Review of oceanographic conditions in American Samoa

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Review of oceanographic conditions in American Samoa

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Reviewed by: Dr Richard Gorman
Approved for release by: Dr Rob Bell
1. **Introduction**

This brief report summarises the oceanographic conditions and nearshore coastal processes of American Samoa with projections for climate change impacts on these processes. It has been prepared for JacobsGIBB Ltd, (based in Reading, United Kingdom), as part of the American Samoa Economic Valuations Study.

This report is based on a very brief literature review of information within the public domain.

2. **General oceanographic climate**

2.1 **Introduction**

Tutuila (14.33°S 170.71°W) and the Manu’a Islands (14.19°S 170.71°W) are located within the easterly tradewind belt with winds from the south-easterly quadrant dominating. The tradewinds are more consistent in the winter months (June to September). The summer months (December to March) are characterised by more variable winds with more frequent westerly to northerly winds. Tropical storms, bands of converging winds or low pressure systems higher in the atmosphere all contribute to typically higher rainfall during summer. However, the highest rainfall in nearly 20 years, totalling 271 mm at Pago Pago, affected the islands between the 18th – 20th May 2003 causing mudslides that killed 4 people and prompting a state of emergency to be declared.

2.2 **Water levels and waves**

The astronomic tide in American Samoa is mixed semi-diurnal with a spring range of 1.1 metres and neap range of 0.4 metres. The Shoreline Inventory update (Ser Engineering Inc & Bolt Collins, 1994) provide the following tidal levels relative to Mean Low Water (MLW):

<table>
<thead>
<tr>
<th></th>
<th>3.0 ft</th>
<th>0.91 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest Tides, observed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean High Water</td>
<td>2.4 ft</td>
<td>0.73 m</td>
</tr>
<tr>
<td>Mean Tide Level</td>
<td>1.2 ft</td>
<td>0.37 m</td>
</tr>
<tr>
<td>Mean Low Water</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lowest Tide, observed</td>
<td>-2.6 ft</td>
<td>-0.78 m</td>
</tr>
</tbody>
</table>

Review of oceanographic conditions in American Samoa
No quantitative information was available on extreme water levels for American Samoa. Extreme levels are most likely to occur during tropical storm or cyclones where a low pressure system, wind and wave set-up act to raise sea levels at the shoreline.

Analysis of monthly and annual mean sea level data held by the Permanent Service for Mean Sea Level (UK) for the tide gauge at Pago Pago suggests that annual mean sea level typically varies by about 0.1 m, but on occasions up to 0.2 m, from year to year due to differences in oceanic currents and the ocean response to winds, climate and oscillations such as El Niño and the Interdecadal Pacific Oscillation (IPO). Over the period that tide data have been collected at Pago Pago (1957 – Present) an average rