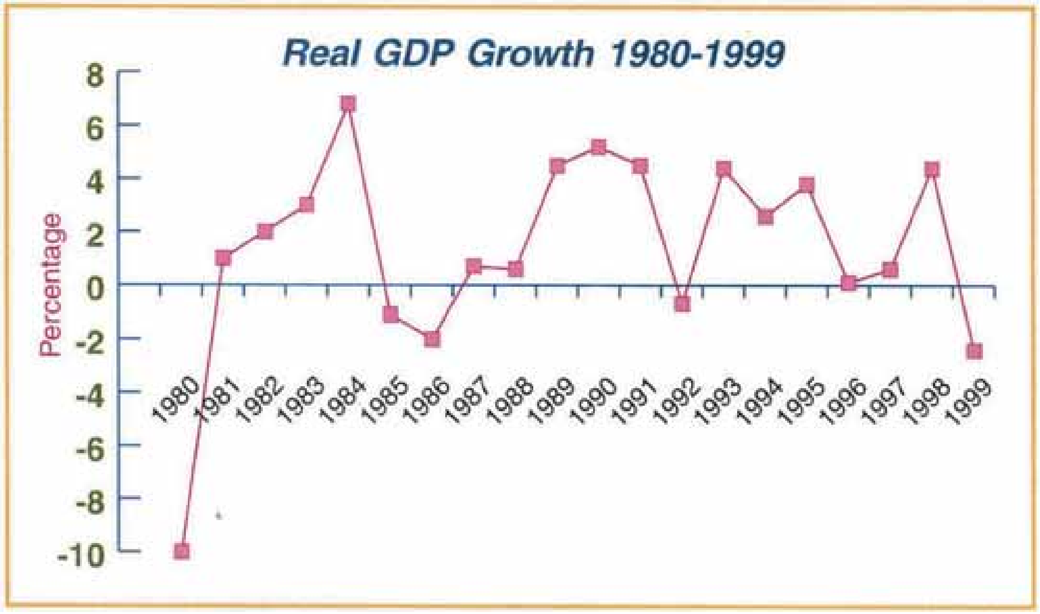
[7] Business Interruption (BI). In the context of insurance BI responds to reduction in turnover plus increased costs of working (e.g. alternative premises) less any savings in standard charges (e.g. electricity, wages) arising out of a claim under the property insurance policy. Some BI is not usually insured e.g. tourist reduction. Therefore while it can be assumed that insurance will make a major contribution there are uninsured losses to be taken into account.

Cyclone UMA had a severe impact on the Government's finances in the form of lower revenue and higher expenditure. There were immediate supply shortages following Cyclone UMA and prices increased by 17.5%. The fiscal deficit in 1987 increased to VT797 million from VT635 million in 1986. The trade balance deficit widened to VT279 million, due to the high number of imports to accommodate the reconstruction following UMA.[8]

Real economic growth in the 1987/88 period stagnated around 0.6 - 0.7% see chart below. However, in terms of GDP, the economy in Vanuatu did not show a decline. On the contrary, it grew moderately.[9]

1989 saw a recovery of Tourism and Copra with increases of 37% and 35% respectively.[10]



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[8] "20 years of Central Banking in Vanuatu" Published by Reserve Bank of Vanuatu; November 2000. Page 15

[3] "20 years of Central Banking in Vanuatu" Published by Reserve Bank of Vanuatu; November 2000 page 13

[10] "20 years of Central Banking in Vanuatu" Published by Reserve Bank of Vanuatu; November 2000 page 13

With respect to temporary loss of tourism opportunities and damage to seaport or airport it is useful to use Uma as a guide:

- There would be a sudden dip in GDP.
- Property loss and consequential loss would be high. The period of interruption will range from 3 months to 18 months. In some cases business will not survive.
- Some uninsured losses are what I would describe as "sleeping" since they are dictated by insurers by way of deductibles or specifically excluded property. While it can be considered somewhat "tricky" to "go there" in the context of this exercise go there we must – at some stage.

To help with the prediction, I was counting on the Department of Statistics through Government Statistician, Nancy Wells, to not not only provide information but to act as a think tank with Jeffrey Wilfred, Director General of Economics and Finance (now DG of Agriculture) and Manasseh Taris, Director General of Public Works. However their input was not forthcoming despite numerous requests.

Riskman also invited, optimistically, the major infrastructure players such as Telecom and Unelco, to share in an exercise as per 2.10 and that also did not succeed.

Riskman has developed a matrix of describing insured and uninsured losses and this, or something similar must *be developed* with the sectors and ideally coordinated through the Government Risk Management Committee – see attached file under Outcome 8 called 8.xls.

**Footnote Reference**[1] Business Interruption (BI). In the context of insurance BI responds to reduction in turnover plus increased costs of working (e.g. alternative premises) less any savings in standard charges (e.g. electricity, wages) arising out of a claim under the property insurance policy. Some BI is not usually insured e.g. tourist reduction. Therefore while it can be assumed that insurance will make a major contribution there are uninsured losses to be taken into account.

[1] "20 years of Central Banking in Vanuatu" Published by Reserve Bank of Vanuatu; November 2000. Page 15

[3] "20 years of Central Banking in Vanuatu" Published by Reserve Bank of Vanuatu; November 2000 page 13

[1] "20 years of Central Banking in Vanuatu" Published by Reserve Bank of Vanuatu; November 2000 page 13

[1] Riskman thanks Brian Dellit for his prompt and very courteous assistance

[1] No response to Riskman's requests

# 4 Peri-Urban Contribution to Economy

**Output 3: Assessment of the extent to which people living in peri-urban communities such as Mele, Blacksands, Ifira and Malapoa are engaged in the Port Vila city economy, & the extent to which a disaster that affects these communities is reflected in the national economy**

## Introduction

From a preliminary discussion with Nancy Wells the Government Statistician these areas contribution to the Port Vila economy can be viewed on two main levels:

- "Subsidence contribution" to approximately 22% of agriculture. Supply of fresh vegetables and fruit to the hospitality sector and the main market.
- Buses, taxis, labour to the service and industry and manufacturing sectors.

Department of Statistics through Government Statistician, Nancy Wells has provided the statistics below however I was anticipating direct input from Jeffrey Wilfred, Director Economics and General Finance to help with an assessment to which *the extent to which a disaster that affects these communities is reflected in the national economy.*

Their input was not forthcoming despite numerous requests.

**Resident Population of Port Vila**

| **Area** | **Pop'n** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Agathis East | 763 | 2.60% | Nambatri West | 705 | 2.40% | | | |
| Bauerfield | 3,186 | 10.85% | Nambatu East | 713 | 2.43% | | | |
| Blacksands | 4,744 | 16.16% | Nambatu West | 161 | 0.55% | | | |
| Bouganville North | 200 | 0.68% | Namburu Central (Simbolo) | 1,641 | 5.59% | | | |
| Bouganville South | 86 | 0.29% | Namburu North | 880 | 3.00% | | | |
| Burns Philip | 126 | 0.43% | Namburu South | 218 | 0.74% | | | |
| Colardeau | 147 | 0.50% | Ohlen Radio Station | 661 | 2.25% | | | |
| Ex-British Prison | 408 | 1.39% | Pango Road | 328 | 1.12% | | | |
| Fres Wota 1 | 1,825 | 6.22% | Post Office | 17 | 0.06% | | | |
| Fres Wota 2 | 657 | 2.24% | Public Works | 478 | 1.63% | Blacksands | 4,744 | 16.16% |
| Fres Wota 3 | 146 | 0.50% | Saratokora | 986 | 3.36% | Iririki Island Resort | 8 | 0.03% |
| George Pompidou | 426 | 1.45% | Seaside Futuna | 118 | 0.40% | Malapoa College | 484 | 1.65% |
| Honda Farm | 388 | 1.32% | Seaside Paama | 606 | 2.06% | Malapoa Estate | 349 | 1.19% |
| Hotel Le Lagoon | 49 | 0.17% | Seaside Tongoa | 777 | 2.65% | Malapoa Point | 27 | 0.09% |
| Hotel Le Meridien | 236 | 0.80% | Seven Star | 543 | 1.85% | **Total** | 5,612 | 19.12% |
| Independence Park | 462 | 1.57% | Stade | 564 | 1.92% | | | |
| Iririki Island Resort | 8 | 0.03% | Tagabe Central | 363 | 1.24% | | | |
| Jack Fong | 306 | 1.04% | Tagabe North | 586 | 2.00% | | | |
| Joint Court | 256 | 0.87% | Tagabe South | 340 | 1.16% | | | |
| Malapoa College | 484 | 1.65% | Tebakor Pressing | 364 | 1.24% | | | |
| Malapoa Estate | 349 | 1.19% | Teouma Road | 625 | 2.13% | | | |
| Malapoa Point | 27 | 0.09% | U.S.P | 395 | 1.35% | | | |
| Melcofe | 12 | 0.04% | Vila Central Hospital | 293 | 1.00% | | | |
| Nambatri East | 649 | 2.21% | Vila East School | 184 | 0.63% | | | |
| Nambatri North | 219 | 0.75% | Not Stated | 651 | 2.22% | | | |
| | | | **Total** | **29,357** | | | | |

| Population of Mele, Mele Bay, Mele Maat, Black Sands | |
|---|---|
| | |
| **Village/Area** | **Resident Population (Not Including visitors)** |
| Mele | 1,851 |
| Mele Bay | 115 |
| Mele Maat | 616 |
| Black Sands | 4,818 |

| Mele Population by Place of Residence | | | |
|---|---|---|---|
| **Village** | **Place** | **Population** | |
| Mele | Babual | 117 | |
| Mele | Imutu station | 48 | |
| Mele | Lakenatau | 490 | |
| Mele | Mele | 48 | |
| Mele | Waone St. | 40 | |
| Mele | Weisisi | 157 | |
| Mele | Worawia Station | 146 | |
| Mele | Tupunafare | 70 | |
| Mele | Lakenarau | 171 | |
| Mele | Warasivu | 250 | |
| Mele | Boukaliu | 76 | |
| Mele | Bangasole | 77 | |
| Mele | Bongoro | 131 | |
| Mele | No stated | 30 | |
| **Total** | | **1851** | |

| Blacksands Resident Population By Age Group and Gender | | | |
|---|---|---|---|
| **Age Group** | **Females** | **Males** | **Total** |
| 0-4 | 332 | 357 | 689 |
| 5-9 | 304 | 342 | 646 |
| 10-14 | 222 | 279 | 501 |
| 15-19 | 221 | 235 | 456 |
| 20-24 | 266 | 259 | 525 |
| 25-29 | 248 | 230 | 478 |
| 30-34 | 186 | 187 | 373 |
| 35-39 | 158 | 164 | 322 |
| 40-44 | 82 | 139 | 221 |
| 45-49 | 75 | 85 | 160 |
| 50-54 | 54 | 63 | 117 |
| 55-59 | 29 | 46 | 75 |
| 60-64 | 15 | 28 | 43 |
| 65-69 | 8 | 13 | 21 |
| 70-74 | 8 | 12 | 20 |
| 75-79 | 2 | 2 | 4 |
| 80-84 | 1 | 1 | 2 |
| 85-89 | 2 | 3 | 5 |
| 90+ | | 2 | 2 |
| Not Stated | 42 | 42 | 84 |
| Total Population | 2255 | 2489 | 4744 |

Above Tables available refer Section 3 - XL

# 5 Cyclone Uma Losses

**Output 4: Actual and relative figures for losses of all kinds, particularly in housing, public buildings and infrastructure, associated with TC Uma in February 1987**

1. The following information has been gathered by Riskman with the help of Brian Dellit [11] of Cunninghams, loss adjusters based in Australia.
2. These estimates appear on the following page.
3. After Uma hit there were approximately 12 loss adjusters engaged in a variety of insurance assessing for a period of 3 months. Brian's firm was involved with about 70% of the insured losses assessed.
4. A preliminary discussion puts the insured losses of the private sector at around A$25,000,000. It is unknown what sums were born by the private sector but we would estimate somewhere in the vicinity of $5,000,000; maybe higher.
5. We also estimate that Government infrastructure was damaged to about A$25,000,000. From memory Public Works was blown away and it was some 4.5 years before they had proper accommodation again. In our opinion Public Works demise was quite negative. It is essential for them to operate effectively immediately after a devastating loss. It is ironic that even after such an experience a new administration building was built but without cyclone shutters!
6. While there is no doubt the insurance market coped with the loss there was significant loss of cyclone insurance capacity immediately following the cyclone. For example QBE Insurance, at the same time as discharging their liability under their policy, cancelled all further cyclone cover.
7. Many insurance companies withdrew from the market e.g. Vanuatu General, Sun Alliance, National Pacific, American Home. The world's largest broker Marsh also withdrew. Although the cyclone had some influence on their decision, other commercial considerations were also a major factor. Immediately following UMA the only insurance market available to local business was the London market. Most of the domestic properties remained uninsured against cyclone for several months. This exposed the banks that had loans over the properties. Local insurance intermediaries placed policies into the London market.
8. Within 12 months local insurers regrouped and subject to new cyclone criteria agreed to insure buildings, contents and business interruption against cyclone.

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[11] Riskman thanks Brian Dellit for his prompt and very courteous assistance

## Cyclone "Uma", Vanuatu 1987

| Summary | AUD$ | Total claims | Number of claims | 2 largest commercial claims | |
|---|---|---|---|---|---|
| Commercial | | $15,000,000 | 214 | Buildings | $1,000,000 |
| Domestic | | $5,785,714 | 500 | Contents | $400,000 |
| Marine | | $7,142,857 | 50 | Stock | $100,000 |
| Government | | $25,000,000 | 0 | BI | $500,000 |
| **Total** | | **$52,928,571** | **764** | **Total** | **$2,000,000** |

| Commercial | | |
|---|---|---|
| Buildings | $8,571,429 | |
| Contents | $2,857,143 | |
| Stock | $714,286 | |
| BI | $2,857,143 | |
| **Total** | **$15,000,000** | **214** |

| Domestic/Rentals | Total claims | Number of claims | 2 largest domestic claims | |
|---|---|---|---|---|
| Buildings | $4,285,714 | | Buildings | $150,000 |
| Loss Rents | $714,286 | | Loss Rents | $10,000 |
| Contents | $714,286 | | Contents | $50,000 |
| Temporary Acc | $71,429 | | Temporary Acc | $0 |
| **Total** | **$5,785,714** | **500** | **Total** | **$210,000** |

| Marine | Total claims | Number of claims | 2 largest marine claims | |
|---|---|---|---|---|
| Ships | $5,714,286 | | Ships | $250,000 |
| Cargo | $714,286 | | Cargo | $100,000 |
| Pleasure boats | $285,714 | | Pleasure boats | $50,000 |
| Other | $428,571 | | Other | $0 |
| **Total** | **$7,142,857** | **50** | **Total** | **$400,000** |

Comments - Brian Dellit of Cunninghams Australia

Unfortunately this detail is based on memory and is not totally accurate. After 15 years, all records of claims have been destroyed. Cannot recall the Excesses applicable. Cannot recall exact number of claims, but I believe there were more than 700.

**Footnote Reference**

# 6 Port Vila January 2002 Earthquake Losses

**Output 5: Actual and relative figures for losses of all kinds, particularly in housing, public buildings and infrastructure, associated with the Port Vila earthquake of January 2002**

| **Earthquake January 2002** | |
|---|---|
| Estimated total insured commercial claims | A$6,010,735 |
| Estimated total insured domestic claims | A$2,355,798 |
| **Estimated insured damage** | **A$8,366,533** |
| Estimated total uninsured public buildings | A$1,00,0000 [12] |
| Estimated total uninsured infrastructure | A$1,000,000 [13] |
| *Estimated uninsured damage* | *A$2,000,000* |
| *Estimated total damage* | *A$10,366,533* |

Two loss-adjusting firms, Cunninghams of Brisbane Australia and McLarens of Fiji have been engaged in the assessing and adjusting. McLarens have been involved with about 80% of the insured losses assessed. The remedial work, under the supervision of McLarens has been more or less continuous through to December 2002.

Response from QBE Vanuatu 03 June 2002.

"I have discussed this matter with our Head Office and the information we are prepared to give to you is only the global cost of the earthquake. As indicated the other day this is about Vt300M. As at the end of May the total was Vt326M however as the repair of premises is completed we expect this may reduce slightly.

We are not prepared to give the splits you have requested between Commercial material damage and business interruption plus uninsured losses and the domestic material damage and loss of rents.

While we understand that you have a contract with SOPAC to provide disaster information, we believe however that due to your involvement with C&K Insurance and Consolidated Insurance Ltd it is not commercially appropriate for us to give you the detailed information you have requested".

**Footnote Reference**

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[12] No response to Riskman's requests

[13] No response to Riskman's requests

# 7 Cyclone Certification

**Output 6: Summary of the current requirements of the Vanuatu insurance industry for cyclone-readiness inspections and engineering certificates to be issued for private housing and public buildings**

1. In recognition of the highly damaging effect that cyclones can have, the Government of Vanuatu is high profiled in its endeavours to educate and instruct the population on protective measures. There is extensive coverage in the local telephone book and there is an excellent warning procedure through the countries media. Radio New Zealand International (SW service) also includes cyclone-warning bulletins.
2. In 1990 the Vanuatu Government introduced a draft building code, which not only deals with cyclone standards (based on Australian standard AS1170) but also earthquakes (based on the New Zealand standard).
3. Shuttering is carried out in such a way that the atmospheric pressure from the outside is equated to that inside a building to implode (opposite to explosion) due to uneven pressure inside and outside a building.
4. For commercial occupation risks Insurers require the issuing of a compliance cyclone certificate by the local engineer and/or architect. Preferably an engineer. This procedure is one that has been evolved by the insurance market and is working very well since there is no legislation yet passed to give legal teeth to the draft code. It understood that legislation will be passed in 2003 making the draft code law. The Insurance market in reality has policed the cyclone standards since cyclone UMA.
    - Fixed shutters of the traditional wooden type are hinged or secured to the building and are secured in place either by a bolt or locking device.
    - Fixed shutters similar to roller doors in function are either automated or manual.
    - Portable shutters are generally constructed of plywood that are fitted over glass windows/doors and are slotted into a channel one end and bolted at the other end.
    - The requirement for commercial buildings is to have all ground and first floor glass shutter protected.
5. For residential properties viz private dwellings and rented premises in domestic occupation, the local insurers have adopted the following questionnaire. However it should only be regarded as an interim procedure. With the insurance market becoming increasingly selective it is Riskman’s opinion that Vanuatu domestic property owners will have no option but to comply via an independent Engineers report.
6. Complying roller shutters are becoming more popular as these look good and also provide security features.

## Cyclone Questionnaire

## Complete one form for each House

**Name**
**____________________________________**

**Address of**
**property:___________________________________**

**Policy number ___________________**

If the answer to any question is "No", cyclone insurance cannot be provided.

1. If the walls of your home are of Fibro, Iron or Timber, an Engineer's certificate must be attached stating the building meets AS 1170 standards.

Attached Yes/No

2. If the walls are concrete block, have they been reinforced with concrete and iron rods?

Yes/No

3. Are cyclone screws and washers, (No. 14, Type 17) used to secure the roofing material?

Yes/No

4. Are the screws used to secure the roofing material at no greater spacing than 550 mm?

Yes/No

5. Does the building have Shutters on all Windows and external Glass Doors? If of external plywood, are they at least 15 mm thick?

Yes/No

6. If of battens, are they at least 25 mm thick and no more than 25 mm apart?

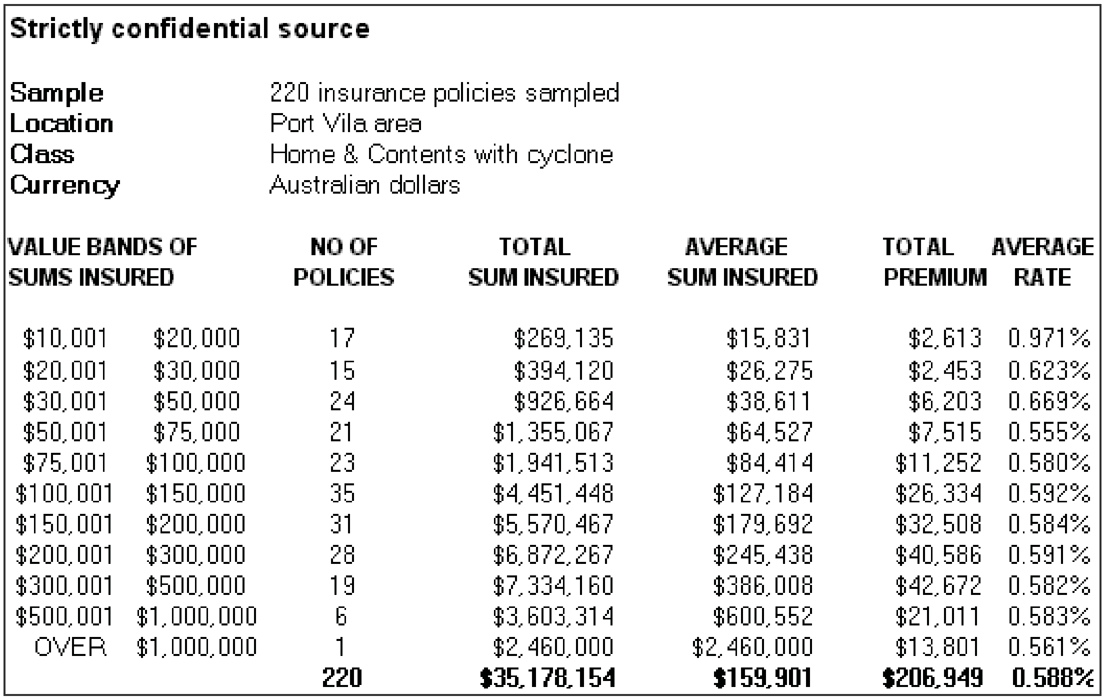
Yes/No

Signed ___________________________ Date ______________________

# 8 Penetration of Private Insurance

**Output 7: Tabulation of the degree to which people from various communities and levels of society carry their own private/business insurance cover, and the amounts of cover adopted for various insured areas**

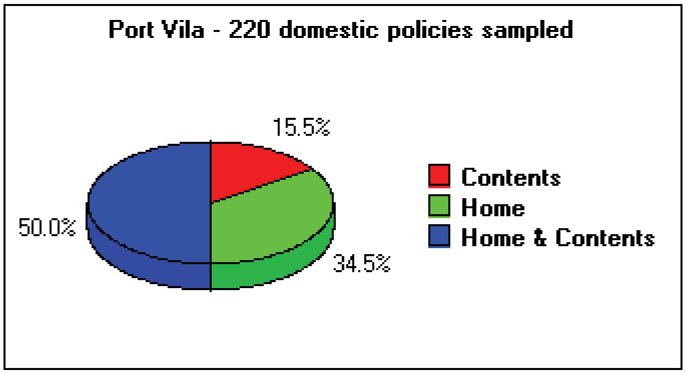
1. The following confidential tables will be useful in developing models as to the "built up" areas of Port Vila. The sample taken by Riskman was of 265 policies in the Port Vila and Santo areas including Ni Vanuatu and Expatriates. See the three value band tables below and following page.
2. Riskman would estimate that areas such as Mele would have less than 20% of buildings and contents insured. It is noted that properties, which qualify for a bank loan, would be insured. Perhaps a questionnaire could be developed to sample the Mele community during the workshop to be held January 2003.
3. The amounts of cover adopted by insurance buyers appear adequate. Evidenced by the recent earthquake and personal experience over time in Port Vila.

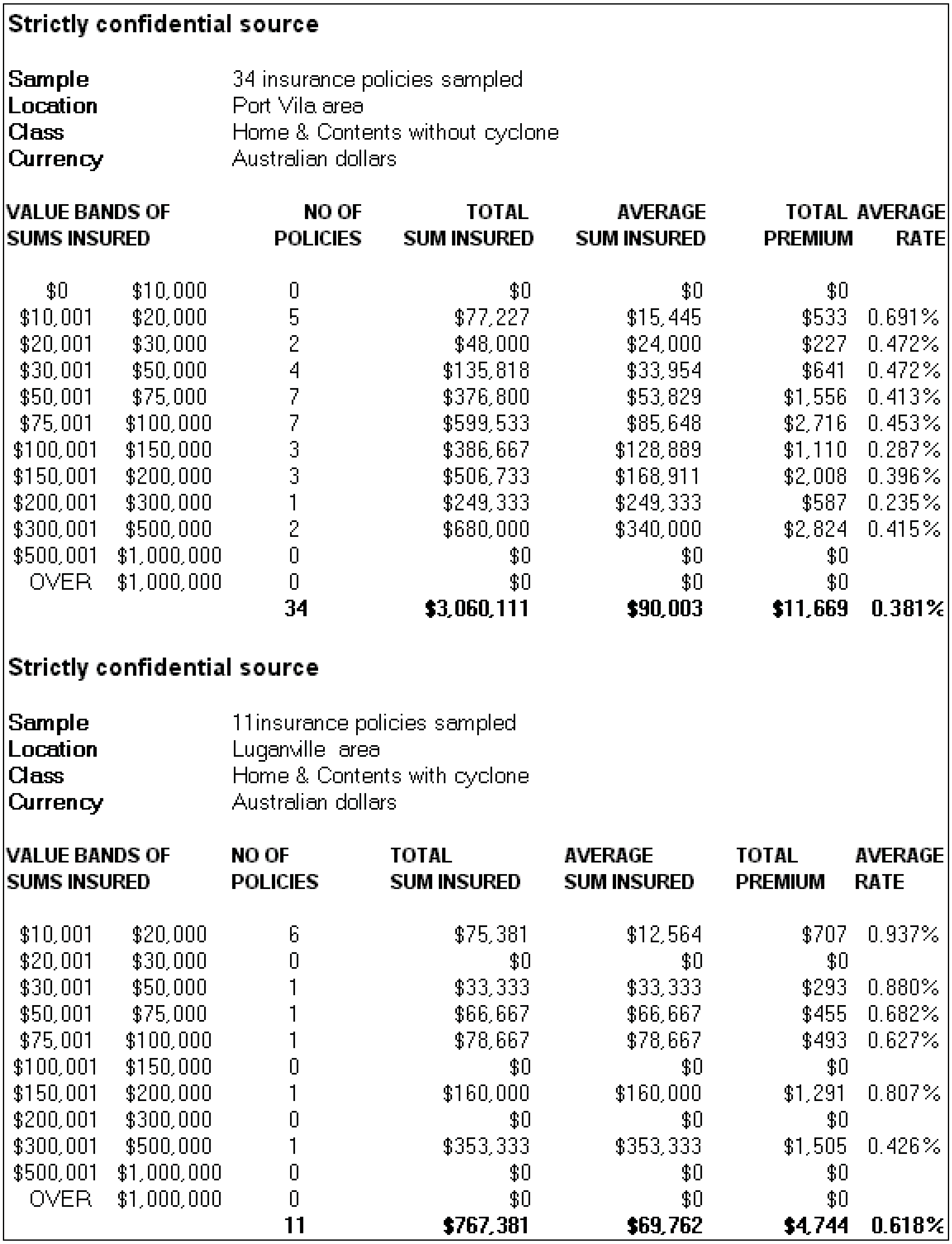


**Strictly confidential source**

**Sample** 220 insurance policies sampled
**Location** Port Vila area
**Class** Home & Contents with cyclone
**Currency** Australian dollars

| VALUE BANDS OF SUMS INSURED | | NO OF POLICIES | TOTAL SUM INSURED | AVERAGE SUM INSURED | TOTAL PREMIUM | AVERAGE RATE |
|---|---|---|---|---|---|---|
| $10,001 | $20,000 | 17 | $269,135 | $15,831 | $2,613 | 0.971% |
| $20,001 | $30,000 | 15 | $394,120 | $26,275 | $2,453 | 0.623% |
| $30,001 | $50,000 | 24 | $926,664 | $38,611 | $6,203 | 0.669% |
| $50,001 | $75,000 | 21 | $1,355,067 | $64,527 | $7,515 | 0.555% |
| $75,001 | $100,000 | 23 | $1,941,513 | $84,414 | $11,252 | 0.580% |
| $100,001 | $150,000 | 35 | $4,451,448 | $127,184 | $26,334 | 0.592% |
| $150,001 | $200,000 | 31 | $5,570,467 | $179,692 | $32,508 | 0.584% |
| $200,001 | $300,000 | 28 | $6,872,267 | $245,438 | $40,586 | 0.591% |
| $300,001 | $500,000 | 19 | $7,334,160 | $386,008 | $42,672 | 0.582% |
| $500,001 | $1,000,000 | 6 | $3,603,314 | $600,552 | $21,011 | 0.583% |
| OVER | $1,000,000 | 1 | $2,460,000 | $2,460,000 | $13,801 | 0.561% |
| | | **220** | **$35,178,154** | **$159,901** | **$206,949** | **0.588%** |





**Strictly confidential source**

**Sample** 34 insurance policies sampled
**Location** Port Vila area
**Class** Home & Contents without cyclone
**Currency** Australian dollars

| VALUE BANDS OF SUMS INSURED | | NO OF POLICIES | TOTAL SUM INSURED | AVERAGE SUM INSURED | TOTAL PREMIUM | AVERAGE RATE |
|---|---|---|---|---|---|---|
| $0 | $10,000 | 0 | $0 | $0 | $0 | |
| $10,001 | $20,000 | 5 | $77,227 | $15,445 | $533 | 0.691% |
| $20,001 | $30,000 | 2 | $48,000 | $24,000 | $227 | 0.472% |
| $30,001 | $50,000 | 4 | $135,818 | $33,954 | $641 | 0.472% |
| $50,001 | $75,000 | 7 | $376,800 | $53,829 | $1,556 | 0.413% |
| $75,001 | $100,000 | 7 | $599,533 | $85,648 | $2,716 | 0.453% |
| $100,001 | $150,000 | 3 | $386,667 | $128,889 | $1,110 | 0.287% |
| $150,001 | $200,000 | 3 | $506,733 | $168,911 | $2,008 | 0.396% |
| $200,001 | $300,000 | 1 | $249,333 | $249,333 | $587 | 0.235% |
| $300,001 | $500,000 | 2 | $680,000 | $340,000 | $2,824 | 0.415% |
| $500,001 | $1,000,000 | 0 | $0 | $0 | $0 | |
| OVER | $1,000,000 | 0 | $0 | $0 | $0 | |
| | | **34** | **$3,060,111** | **$90,003** | **$11,669** | **0.381%** |

**Strictly confidential source**

**Sample** 11insurance policies sampled
**Location** Luganville area
**Class** Home & Contents with cyclone
**Currency** Australian dollars

| VALUE BANDS OF SUMS INSURED | | NO OF POLICIES | TOTAL SUM INSURED | AVERAGE SUM INSURED | TOTAL PREMIUM | AVERAGE RATE |
|---|---|---|---|---|---|---|
| $10,001 | $20,000 | 6 | $75,381 | $12,564 | $707 | 0.937% |
| $20,001 | $30,000 | 0 | $0 | $0 | $0 | |
| $30,001 | $50,000 | 1 | $33,333 | $33,333 | $293 | 0.880% |
| $50,001 | $75,000 | 1 | $66,667 | $66,667 | $455 | 0.682% |
| $75,001 | $100,000 | 1 | $78,667 | $78,667 | $493 | 0.627% |
| $100,001 | $150,000 | 0 | $0 | $0 | $0 | |
| $150,001 | $200,000 | 1 | $160,000 | $160,000 | $1,291 | 0.807% |
| $200,001 | $300,000 | 0 | $0 | $0 | $0 | |
| $300,001 | $500,000 | 1 | $353,333 | $353,333 | $1,505 | 0.426% |
| $500,001 | $1,000,000 | 0 | $0 | $0 | $0 | |
| OVER | $1,000,000 | 0 | $0 | $0 | $0 | |
| | | **11** | **$767,381** | **$69,762** | **$4,744** | **0.618%** |

4. More importantly to note are the actual terms and conditions provided by insurers. They <u>do vary</u> and it is very important to note that the major insurer in Vanuatu, QBE Insurance <u>do not cover Tsunami</u> under their standard Domestic Specified Perils Policy. Nor is flood insured. However in the light of this report I have asked QBE as to whether or not they would grant cover under some circumstances.
5. QBE's standard Commercial Property and Business Interruption policy excludes physical loss, destruction or damage occasioned by or happening through - flood or water from or action by the sea, tidal wave or high water unless there is an earthquake

or seismological disturbance. This means that it must be able to be proved that a seismic event was in fact recorded. They do not insure Tsunami as such.

6. For both Domestic and Commercial policies, when cover is granted by QBE's Hurricane, Cyclone, Storm &/Water Tempest extension, loss or damage caused by sea, tidal wave, high-water, flood, erosion, subsidence or landslip, IS EXCLUDED.
7. It is estimated that 80% of CBD businesses carry Property Insurance and of those that do carry insurance about 40% would carry Business Interruption insurance. Most major business houses are well insured.
8. Telecom Vanuatu Ltd (TVL) has an excellent insurance program. As TVL are part of a global corporate program Riskman was expecting very high deductibles or retained risk. The deductibles are $6,000 each for Material Damage and Business Interruption respectively. Values appeared very adequate and there was no doubt in Riskman's opinion that TVL could rely on insurance funding in the event of the catastrophic perils under discussion.

   In addition they have an impressive contingency plan with a containerised exchange that can be shipped in relatively quickly.
9. Riskman contacted Unelco several times and met to obtain details of their insurance. Since the information was not available Riskman is not able to comment on how robust their insurance will be in the event of a catastrophe.
10. From discussions with John Chaniel, it does appear that Cyclone and Earthquake risks are insured in so far as main buildings, plant, and equipment including pump station. But there may be some shortcomings in the water infrastructure such as storage tanks and reticulation. These appear not to be insured. This fact in itself is not critical. What is critical is what happens if it is destroyed? Are there funds available? It is not clear if Tsunami risk is insured. Their insurance is placed in the French insurance market and through personal experience some major perils are absent from French policies.
11. The insurance arrangement for Air Ports Vanuatu Ltd (APVL) is well intentioned but it is very clear that APVL's risk financing is well short of the mark. They have, relative to their cash flow and capital base, high amounts of retained risk (see table below) from choice[14] and as dictated to by the insurance market. Please refer to XL spread sheet as part of this section.
12. The question is: does the quality/reliability of Unelco's or APVL insurance impact negatively on Port Vila in the event of a catastrophe? The answer can be determined by "auditing" perhaps using something along the lines that Riskman has developed; viz spread sheet and interview viewing the insurance policies. However the template needs further development to also include the financial strength of the insurers.

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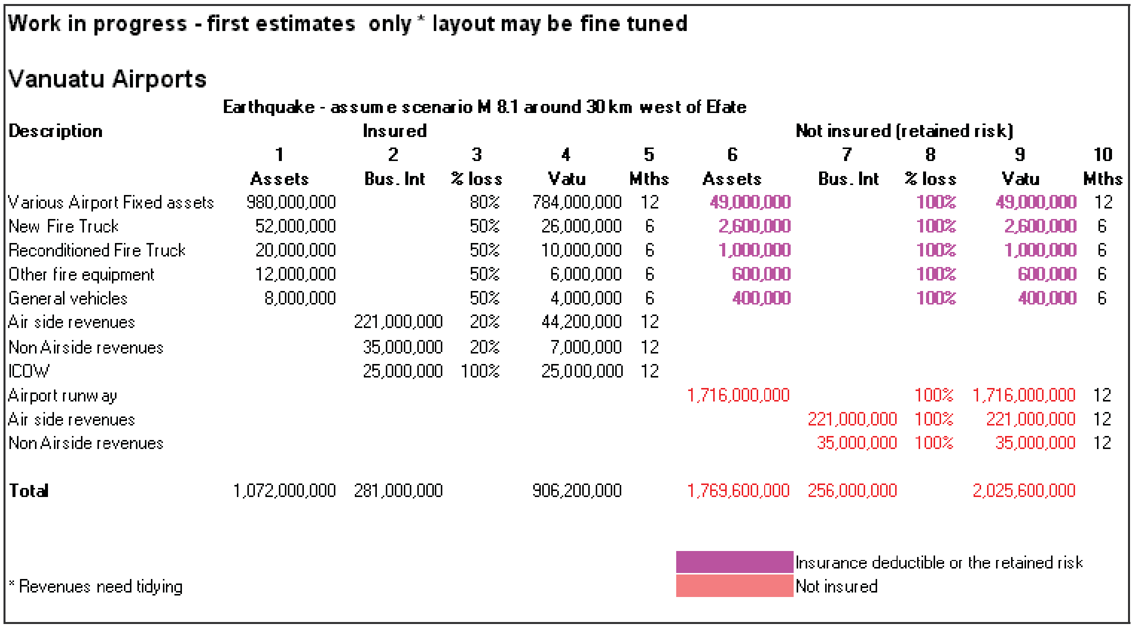
[14] Based on affordability. Riskman is very appreciative of the positive assistance given by CEO Des Ross



**Work in progress - first estimates only * layout may be fine tuned**

**Vanuatu Airports**

**Earthquake - assume scenario M 8.1 around 30 km west of Efate**

| **Description** | **Insured** | | | | | **Not insured (retained risk)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| | **Assets** | **Bus. Int** | **% loss** | **Vatu** | **Mths** | **Assets** | **Bus. Int** | **% loss** | **Vatu** | **Mths** |
| Various Airport Fixed assets | 980,000,000 | | 80% | 784,000,000 | 12 | 49,000,000 | | 100% | 49,000,000 | 12 |
| New Fire Truck | 52,000,000 | | 50% | 26,000,000 | 6 | 2,600,000 | | 100% | 2,600,000 | 6 |
| Reconditioned Fire Truck | 20,000,000 | | 50% | 10,000,000 | 6 | 1,000,000 | | 100% | 1,000,000 | 6 |
| Other fire equipment | 12,000,000 | | 50% | 6,000,000 | 6 | 600,000 | | 100% | 600,000 | 6 |
| General vehicles | 8,000,000 | | 50% | 4,000,000 | 6 | 400,000 | | 100% | 400,000 | 6 |
| Air side revenues | | 221,000,000 | 20% | 44,200,000 | 12 | | | | | |
| Non Airside revenues | | 35,000,000 | 20% | 7,000,000 | 12 | | | | | |
| ICOW | | 25,000,000 | 100% | 25,000,000 | 12 | | | | | |
| Airport runway | | | | | | 1,716,000,000 | | 100% | 1,716,000,000 | 12 |
| Air side revenues | | | | | | | 221,000,000 | 100% | 221,000,000 | 12 |
| Non Airside revenues | | | | | | | 35,000,000 | 100% | 35,000,000 | 12 |
| **Total** | 1,072,000,000 | 281,000,000 | | 906,200,000 | | 1,769,600,000 | 256,000,000 | | 2,025,600,000 | |

* Revenues need tidying

| | |
|---|---|
| 🟪 | Insurance deductible or the retained risk |
| 🟥 | Not insured |

13. The outcome could be put on a data base model that could be developed to identify gaps in essential post loss risk financing. Should a catastrophe insurance fund be made available to a "Unelco" or "APVL" organisations if shortcomings cannot be solved by conventional insurance?

14. Information contained in Output 1 addresses some of the medium business insurance arrangements in Port Vila.

# 9 Value of Government Assets

**Output 8: Assessment of the value of Government assets that are at risk in the Port Vila-Mele area given that a significant proportion of infrastructure is now in the hands of private organisations, and typical losses that might be faced in the event of catastrophic earthquake or cyclone events**

1. Apart from the main wharf, which is insured for replacement value and the Government main computer system, the Government carries no conventional insurance.

2. Revenues are not insured.

3. Tsunami and Earthquake would cause havoc and put the community at serious risk.

4. As mentioned in Paragraph 2.10 I was counting on the Government Risk management Committee (which is simply the Directors General) [lead by Jeffrey Wilfred, Director General of Economics and Finance (now DG of Agriculture) and Manasseh Taris Director General of Public Works] to develop some basic answers to the above statement. However their input was not forthcoming despite numerous requests.[15]

5. As also mentioned under paragraph 2.12 Riskman has developed a matrix of describing insured and uninsured losses and this, or something similar must *be developed* with the sectors and ideally coordinated through the Government Risk Management Committee – see XL file called under Outcome 7 [16]

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[15] Email correspondence has been included – in Outcome11 pdf version

[16] Refer letter 30 May to Government and large organisations contained in Outcome 11 pdf version

6. The answers to the above statement can be readily verified once the Government actually identify their assets and the corresponding values.
7. The clue however is Cyclone UMA. It took about 4 years to re-establish the Public Works Department after UMA. I predict that not much has changed and therefore the same length of time may elapse to re-establish pre loss activity.

# 10 Government Risk Management System

**Output 9: Short history of the development of the Government Risk Management System (GRMS) together with a description of its importance in developing and instituting any national catastrophe insurance scheme, as well as an assessment of the success of the GRMS to date, and the factors affecting that success or otherwise**

1. Kindly refer to Power Point presentation.
2. It is Riskman's view that the GRMS model is a prerequisite for risk transfer – large or small. Conventional or catastrophic insurance.
3. The jury is out on the success of the Vanuatu Government's Risk Management Project. I say this for the simple reason that the behavioural changes required to make it 'successful" are the same changes that are required for any project in the Pacific Region. GRMS as it currently stands can perhaps be appropriately described as good software. Great potential if the end user actually goes for it. Do we hit the refresh button, reboot or change the software? Do we change the operating system? Personally I think not.
4. GRMS is home grown based on first principles. It will succeed with leadership and some funding to pay for a coach to keep the leadership on track.
5. The factors affecting that success or otherwise are referred to in the power point presentation and position paper dated November 2002. The latter is available to SOPAC if required.

# 11 Capacity to Institute Scheme

**Output 11: Analysis of the capacity of the Vanuatu Government to institute and support any catastrophe insurance scheme through either an insurance pool or a national disaster fund, or a combination of both**

1. I understand from what I have gleaned that this is not really part of Riskman's brief. Simply because the logistics of getting something workable require more resources that I have at my disposal in the context of this report.
2. Riskman's view is that while in theory such a scheme could be developed the evidence is that without a very big budget and fresh outside faces of suitably experienced and qualified expatriates such a pool would not be workable.
3. What would work is sub contracting out the fund to say Riskman to manage just as it does for its captive clients. Refer to www.riskman.vu "Captive Insurance". Claims settling would follow the normal insurance industry model.
4. I have to conclude that unless we see some major improvement in commitment from the stakeholders, it is difficult to see Riskman's vision coming to pass in the near future.

[1] Business Interruption (BI). In the context of insurance BI responds to reduction in turnover plus increased costs of working (e.g. alternative premises) less any savings in standard charges (e.g. electricity, wages) arising out of a claim under the property insurance policy. Some BI is not usually insured e.g. tourist reduction. Therefore while it can be assumed that insurance will make a major contribution there are uninsured losses to be taken into account.

[1] "20 years of Central Banking in Vanuatu" Published by Reserve Bank of Vanuatu; November 2000. Page 15

[3] "20 years of Central Banking in Vanuatu" Published by Reserve Bank of Vanuatu; November 2000 page 13

[1] "20 years of Central Banking in Vanuatu" Published by Reserve Bank of Vanuatu; November 2000 page 13

[1] Riskman thanks Brian Dellit for his prompt and very courteous assistance

[1] No response to Riskman's requests

[1] No response to Riskman's requests

# Appendix 7

# Catastrophe Insurance Pilot Project, Port Vila: A Framework for the Development of a Disaster Insurance Scheme

*by*

**George Walker**

Aon Re Australia Ltd, Sydney, Australia

**SOPAC JOINT CONTRIBUTION REPORT 147**

*December, 2003*

**South Pacific Applied Geoscience Commission**

**Hazards Assessment Unit**

# CATASTROPHE INSURANCE PILOT PROJECT, PORT VILA

## A Framework for the Development of a Disaster Insurance Scheme

**George R Walker** ME PhD FIEAust FIPENZ FAIB
Head of Strategic Development
Aon Re Australia

## 1 The Role of Disaster Insurance

When disasters strike, the resulting financial losses, whether or not they are initially met by government, charities, insurance or business, ultimately have to be paid for or absorbed by individuals, as shown somewhat simplistically in Figure 1

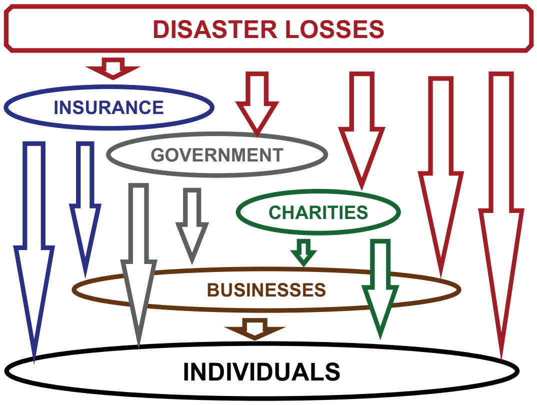

Figure 1 Distribution of Catastrophe Losses

How these losses are ultimately distributed among individuals is one of the main issues of disaster management.

Disasters are generally measured by both their social impact – ie by the lives lost, injuries sustained and numbers made homeless - and their economic impact - ie the financial losses caused by the disaster. However the real tragedy of disasters is the subsequent individual hardship endured by those affected by them. This hardship generally has a strong financial component arising from the loss of family income due to death or injuries to the main income earner, loss of jobs or loss of business income, the cost of repair or reconstruction of damaged homes and/or renting of alternative accommodation, or increased taxes to cover losses assumed by government authorities. Mitigation of this financial aspect of hardship is generally the primary objective of national disaster insurance schemes.

Government aid, charities and insurance are the main mechanisms by which this hardship can be reduced. Each of these spreads the financial losses beyond those directly affected, so reducing the maximum individual impact. Government aid does it by using money collected by taxation to assist those deemed most in need. This spreads the loss across the whole population in proportion to the contribution to taxes. Charities do it by seeking voluntary donations from those who have not suffered loss and passing these on to those seen to be most in need. Generally these two forms of aid complement each other, with government aid focussing on infrastructure and assistance in the form of low interest loans and special grants to both industry and individuals, and charities focusing on individual cases of extreme need. Both these forms of mitigation tend to be reactive in that the funds used have to either come from the current account in the case of government, or be raised by special appeal in the case of charities. In the case of governments this may mean borrowing money from international agencies such as the World Bank and increasing taxes to pay this back over time.

Insurance, by contrast, is a proactive form of mitigation of hardship whereby an individual or organisation is able to transfer all or part of the financial risk of loss in advance of a disaster for a fee. If a disaster strikes and loss is suffered then the relevant financial compensation is made. The insured individual or organisation is assured of the compensation and not dependent on an assessment of need by government agencies or charities, and can get on with the recovery process less fettered by bureaucratic restraints. Government and charities are relieved of a portion of the financial and administrative burdens of recovering from disasters. And because of the internal international transfer of risk that occurs within the insurance industry through reinsurance the losses can be widely spread around the world, which means that the national economy will be subjected to a lesser financial shock.

For these reasons many governments in relatively developed countries, where insurance tends to be embedded in the culture, have made special provision for insurance against disasters. In some cases, where the risks are perceived as relatively low, this may be limited to a requirement that losses from disasters be covered by standard household policies. In other cases it has led to separate government organised and managed schemes. A review of these schemes shows that almost all of these schemes differ in some way from each other. This is because they depend on many factors.

# 2 National System of Disaster Insurance

Ideally a national system for disaster insurance scheme should meet the following criteria:

- Provide wide coverage
- Provide adequate funds for reconstruction and repair of damaged structures
- Be affordable
- Have an efficient administrative system including response to claims
- Be free of moral hazard
- Be technically sound
- Be politically acceptable
- Be linked with mitigation activities

## 2.1 Width of coverage

The primary purposes of national disaster insurance is to reduce the personal financial and associated emotional distress on persons affected by a disaster, and the drain on public funds in trying to alleviate the distress and restore community services. Ideally a national system should ensure cover of the whole population for all classes of losses from all hazards. In practice this is generally not achievable.

Consider the different classes of losses. A typical major disaster will involve damage to dwellings, businesses, agriculture and government infrastructure. It will also involve loss of life and injuries which also have a financial cost associated with them. From an insurance perspective these are different classes of insurance which each have their own characteristics.

Dwellings involve buildings, which may contain one or more dwellings, which in turn may be owner occupied or rented, and contents, which are usually owned by the occupier. The primary characteristics of dwellings are their large number, relatively small individual value, and relative uniformity, which make them ideal for relatively standard insurance policies. In total they account for about one third of the total asset value of constructed facilities of a country and are generally the subject of the lowest level of building control in terms of design and construction.

Businesses are very diverse in terms of both their size and the nature of the risk. In general business losses can be divided into three main categories – buildings, contents including stock, and business interruption. Whereas with dwellings the building damage losses are dominant, this is not necessarily the case for businesses. Business interruption losses can be much larger than the losses due to building damage, particularly if the cause is infrastructure damage –eg loss of power or water. In the case of warehouses, the contents losses can also heavily outweigh the associated structural damage, particularly where water damage is involved. Small, medium sized, large and global businesses also each have their own characteristics. Because of this diversity, businesses need to be divided into sub-classes that get smaller with increase in size and specialisation of the business. In total commercial and industrial buildings also account for about one third of the total asset value of constructed facilities in a country. The level of building control exercised over their design and construction tends to increase with size, with that associated with small businesses being the least, and generally similar to that of dwellings.

Infrastructure losses include those arising from damage to railways, roads, dams, power stations, telecommunication systems, ports, airports, etc. In many countries these are mostly government owned facilities. They account for the other third of total asset value of constructed facilities in a country. Apart from the direct cost of repair and reconstruction, they are also a major cause of business interruption losses. Generally infrastructure has the highest level of control over its design and construction.

Agricultural losses from disasters can be very large. They can also be difficult to quantify. Whereas dwelling, businesses and infrastructure losses tend to be strongly correlated with each other, agricultural losses are often uncorrelated with these other forms of loss. Even the nature of the disasters giving rise to them is different, with droughts, pests and diseases playing a major role.

Losses due to death and injury are generally in the domain of life and health insurance. If they occur while persons are at work then they are in the domain of workers compensation.

As a result of these differences it is unusual to have a single national disaster insurance scheme covering all classes of loss. Most government backed schemes are concerned only with dwellings, some are concerned with all private property losses (but normally excluding business interruption), most schemes covering agriculture are for agricultural losses only, and most schemes covering government infrastructure losses are restricted to these.

In respect of hazards covered this also varies significantly. A number of government backed schemes cover all perils, but others are focussed on specific perils. The latter usually occur where the normal insurance industry provides cover for most hazards, but regards the specific perils as uninsurable.

The other factor that affects the width of cover within the community is the level of compulsion associated with the scheme. A number of schemes, mainly in the US, are purely voluntary, but most are in the form of compulsory additional cover to normal fire insurance policies. Where it is voluntary the take up appears to be generally less than fifty percent. Where it is compulsory as an addition to fire insurance, then the proportion of the community covered will be equal to the proportion covered for fire insurance. In Western countries this tends to be high, but in many other countries it is relatively low, particularly in regard to dwellings and small businesses.

## 2.2 Adequacy of Cover

Unlike normal insurance, a national disaster insurance scheme primarily provides a social service, not a commodity. As such it is not necessary that the scheme restore property to its previous situation in terms of either indemnity value or replacement value, which is the basis of most normal insurance.

Many schemes are limited in what they provide. Some have large deductibles. Some put upper limits to the cover provided. Others do both by providing a fixed amount of cover subject to a specified level of damage.

What is essential is that it makes a significant contribution to the reduction of hardship. In relation to dwellings this may mean providing sufficient funds to cover most of the cost of a basic dwelling. In the case of business or agriculture it may be to provide sufficient to keep the business or farm going. In the case of governments it may be to avoid severe increases in taxation. If it does not achieve this then it may be not serve its purpose.

## 2.3 Affordability

Affordability is primarily a function of the premiums and their value in relation to the financial circumstances of the owners.

The necessary premiums to be charged can be analysed using the following factors:

- The risk of damage
- The level of cover to be provided
- How the premiums are to be levied
- The approach adopted for financing the risk
- The administrative costs of the scheme

Determining what is an affordable premium however is not a scientific exercise. It is a socio-economic issue. It will depend on income after basic expenses on items such as food, health and accommodation have been paid. Affordability can limit the premiums, resulting in the level of cover provided being tailored to fit the premiums, not the reverse, which is the way normal insurance generally works.

The manner in which premiums are levied can also be important in respect of affordability. In normal insurance systems the premium is proportional to the cover. For full indemnity or replacement value cover this is fair and equitable. However if only restricted cover is provided questions of social equity arise. If the cover is the same then under the normal insurance approach premiums would be the same – meaning that rich and poor alike pay the same. However if this is associated with a first loss replacement cover it can result in the poor subsidising the rich. For what is essentially a social service, this is not a desirable outcome.

## 2.4 Administrative costs

An affordable scheme needs a practical and efficient system of administration. This includes the system for collecting the premiums, managing the accumulated funds, providing a timely and equitable response to claims following a disaster, and providing overall management of the system.

There are essentially two basic ways of administering a natural disaster insurance scheme. One way is to do it through normal insurance channels, with individual companies being responsible for the collection of premiums and payment of claims and the accumulated funds being placed in a joint pool, which is often underwritten to some extent by Government, and which is managed by representatives of industry and government. The other approach is for Governments to establish a separate government system with its own fund independent of the industry.

In countries where normal property insurance for fire and theft is almost universal, the insurance industry provides an efficient channel for administering a pool-based system, or at least collecting the premiums for a government based fund. Most existing schemes around the world operate in this environment. Where this is not the case the issue of width of cover becomes an issue. Should the scheme be restricted to property covered by normal insurance, or should it be universal with all property owners being levied for the requisite premium? If the latter approach is adopted then an efficient scheme for collection of the premiums and payment of the claims needs to be implemented. This may be undertaken through the insurance industry, but could be done through other channels such as those used for land tax. Means of enforcement is an issue that would also need to be addressed.

Claims handling poses special problems for separate disaster fund schemes. This is because during normal operations they have no claims or very few of them. Yet when a disaster strikes they are expected to be able to cope with large numbers of claims at very short notice. If claims handling costs are to be kept within reasonable bounds, or the scheme is not to be discredited due to public reaction to poor claims handling ability, it is necessary to have a sound and tested system in place at an agreed cost. The costs of this also have to be reflected in the premiums.

Part of the cost of administering the system is the cost of monitoring the risk and managing this risk. Increasingly this is being undertaken using sophisticated computer based tools.

The financial risk from damage to property is a complex interaction between the occurrence risk of event causing the damage, topographical and geological factors such as soil characteristics, terrain and valley shapes, the geographical distribution of dwellings, the vulnerability of the dwellings to the hazard, and the cost of repairs and reconstruction. For some of the larger events like earthquake shaking damage, typhoon wind damage, and river floods, complex Geographical Information Systems (GIS) based models are the best way of ascertaining this risk, but their development is expensive. For other hazards like landslides and local severe storms the risk must generally be estimated by extrapolation from historical records. The problem is made more complex where a single event can produce several different hazards – eg a typhoon can produce wind damage, flood damage and landslide damage.

Computer based catastrophe loss models can be developed to produce statistical information on the risk of loss from different types of hazards. This that can be input into financial risk management systems that simulate the operations of the disaster insurance scheme over time including the premium income, the risk transfer mechanisms, the administrative costs, and the investment income from the accumulated funds. This allows analysis of the sustainability of different options.

## 2.5 Moral hazard

Another important need relates to moral hazard. Schemes need to be robust without too many opportunities for exploitation – especially in the aftermath of a disaster. Moral hazard is not just concerned with claims. The premium income and, if allowed to accumulate, the reserves, also need to be protected from exploitation.

Loss adjusters are familiar with the problems of moral hazard in the aftermath of disasters. A common example in respect of flood is the placing of old stock or household goods on the floor when a flood is threatening in the expectation of having them replaced by insurance. Where this has become a problem some insurance companies have countered it by inserting a clause in the policy conditions that moveable contents will only be covered if the flood level in the building exceeds a specified height that is less than the usual table or bench height. Shingle roofs are common in some parts of the world. As they age the timber cracks and they deteriorate. Hailstorms provide an opportunity to get them replaced, as it is difficult for insurance companies to distinguish between natural cracking and cracking caused by hail.

A more serious problem can occur where payment of claims is in cash on the basis of a builder's quotation without any checking by a loss adjuster. In the rush of claims following a major disaster it is not unknown for this situation to arise to be soon followed by enterprising entrepreneurs offering to provide inflated quotations for a fee. This is a hazard that can be avoided by having a rigorous claims system in place before the disaster.

Some forms of insurance can also encourage moral hazard. One example is a franchise system whereby if a claim is less than a certain amount no payment is made, but if above the amount full payment is made. This can encourage the inflation of many small claims, which may be not worth spending a lot of time checking, above the franchise limit. Deductibles based on actual cost of repair provide a much better deterrent to this moral hazard.

The problem of large reserves is a different type of problem. It is a political or commercial form of moral hazard. Large sums of money set aside in government funds or industry pools as long term reserves can become very tempting for politicians and economic advisers seeking to overcome some more pressing immediate financial problem, or unscrupulous people in business. One of the purposes of legislation is to provide protection against this hazard.

## 2.6 Technical soundness

To be effective and sustainable in the event of a major disaster, a scheme must be technically sound. It must be able to cover the prescribed risks without becoming insolvent. Income must balance or exceed expenditure.

The risks to a disaster insurance scheme are generally covered by a combination of

- Pool funds
- Risk transfer – eg reinsurance
- Risk financing – eg contingency loans
- Government guarantee
- Insurance industry contributions

The costs of doing this may include

- Costs of risk transfer
- Costs of risk financing
- Cost of government guarantee

Other costs apart from irregular major claims include

- Costs of administering the scheme including managing claims
- Costs of attrition losses – ie regular small claims
- Taxation
- Costs of measures to mitigate risks

The regular annual income to cover these costs comes from a combination of

- Premiums
- Investment income
- Industry levies
- Government grants

In the simplest system all the risk would be transferred except for a small retention to cover annual attrition losses. The premium income required to maintain this system will be equal to the market value of the risk as expressed in the cost of the reinsurance plus administrative costs and attrition losses. Premiums based on producing this level of premium income can be described as Market Value Based Premiums as in this case the policyholders in aggregate pay the true market value of the risk covered. Market Value Based Premiums will vary from year to year, being higher in so-called hard markets and lower in soft markets.

To provide protection from the fluctuations of the market many schemes aim to build up a pool or fund. This can only be done by either charging higher premiums than the Market Value Based Premiums, or by industry or government underwriting a portion of the risk without passing the costs on through premiums. The latter approach is based on an assumption that major disasters are rare and hence there is a high probability that the scheme may run for many years without having to face a major loss. During this period the fund will build up in an exponential manner as a result of the increasing investment income it generates as it grows. As it grows it lessens the unfunded component of the risk, and provides an opportunity through the increasing investment income to eventually either reduce premiums or provide additional cover.

The Norwegian national disaster insurance system is an example of a system based on the Market Value Based Premiums approach. The New Zealand earthquake insurance scheme is an example of system based on building up a fund, which, because the Government carried the full risk for almost al of the first 40 years and no major loss has occurred in its 60-year history, is now in a very healthy position. Both systems are now technically sound because the risks are balanced against the income.

During recent years the development of powerful computer based tools that can simulate the risks and the financial operations of a scheme have made a big contribution towards ensuring technical soundness.

## 2.7 Political acceptance

Political acceptance is fundamental to both the establishment and the sustainability of national disaster insurance schemes. Political acceptance will largely depend on the affordability and perceived need for the scheme by the community. Apart from risk factors that cannot be changed in a short time frame, major factors determining this will be the level of cover to be provided, and how the premium is to be levied.

The minimalist approach is to cover all property owners for the same amount, irrespective of the value of the existing property, and pay the same premium. However the wealthier section of the community may be willing to pay higher premiums for greater cover, raising the question of whether this should be provided as an option under the scheme to increase the premium income, or, in the case of a separate national fund, left to the private sector in order to limit the probable maximum loss to the fund.

Other factors affecting political acceptance are the existing level of property insurance in the community and how the new scheme relates to any existing schemes.

## 2.8 Mitigation

A key factor affecting affordability is the vulnerability of buildings, facilities, their contents, and business operations, to the hazards. Nothing much can be done to change this at the start other than exclude the most vulnerable risks from the scheme – which to some extent can defeat the objective of the scheme, and may also be politically unacceptable. However the initial situation can be improved over time by incorporating incentives or regulations that will over time reduce the overall vulnerability. Indeed without them an insurance scheme can be a disincentive to mitigation and result in increased vulnerability over time.

The most effective means of doing this are the imposition of relevant building standards and land planning requirements for all new construction. There is often a relatively long period of time between major disasters, and during this period significant reductions in the overall vulnerability can be achieved by these measures. A good example of this is in Queensland, Australia, where changes in building requirements introduced in 1982 have resulted in a significant overall reduction in vulnerability to tropical cyclone winds during a period when there has been no major event. However there are significant costs associated with such measures in terms of added costs of construction, loss of amenity in terms of land use, and the cost of regulatory control measures to ensure compliance. These costs need to be balanced against the benefits if a politically acceptable solution is to be found to this issue.

Risk based premiums which recognise reduced vulnerability due to new construction satisfying specified minimum standards or retrofitting older construction can also be used, although experience to date suggests that this is limited in its effectiveness as owners prefer to pay a relatively small amount of extra premium in preference to a much larger up front single payment to cover the additional construction costs.

For mitigation activities to be effective it is generally necessary to maintain a high level of pubic awareness of the possible consequences of major disasters and the need to mitigate them. Most disaster insurance schemes include within their terms of reference the funding of public education and research activities in relation to disaster mitigation.

In a number of cases the provision of the insurance cover to new properties is subject to prescribed mitigation measures being in place. These options, however, are only available if the purchase of the insurance is voluntary.

# 3 The Design Options

There is a wide range of options available for providing disaster insurance. In the previous section the issues that need to be taken into account in selecting the appropriate option were discussed, with political and cultural issues identified as being as important as technical issues. In this section the principal options are discussed.

## 3.1 Classes to be covered

The range of classes of loss arising from a major disaster is summarised as follows:

- Dwellings – Building, Contents
- Small Business – Building, Contents, Business Interruption
- Medium and Large Business – Building, Contents, Business Interruption
- Agriculture – Crops, Livestock
- Government Owned Risks – Buildings, Utilities, Infrastructure, Emergency Services
- Health – Death, Accident Cover, Workers Compensation

A completely universal scheme would provide cover against all these classes. The most comprehensive scheme existing scheme appears to be the Consorcio de Compensacion de Seguros in Spain that covers everything except death and injury.

Normally agricultural losses are the subject of separate disaster insurance schemes. The reason for this is that the nature of agricultural losses is very different from that of losses arising from building damage. Also there is a range of hazards coming under the general description of pestilence and disease that have no equivalent in terms of building damage. Even in Spain where agricultural losses are covered by the overall scheme, they are handled separately within the scheme.

Historically governments have not insured their own losses. This appears to be due to an economic argument that owing to their size and their sovereign position in the national economy, there is no long-term advantage to governments in insuring their own losses. However the wisdom of this approach for smaller economies in a global economic society is now being challenged. In Australia, for instance, the Federal Government and several of the State Governments have centrally managed insurance schemes to cover major losses to their own assets.

Government relief schemes are an alternative to national disaster insurance schemes. This approach of a protected national disaster relief fund is a fundamentally different option to the disaster insurance approach. It is the traditional approach, but has two inherent weaknesses. The relief it provides tends to be ad hoc, and the subject of a great deal of bureaucratic procedures designed to prevent its exploitation, with the relief funds often taking a long time to reach those in need. It also tends to act as a disincentive to mitigation, with owners having little self interest in reducing risks. Insurance systems are much more compatible with the principles of modern risk management than relief. Indeed this is one of the primary reason why in Australia Governments have opted for their own internal insurance schemes, despite the traditional economic arguments about their economy efficiency – arguments which ignored the benefits of modern risk management.

## 3.2 Hazards to be covered

Disaster insurance is intended to cover catastrophic events, which can involve several coincident hazards. The range of events and associated hazards that could be included are:

- Earthquake – Shaking, Fire, Landslide, Tsunami, Subsidence (Liquefaction)
- Tropical Cyclone – Wind, Rain, Flash Flood, Stream Flood, Landslide, Storm Surge
- Thunderstorm – Wind, Hail, Rain, Flash Flood, Lightning,
- Other Weather Events – Rain, Flash Flood, Riverine Flood, Bush Fire, Wind
- Volcanic Eruption – Shaking, Debris Flow, Ash Fall, Lava Flow, Fire
- Man Made Hazards – Explosion, Major Fire, War, Terrorism, Riot
- Other – Pestilence, Disease

Only the Spanish scheme appears to cover all these hazards. Most government backed schemes are only concerned with natural hazards, and most restrict their cover to one or more specific hazards. There are generally historical reasons for the range of hazards covered, with most schemes appearing to have been initiated in the aftermath of a major disaster, the losses from which have either been poorly covered, or were not covered at all by insurance, or would not be covered following the disaster. A current example of the latter is the reluctance of the insurance industry to insure for terrorism following the terrorist attack on New York and Washington on 11 September 2001, which is leading to demands in some countries for national insurance pools to specifically cover acts of terrorism.

## 3.3 Type of scheme

The types of scheme can be classified as follow:

- Industry only, either as part of normal insurance, or collaboratively through an Industry Pool.
- Government Fund, providing either insurance direct to consumers, or providing reinsurance to insurance companies enabling them to provide disaster insurance cover.
- Joint Industry/Government Pool, through which industry provides the insurance, but which is protected in part by a Government guarantee and/or a co-insurance arrangement between the Government and industry.

In most countries some hazards like wind damage are covered by normal insurance, and in some countries like the United Kingdoms and Australia almost all hazards to buildings are covered this way. In some cases where the risks are considered too much for individual companies to handle on their own in a competitive environment, disaster insurance pools to which the different companies belong have been formed. The schemes in Norway and Switzerland are of this type, as is the scheme in Florida for windstorm damage to dwellings. Government's only role in these is to provide a supportive regulatory environment for the pool's operation, which ensures that all participating companies follow the same rules in regard to premiums and cover.

There are two types of purely government schemes. One type is where the government runs its own special insurance company. These schemes may be backed up by a special Fund or operated as part of normal Government income and expenditure. The schemes in New Zealand and Iceland are examples of this type using a Fund, and Spain an example of this type incorporated into normal Government operations. The other type is where the government operates a reinsurance scheme with the cover being provided through insurance companies in the normal way. This is the system used in France and in Japan.

Joint industry government pools generally operate as industry pools, with policies being sold and claims being handled by individual companies, generally in conjunction with their own more general policies, but with some of the risk being carried by the government. The government may do this by guaranteeing to cover losses within a specified range or above a specified limit, or by accepting a proportion of the losses on a coinsurance basis. The recently introduced Taiwan Residential Earthquake Insurance Program is of this type. The California Earthquake Authority's scheme is also a joint scheme, but in this case the government's role has been to organise it and run it, but not to carry any of the risk.

## 3.4 Universality of Cover

A major issue that needs to be resolved in relation to disaster insurance is how universal the cover is to be. The options are:

- Voluntary, either as an addition to a normal policy, or as a separate policy
- Compulsory, either in conjunction with normal insurance, or as a separate universal policy

A voluntary system normally only works where the level of ordinary insurance is high and awareness of the hazard covered is also high. The cover may be provided as an addition to an ordinary insurance policy, or as a separate insurance policy. All the disaster insurance schemes operated in the United States are voluntary ones. A significant problem with voluntary schemes is adverse selection due to them being more attractive to those at high risk than those at low risk.

Outside of the United States most of the government disaster insurance schemes have a compulsory element. In many cases the requirement is that it is compulsory to provide disaster insurance in conjunction with a normal insurance policy. In Norway, Iceland, Spain, France, Switzerland and New Zealand this is the situation in respect of property insurance. This works well where the level of insurance is high.

The other option is to require it to be compulsory for everyone having assets covered by the scheme. The system recently introduced in Turkey is of this type. If this approach is adopted then the question arises as to how premiums will be collected and claims handled. A number of options are available.

a) The cover is provided through insurance companies who also manage the claims, with owners being required to show evidence of payment at the time of paying taxes.

b) Insurance companies collect the premiums and pass them on to a special purpose government insurance organisation that handles the claims.

c) A levy is charged in conjunction with property tax, which goes to a special purpose government insurance organisation.

d) A combination of (a) and (c), or (b) and (c). If the former the scheme might allow owners to insure directly with insurance companies, and not be part of the scheme. However this could lead to a problem of adverse selection with the insurance companies only accepting the good risks and the scheme being left with a preponderance of bad risks.

## 3.5 Extent of Cover

Another critical issue is the extent of cover to be provided to policyholders. The options are:.

- Replacement value generally in conjunction with a deductible or franchise, and possibly a level of coinsurance or first loss limit.
- Indemnity value generally in conjunction with a deductible or franchise, and possibly a level of coinsurance or first loss limit.
- Limited amount of cover in conjunction with claim conditions such as a specified minimum amount of damage.

The choice depends a great deal on the level of premiums that can be charged and the level of risk that the government may be prepared to assume.

The most complete cover is unlimited full replacement cover with a minimal deductible. This is the type of cover provided through normal insurance in countries such as the United Kingdom and Australia. However it is only practical where the overall risks are low.

The level of risk to the scheme can be reduced by limiting claims to indemnity values and/or imposing significant deductibles and/or limits. Significant deductibles are the most effective but they would need to be large. Most disaster insurance schemes outside the United States and New Zealand appear to be based on indemnity cover. New Zealand uses a first loss limit approach but this is not regarded as a good system, as it effectively means the poor subsidise the rich. Co-insurance would be better than this.

Where the cover is for a limited amount it may be a percentage of the replacement or indemnity value, or an absolute amount. This system is used in Japan with specified percentages of the total indemnity value being covered subject to different specified levels of damage. It is also used by the Taiwan Residential Earthquake Insurance Program, in which the cover provided is for a fixed amount subject to a specified level of damage occurring. A problem with this system is the specification of the level of damage, which is often in such terms as ‘total loss’, or ‘half total loss’, and the assessment of this when damage occurs. A considerable risk of moral hazard appears to exist unless there are firm guidelines and a rigorous system of control.

A fixed level of cover is appropriate if the primary objective is seen as social – ie ensuring everyone gets a basic amount to start again without any frills. In most cases it will be less than is needed, but it assumes there is a correlation between the value of property and the wealth of the owner. Thus the needs of the poorest may be almost fully met, while those of the rich may be only marginally met. It is assumed that the latter will be able to insure for the gap through normal insurance channels outside of the scheme.

If premium levels are essentially determined by affordability and not by the overall risk, as is often the case in high risk and less wealthy countries, then the selection of the appropriate option on the cover will be a critical decision.

## 3.6 Form of Premiums

There are essentially three forms of premium:

- Fixed Premium
- Fixed Premium Rate
- Variable Premium Rate

The form of the premium will to a considerable extent depend on the form of cover – and vice-versa.

If the cover is for a fixed amount subject to a specified level of damage then a fixed premium is appropriate. A significant limitation of this approach is that the premium level needs to be matched with the ability of the poorer section of the community to pay. It also treats all risks the same, which can be a disincentive to mitigation.

A fixed premium rate based on the indemnity or replacement value is the most common approach. Its advantage is simplicity of administration. Its weakness is that it treats all risks the same, so that good risks subsidise the bad risks. There is also a moral hazard in regard to the determination of indemnity or replacement value that can result in significant underinsurance. This can be a particular problem where insurance is related to mortgages, and the temptation exists to just insure for the amount of the mortgage.

A variable premium rate that is risk related in terms of hazard risk and vulnerability is a fairer system in many respects, and provides a much greater encouragement to mitigation. However it requires a more complex system of administration backed up by computer based systems, and would probably favour the rich, as there is also a tendency for the dwellings of the poor to be more vulnerable than those of the rich.

## 3.7 Upper Limit

One of the issues associated with disaster insurance schemes is the nature of the upper limit of the scheme. There are in essence three options

- No upper limits and no government guarantee
- No upper limits with a government guarantee
- A fixed upper limit with proportional cover above this.

Schemes backed by industry pools without government participation tend to have no upper limits – just as normal insurance companies offering disaster cover have unlimited exposure. The Norwegian scheme is an example of such a system. It is accepted in these systems that if an extremely rare extremely large loss occurs then some companies may become insolvent. Hurricane Andrew was an example of an event that had this effect. The losses sustained by the insurance industry as a result of the terrorist attack on the World Trade Centre are also expected to cause some insolvency. Experience indicates that when insolvency occurs, governments are under great pressure to meet any consequent unmet insured liabilities.

Where governments are involved it is more common for the system to be guaranteed by the government if losses exceed the capacity of the scheme. The New Zealand, French, and Iceland schemes are examples of this approach, and it happens automatically with the Spanish scheme.

In some cases an upper limit to the liability of the scheme for a single event is specified. The Japanese scheme and Taiwan Residential Earthquake Insurance Program are examples of this approach. If a loss exceeds the upper limit then all claims are reduced in proportion to the amount by which the limit is exceeded. Such a system has not been tested, and it is not clear how such a system will work in practice, as in general the total loss will not known for a considerable time after the event, and early estimates often underestimate the loss.

## 3.8 Claims Handling

Claims handling is generally a function of the type of scheme. If it is a scheme operated through insurance companies in conjunction with their own general policies then the insurance companies generally handle the claims. If it is a government scheme with its own organisation then the organisation handles them. An example of the latter is New Zealand.

Since major losses are relatively rare and a separate disaster insurance scheme has few regular occurring claims, special arrangements with outside organisations have to be made, and plans need to be in place to ensure that the system works when needed. The New Zealand Earthquake Commission has invested a significant amount in claims management. This includes pre-existing contracts with off-shore loss adjusters, and sophisticated software systems that can simulate the expected number of claims given notification of the magnitude and location of a an earthquake, and then work out the number of assessors needed, the resources they will require, and their allocation in terms of time period and location until the claims have all been handled.

## 3.9 Financial Risk Management

An important aspect of any disaster insurance scheme is the way the financial risk to the scheme is managed. Reinsurance generally plays a significant role in this. Some of the options are:

1) No reinsurance, and government absorbs risk above level of accumulated funds.
2) Risk completely reinsured up to a specified probable maximum loss (PML) apart from a small retention for small attrition losses.
3) Reinsure a layer of risk above a retention to cover attrition losses and rely on accumulated funds and government guarantee to meet risks above this level.
4) Reinsure gap between level of accumulated funds and PML

Modelling the behaviour of disaster insurance funds shows that if the objective is the accumulate a Fund or Pool of sufficient size to ensure a sustainable system then the quickest way to do this is the first option – ie buy no reinsurance and let the government take all the risk above the level of accumulated funds, until the latter have reached a stage that some of the income they generate can be used for reinsurance. Because major losses are rare there is a reasonably high probability of this approach working. The New Zealand residential earthquake scheme is a successful example of this approach being used until the Fund had reached a significant level.

To achieve a sustainable system from the start, without external support, the only option is to fully reinsure the risk up to the PML – generally taken to be approximately the 200 year return period – apart from a small retention to meet annual attrition losses, and have a government guarantee to cover extreme losses above the PML unless an upper limit to the scheme is specified. The Norwegian system comes closest to this system – it provides no safety net above the PML. From a rationalist economic point of view this is an ideal user pays system with the user paying the market cost of the risk. The disadvantage is that the system is at the complete the mercy of the reinsurance industry and in a hard market may find it difficult to purchase the full reinsurance required and encounter consumer resistance passing on the higher premiums.

Most schemes aim to build up a fund to make the scheme more independent of fluctuations in the cost of risk transfer, but most governments are hesitant to initially assume all the risk. The premium income must first fund the administrative costs and the annual attrition losses. What is left over is available for buying reinsurance and growing the fund. If the Fund has to start from scratch, unless premiums much higher than the Market Level Based Premiums are charged – and this raises serious questions of fiscal responsibility – then there needs to be a sharing between reinsurance and government with a proportion of the premium income after meeting administration costs and attrition losses being used for reinsurance and the remainder used to grow the Fund. Modelling shows that if this approach is adopted the most effective use of the reinsurance is to adopt Option 3) above of purchasing it just above the attrition level. Option 4) only becomes an option when the accumulated Fund size reaches a level that with the income from premiums and investments is sufficient to reinsure the difference between the fund size and the PML at a level providing significant protection to the Fund and enable the Fund to continue to grow with the growth of exposure. When this situation is reached the scheme will have effectively reached a sustainable level of operation.

## 3.10 Management

Disaster insurance schemes are generally managed by boards of commissioners or directors.

If it is an industry only scheme then the board will be formed from representatives of the participating companies in accordance with an agreed constitution of the scheme.

A joint industry/government scheme will be formed by a combination of government and industry representatives. Such schemes will usually be subject to government legislation that prescribes how the representatives are to be elected or selected, and their terms of reference.

If it is to be a separate scheme run by a government organisation, a government appointed board, representative of all the stakeholders, would normally manage it. In addition to government and insurance industry representatives this could include technical experts and representatives of policyholders. Again the method of appointment of representatives and their terms of reference would need to be embodied in the legislation establishing and governing the organisation.

If the scheme is operated as a government departmental function then presumably departmental officers would run it with the assistance of an advisory committee which might be similar in structure to the government appointed board for the specialist government insurance organisation described above.

## 3.11 Administration

There are four options for administering a disaster insurance scheme. These are

- Outsourcing it to an insurance company or reinsurance company.
- Creating a separate unit to administer it, either an independent unit owned by participating companies in the case of a pure industry pool, or a separate government or semi-government unit in the case of a joint industry/government pool or specialist government insurance organisation.
- Administering it within a government department as part of its normal functions. This would be the case if it was a departmental run scheme, but it is also an option for a specialist government insurance organisation.
- If the government has an existing insurance organisation such as a government reinsurance company, it could be made responsible for the administration of the system. It is understood this is how the interim earthquake insurance scheme is to be administered.

## 3.12 Mitigation

Most schemes around the world embody some degree of mitigation, mostly of the indirect form. This generally takes the form of setting aside a specified percentage of the premium income for public education and research that fosters mitigation. This often extends to encouraging the development of appropriate building codes and land use guidelines, and lobbying government for their incorporation in legislation and implementation. The New Zealand scheme is a good example of this.

A few schemes directly address the mitigation issue. In Fiji for example the provision of insurance for wind damage is subject to a certification that the building design meets a certain level or has been upgraded to this level. Flood insurance is also generally offered subject to moveable items being only covered if above a certain level of inundation of the building. In the United States the national flood insurance scheme is only available in areas where the local authority has embodied their flood plain requirements in their local byelaws. In Texas there is a government backed scheme of insurance for wind damage to dwellings in coastal areas which, for construction built since it was introduced, is only available for construction certified as meeting its own building code requirements.

The problem with direct schemes is that that non-complying construction may be excluded from the scheme. Alternatively all can be covered but the premiums and cover for complying buildings can be much better than those for non-complying buildings, with incentives offered to the owners of non-complying buildings to upgrade. The national flood insurance scheme in the United States uses the latter approach for non-complying buildings in approved local authority areas.

# 4 The Design Tools

## 4.1 Background

Among the many important decisions to be made in establishing a sustainable disaster insurance system, the following are among the most important.

- Which risks should be covered and with what limits and/or deductibles.
- What is the appropriate technical price for each type of risk exposure (residential, commercial, agriculture etc.) and therefore the premium to be charged, based on premium volumes likely to be written at different rates, and how this impacts on the overall profitability of the company.
- What is the probability of ruin of the scheme (generally linked to the probability of the level of solvency for the entity falling below a given point) and is this acceptable?
- How much capital does the scheme require to be sustainable?
- How much reinsurance should be purchased, recognising the value of reinsurance as a form of capital and a key financial management tool? (Another benefit is to provide a specific management focus on the risk retention policy, reinsurance leverage, credit risk and administrative cost.)
- How should the assets of a company be invested? What asset mix should the company employ, and how should this change to ensure optimal returns in both the short and long terms.

Each of these questions is obviously dependent upon the others. One cannot answer how much capital is required until one knows what coverage will be offered, the premium volume, the overall insurance exposure risks, and how the assets will be invested and the associated risks. Similarly, one cannot determine the optimal asset mix until one knows the premium volume, its volatility and the amount of capital available. And the premium depends as much on the policy conditions and the insured risk, as well as being restrained by affordability.

These various factors can be described as the system variables, with the object of the system design being to determine the appropriate combination of values of them. However doing this in a rational way has only become possible very recently.

Most of the current schemes were probably designed in a somewhat ad hoc manner as a result of particular political imperatives at the time. A major problem with disaster insurance schemes is that they are concerned with risks for which the level of loss is very high and the associated risk of occurrence is very low. As a consequence it is very difficult to derive reliable information on the risks by extrapolation of past losses. Factors contributing to this unreliability are:

- Major losses in a particular area from a particular type of hazard generally occur on average less than once in an average human lifetime.

- Detailed record keeping on losses is generally only available for periods much less than an average human lifetime.
- During an average human lifetime exposure and vulnerability in a particular locality can change by an order of magnitude.
- Although major losses occur somewhere more frequently differences in exposure and vulnerability from one region to another varies greatly.
- There are large differences in the value of money in time and space due to inflation and fluctuations in currency exchange values which make relating losses over time and between different countries very difficult.

Prior to the advent of sophisticated computer based information technology systems it was almost impossible to undertake rational analysis of the financial risks associated with disaster insurance systems, and consequently to design them in a rational manner. However powerful tools are now available which have changed this situation. These tools enable the simulation of the losses based on the physical characteristics of the hazards and their occurrence, and their effects on the built environment, about which there is generally much more scientific knowledge than there is on financial losses. They also enable the risk characteristics of different types of losses to be combined with each other, with the financial risks associated with fund management, and with the operational costs and system variables such as premiums, insurance cover, and reinsurance, to simulate the performance of disaster insurance systems into the future. This enables the effect of different combinations and values of the system variables on sustainability in terms of Fund growth and solvency to be studied and the most satisfactory system in terms of both technical requirements and social and political restraints established.

There are two separate types of tools used for this process:

- Catastrophe loss models
- Financial risk management models

The primary design tools are the financial risk management models, but the primary input to these models is the output from the catastrophe loss models.

## 1.10. Catastrophe Loss Models

When discussing risk assessment it is first necessary to define the risk. In the case of insurance it is the risk of insurance loss. This is a function of a number of factors:

a) The risk of occurrence of the physical event causing the loss.

b) The risk of the physical event impacting on populated areas.

c) The risk of damage given the occurrence of a hazard, which will be a function of the vulnerability of the buildings, facilities, infrastructure and crops to damage.

d) The insurable losses arising from the damage

The result is generally expressed in terms of the return period in years of a specified loss. Unfortunately the term ‘ return period’ is often misunderstood. It is used as a descriptor of probability because to most people it is more understandable to say, for example, that a loss of $100 billion has a return period of 120 years than to say it has a probability of exceedance during the next 12 months of 0.00830, which would be the case if the loss occurred purely randomly with time. Strictly it means is that if current conditions were to remain unchanged for thousands of years, the average time between losses exceeding $100 million would be 120 years, which puts it into a context that enables the risk to be compared with other human timeframes, and hence provide a basis for decision making. However for use in analytical calculations it is the value 0.00830 that is generally more useful.

It will be noted that the reciprocal of 120 is 0.00833, which is very close to 0.00830. This is not a coincidence. For large return periods, and assuming purely random occurrence, the probability of exceedance is so close to the reciprocal of the return period that it is generally assumed to be the case. The approximation gets less accurate as the return period gets less. For example a return period of 10 years corresponds to a probability of exceedance of 0.0952 compared with the reciprocal value of 0.1, and a return period of 1 year corresponds to a probability of exceedance of 0.6321 compared with a reciprocal value of 1.

The qualification of the occurrence being random is significant. Most assessment of insurance risk is based on this assumption, but it is only an approximation in practice. Typhoons do not occur purely randomly in time. Tropical cyclone occurrence is a function of large scale climatic conditions that vary with time. One cause of this variation is the well known oscillation in climatic conditions that produces the periodic El Nino phenomena. During El Nino periods the risk of tropical cyclones increases in the central Pacific and decreases in the western Pacific- and vice-versa during La Nina periods. If a tropical cyclone occurs then the probability of getting another one within the same region within a few weeks is higher than average because of a weather characteristic known by meteorologists as persistence, which means that if a certain weather pattern becomes established it tends to persist for a while. Earthquakes likewise do not actually occur randomly with time. They are the result of a build up of stress within the earth. When they occur they release stress, and transfer it to other places, so decreasing the risk in some places and increasing it in others.

The assumption of randomness of occurrence is typical of many of the assumptions and approximations that are made in insurance risk assessment. In time as knowledge of the time dependency of typhoons and earthquakes increases, it will be taken into account, but for now it is just one of the reasons why insurance risk assessment even at its best is still only an approximation, and needs to be used in a prudent manner.

However unless some assessment of the risk of insurance losses can be undertaken, they will be uninsurable. That has always been the case. In respect of disaster losses the difficulties of this assessment have often been the reason for government systems being developed – the insurance industry being unwilling to accept risks they could not assess. In recent years techniques have been developed that have led to large improvements in assessing these risks. Uncertainties remain, but providing they are recognised, sufficient information can now be generated on which to base a rational approach to disaster insurance.

With the information on insurance loss in probabilistic form decisions can be made on the levels of risk to be transferred and retained, estimates of average annual losses can be derived as a basis for premium setting, and dynamic financial analysis (DFA) tools can be utilised for managing the scheme and optimising it in terms of sustainability and costs.

Two main forms of risk assessment are used for disaster insurance loss assessment.

- Statistical analysis of past losses.
- Geographical information system (GIS) based simulation of hazards and losses.

In general statistical analysis of past losses is the most reliable approach for more frequent loss events of small to moderate magnitude, while GIS models are more suitable for modelling extreme events with low probability of occurrence. To obtain the overall characteristics of the loss it is generally necessary to combine results from different types of analyses.

### 1.10.1. Statistical Techniques

Statistical techniques are based on analysing past losses using extreme value probability distributions of one form or another. The technique assumes that future losses will have the same statistical characteristics as past losses. Normally losses are assembled in ascending order of magnitude and cumulative probabilities assigned to each loss as a function of its position in the order. Various forms of extreme value probability distributions are then fitted to this data. These fits are generally of the form of the loss or logarithm of the loss versus the logarithm or double logarithm of the exceedance probability.

There is no reason why in general any set of losses should fit any particular probability distribution since they are the result of a complex set of variables incorporating uncertainties of many different types, but different practitioners often favour one over another, while others just fit the best curve. Those with a background in insurance often use the Pareto distribution, which corresponds to a straight line fitting the logarithm of the loss plotted against the logarithm of the exceedance probability. Those with an engineering background often use either the loss plotted against the double logarithm of the exceedance probability (corresponding to Fisher-Tippett Type I extreme value distribution or Gumbel distribution), or the logarithm of the loss plotted against the double logarithm of the exceedance probability (corresponding to Fisher-Tippett Type II and III extreme value distributions such as the Weibul distribution).

The basic output of this analysis is the average number of events per year, and probabilities of different levels of loss being exceeded if an event occurs. This information can then be used to simulate randomly the event losses over long time periods and obtain statistical information on the annual aggregate losses and annual maximum event loss, on which premiums and reinsurance respectively are based.

For return periods less than the length of time of the record of the losses, this method can be reasonably reliable, and is certainly more reliable than any alternative. Unfortunately reliable data on losses over long periods of time is generally not available. There are a number of reasons for this.

- In the aftermath of disasters collating information on losses has had a low priority, particularly before computers dispensed with the need for collation to be undertaken manually using paper based records – a tedious and costly exercise.
- As a result of inflation and portfolio growth past losses can only be meaningfully used if they are indexed in some way to give the estimated loss that would occur with the current portfolio and current monetary values.
- If policy conditions have changed over time such as a change from indemnity to replacement cost as the basis of insured value, this needs to also be taken into account.

The limitations imposed by these conditions generally mean that only short records of useful loss data are available. Generally better information is kept on large losses than on small losses over longer periods, but then a problem arises over the allocation of the cumulative probabilities to these in view of the missing data. A further problem arises if one or two losses are very large and clearly not representative of the duration of the record. In this case an estimate has to be made of its return period to avoid the results being biased by this event.

The application of statistical techniques to insurance risk assessment is therefore as much an art as a science, despite being based on sophisticated mathematical analysis. But it is necessary if a reasonable indication of short-term losses and their variation are to be obtained.

### 1.10.2. GIS Loss Simulation Techniques

During the 1970's civil and structural engineers, concerned about design criteria for earthquakes and tropical cyclones began to use the computer to simulate the hazards because basic occurrence information such as the magnitude and location of earthquakes, and the central pressures and tracks of tropical cyclones, seemed more reliable than the occurrence information on the resultant hazards such as earthquake intensity and wind speed. About the same time in the insurance world a technique started to be developed for estimating disaster insurance losses by superimposing the geographical pattern of maximum wind speeds or maximum earthquake intensities from an event, real or imaginary, on populated areas and, using information on individual loss as a function of these hazards, integrating the loss over the affected areas to determine the total expected loss from the event.

These two developments coalesced during the 1980's and by the beginning of the 1990's commercial GIS insurance loss models for earthquake and tropical cyclones were available in limited regions of the world. During the 1990's there was continual expansion of the geographical scope of the models, which now embrace most major insured areas of the world at significant risk from earthquakes and tropical cyclones, and also extension in some regions to other hazards such as flood, hail and wild fire. Their use has now become a standard feature of property PML analysis for excess of loss treaty reinsurance for most major insurance companies, and underpins the growing use of alternative risk transfer and financing approaches such as catastrophe bonds. They have also become widely used for as a basis for setting premiums in a regulatory environment where premium rates have to be justified.

GIS loss models are very complex computer software systems that integrate a number of different types of models as follows.

- A hazard model that simulates geographically the intensity of the hazard causing damage resulting for a specified event. In the case of an earthquake loss model, the hazard model is known as the attenuation model, and maps the estimated earthquake intensities arising from an earthquake of specified magnitude and depth occurring on a specified fault, and taking into account local amplification due to soft soil conditions.

- A vulnerability model that simulates the insured loss attributable to a particular building for different hazard intensities taking into account various building characteristics which affect its vulnerability to damage such as building type, construction materials, and age of construction, as well as its value and policy conditions such as deductibles, limits, etc.

- A portfolio model which is a database of all the buildings covered by the insurance programme containing information on location, value, building type, construction materials, age of construction and any other factors affecting their vulnerability to the hazard, together with policy information on the insurance cover.

- An occurrence model which simulates in a probabilistic manner the occurrence of the events giving rise to the hazard. In the case of earthquake loss, these models are based on a combination of known information about active faults plus historic records of earthquakes. For tropical cyclone loss, these models are generally based on historic records of tracks, central pressures and eye diameters (if available).

- An integration model which simulates the occurrence of events in accordance with the occurrence model, maps the maximum intensities of the hazard for each simulated event in accordance with the hazard model, superimposes this over a map of the portfolio information, calculates the individual losses according to the vulnerability model and aggregates these in the form required, and outputs the results in the desired form.

The basic output of GIS loss models are tables of loss versus the average number of exceedances of this loss per year (or its inverse the return period of the loss) in which form it can be used to randomly simulate the losses over many years which is the information needed for financial risk management models. This information can be produced for the total portfolio loss, or for any sub set of these losses in terms of regional areas, subsidiary companies, building types, location category in terms of say soil type for earthquake loss, or terrain type for wind loss for use for risk rating purposes or internal allocation of costs.

The three major independent international commercial providers of GIS loss simulation models are Risk Management Solutions (RMS), EQE International (EQECAT), and Applied Insurance Research (AIR), which are all based in the United States. Some of the major reinsurance broking firms such as Aon have also developed their own models for internal use, and a number of smaller consultants have also developed models appropriate to their expertise and the regions in which they work.

Although the most sophisticated of these models are very complex, and embody considerable precise calculations, none can be described as accurate, as they depend on a considerable number of assumptions for which detailed knowledge is lacking. The assumptions used in the different models are based on the opinion of experts retained by the individual companies that produce the models. These opinions differ, reflecting the differences of opinion among experts on matters for which detailed knowledge is poor. As a consequence different models can produce widely differing results for the same portfolio. It is not unusual for results to differ by a factor of two or more. If the difference is less than 20 percent it is regarded as very small, but the results may be no more accurate than those that differ by a factor two. Output from these models should be regarded as best estimates based on expert opinion, and indicative of the order of magnitude of the risks of large losses, rather than accurate estimates of them.

By and large where uncertainties exist, the models are more likely to err on the conservative side. Consequently most models probably give relatively conservative results, and generally – but not always – the gradual refinement of models leads to a reduction in the estimated risks over time.

Undertaking detailed studies using these models is generally time consuming and expensive, unless undertaken at a relatively coarse level of portfolio accumulation such as Cresta Zones. They are also very demanding on the quality of the portfolio information required. Undertaking a study using them consequently becomes a major project in its own right.

## 4.3 Financial Risk Management Models

To determine the best set of values for the various design variables of a disaster insurance system such as premiums, cover conditions, reinsurance programme, investment strategy, etc, it is necessary to model the performance of the fund and financial operation of the system as a whole into the future. This type of analysis is commonly known as asset/liability modelling (ALM). When undertaken in terms of risk, a technique known in the insurance industry as dynamic financial analysis (DFA) is incorporated in the analysis to produce a financial risk management system. An understanding of the range of answers from such systems, the interactions between the answers, and the quantification of the effect of changes in policy decisions provides a framework for establishing an optimal design for the disaster insurance scheme and maintaining it.

Figure 2 shows the basic financial structure of a Fund based property insurance scheme. The basic purpose is to collect premiums from customers and pay out claims to them when they suffer a loss. But administrative costs, investment gains and losses, reinsurance premiums and recoveries, borrowings if needed, and government taxes and refunds – eg arising from a government guarantee – also affect the performance of the scheme.

The objective of financial risk modelling is to simulate this structure on a computer, input the uncertainties and proposed policies in regard to premiums, policy conditions and financial risk management strategy, and observe the resulting performance in terms of various balance sheet and profit and loss variables, and other performance indices.

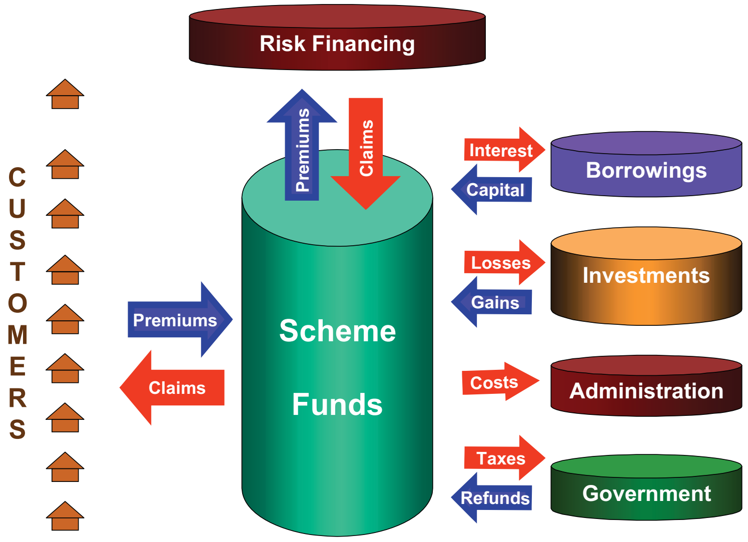

Figure 3 Financial Structure of Fund Based Property Insurance Scheme

Figure3 shows the structure of a typical financial risk management software system designed to simulate the financial performance of a disaster insurance scheme. This takes as its input the projected variability in the amount and the timing of premiums, claims, expenses, growth in asset values and settlement patterns as represented by statistical distributions, together with the output of the analysis of insurance risk described in the previous section.

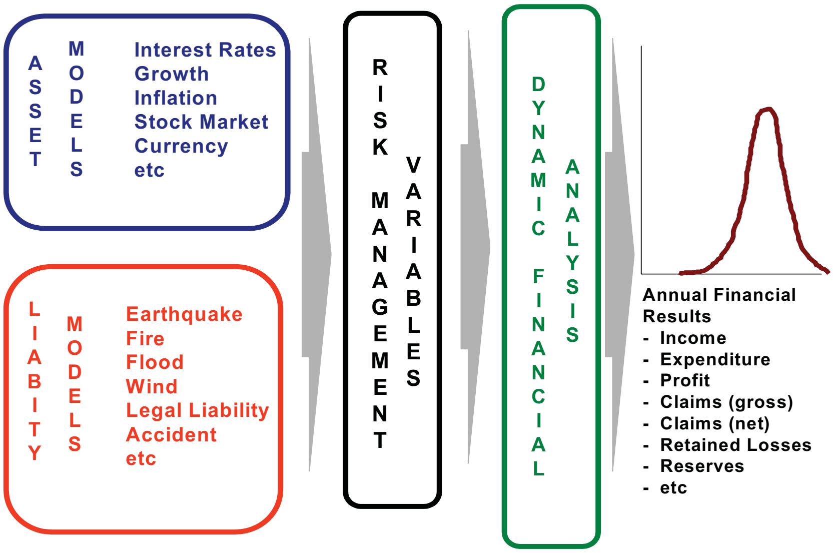

Figure 3 Structure of Financial Risk Management System

The system is normally constructed to simulate several years of operation into the future in order to observe how the system will behave over time. By changing the various risk management variables such as premiums, policy conditions and reinsurance proposals, a user can determine the combinations which give the most satisfactory outcome in terms of such factors as the sustainability of the scheme, affordability of premiums, and tolerance for risk.

Output from such models enables managers and administrators to get an understanding of the risks associated with different strategies, and not to have to rely only on subjective opinion.

The Minerva system recently developed for the New Zealand Earthquake Commission by Aon is an example of such a system. Minerva is designed to simulate the performance of the EQC's Natural Disaster Fund for 10 years into the future, allowing for portfolio growth and inflation. It includes a full probabilistic GIS earthquake loss model covering all dwellings in New Zealand, information on which is input on an individual basis describing location, type of building, age, estimated replacement cost, and the nature of the foundation soils. For estimating the exposure risks in future years new dwellings are created in accordance with input information on expected growth in dwellings, and increases in value are made in accordance with input information on inflation and improvements to existing buildings. The loss model includes several options for attenuation modelling, source modelling and vulnerability modelling, so that users can gain an understanding of the range of results due to different assumptions. The financial behaviour of the fund itself is modelled using two different asset models, one a simple traditional model and one a more complex state-of-art model. The system allows for both deductibles and first loss caps as policy conditions, and for both traditional CatXL reinsurance and alternatives such as Cat bonds and contingency loans. The system outputs in statistical form over 60 different factors describing the financial performance and position, cash flows and contingent liabilities for different investment strategies or returns, and various reinsurance or fund protection arrangements.

# 5 A Framework for the Development of a System

In order to develop a sustainable comprehensive disaster insurance system for the South Pacific region there are a number of factors that will need to be considered.

1) ***What is the current level of disaster insurance in the region?*** Insurance for earthquake and wind damage in South Pacific countries is generally available from the private insurance market as an addition to a normal fire insurance policy, although it is often conditional on specified standards of building construction being met. Flood cover is often available for commercial property as an additional cover, but not for residential property. The situation in respect of agricultural and government assets is not known. However, although insurance is available for property insurance, it may be primarily bought by owners of commercial properties in major urban areas, and by the wealthier householders, with the average householder and possibly small commercial businesses in rural areas not being covered because of the expense or conditions applied.

   Insurance is strongly associated with wealth. High levels of penetration of insurance are largely characteristics of wealthy countries. In less wealthy countries insurance is largely associated only with the wealthier sections of the community. But when disasters strike the uninsured turn to government for financial help. In the less wealthy countries the governments often then turn to international agencies such as the World Bank for funds. These funds come as loans which must be paid back limiting the future development of the country. National disaster schemes in conjunction with mitigation measures are a way of limiting this long term economic impact of disasters on a country.

   An initial step will need to be a study of this issue to determine the actual need for a disaster insurance system, and to which sections of the community it will need to be directed.

2) ***What will it cover?*** Everything (unlikely)? Dwellings only? Agriculture as well? What about government assets? This decision needs to be made early as it will affect the subsequent activities. In general one comprehensive scheme covering all risks is not recommended, because of the big differences in classes and associated objectives. A system of different schemes for the different classes also means that the

development and implementation can be staged in terms of the priorities for different classes. In general dwellings tend to be given highest priority if this approach is followed. Where Government assets are insured this tends to be part of a general insurance programme of government property and liabilities and not a special disaster scheme.

3) ***What is the maximum limit to premiums in terms of affordability?*** In all but the wealthiest countries affordability is the primary reason for being uninsured. Once the need for a government backed system of disaster insurance has been established the next essential step is to ascertain the limits of affordability of in relation to premiums. In the normal insurance world premiums are based on risk. The higher the risk the higher the premium in general. This is because policy conditions are largely standard, the property in question being covered for either indemnity value or replacement value, with generally a small deductible. If affordability is the barrier, as it almost certainly is in the small South Pacific island countries, then the premiums will be determined by affordability and the risk will determine not the premiums but the level of cover that will be provided.

The recently implemented Taiwan Residential Earthquake Insurance Program in Taiwan is an example of this. A fixed value of premium (approximately US$50 per year) was determined based on affordability, and a set of policy conditions determined that were consistent with this. These policy conditions are very limited, a fixed amount insured (approximately U$100,000) which can only be claimed if the dwelling is declared a total loss.

4) ***What is the affordable risk?*** Having determined the premium from a consideration of affordability, the next step is to determine what level of cover can be provided. This will be a function of the hazard risks, and the vulnerability of the property or operations to be covered to the hazards. To undertake it requires loss risk modelling as described in Section 4.2.

Currently no risk loss models exist for the small South Pacific islands with which this study is concerned, so they will need to be developed. The reason there isn't nay is because such models are expensive to develop, and the commercial insurance market in these countries is too small to justify the development of such models as a commercial undertaking. There are two alternatives – engage one of the commercial modelling firms to develop such models under contract, or develop own models using expertise within the SOPAC community.

The latter approach is recommended. Normal models are developed to handle normal policy conditions which are relatively fixed. But these models are needed to develop policy conditions so policy conditions, which need to be incorporated in the models in order to produce the required output of insured loss, need to be incorporated in the models in such a way that they can be varied. Sometimes it is only practical to do this by modifying the software. Engaging commercial companies based in the US or the UK for this can be very expensive. So can the alternative if starting from scratch with no existing expertise.

One of the expensive activities in developing loss models is assembling in database form the extensive information on the hazards which is needed to underpin these models. Another is assembling in database form comprehensive information on the property or activities to be covered. Both these activities are already well underway in SOPAC. The third requirement is expertise in risk and loss modelling. Through GNS in New Zealand and Geoscience Australia SOPAC also has ready access to this expertise. Geoscience Australia is currently engaged in a long term project to develop such models for Australia based on the US Federal Emergency Management Authority's HAZUS GIS disaster modelling project, and GNS scientists in New Zealand are at the forefront of the GIS modelling of earthquake risk, and their are consultants in both countries who are very experienced in this area of expertise.

Furthermore the general structure of such models is portable for the major hazards, and there are models which could probably be made available which would then need customising to the each country using the local data on risk and property at risk.

Which ever approach is adopted it will be a major project that will take considerable time and resources, and will probably need to be done in a sequential fashion in relation to different countries. This will mean that before it is implemented there may need to be a political decision on the priorities of different countries.

5) ***How will the system be structured?*** Once the premiums and affordable policy conditions have been established then consideration can be given to the overall structure of the system. In the case of the South Pacific island nations this will mean considering the following:

- Will there be one common scheme covering all countries, or will each country have its own scheme? If the latter, will they each subscribe to a common pool for reinsurance purposes?
- Will it be a Government Fund or Industry Pool based scheme, and which ever it is how will the Fund or Pool be structured in terms of retention, investment, reinsurance and Government guarantee?

The answers to these questions will depend on technical and non-technical factors, including political factors. To ensure the resulting scheme is sustainable however it will be necessary to utilise financial risk management models as described in Section 4.3. These will need to be developed. Expertise for the development of these generally resides in the insurance industry, mainly within the actuarial consultants and reinsurance brokers.

6) ***How will it be managed and administered?*** This will include consideration of the following questions:

- How will premiums be collected?
- How will claims be assessed and paid?
- What will be the composition of the Board of Management, how will members be appointed, and what will be their terms of reference?
- Who will administer the scheme, and what will be their terms of reference.

7) ***What about Loss Control?*** A disaster insurance scheme can be a recipe for exploitation by the unscrupulous unless there is firm control on claims handling, and active encouragement of mitigation of losses. Building and land planning regulations can play a major role in the latter, but how can these be linked to the scheme? Once the main structure of the scheme has been determined loss control may need to be the subject of a special study.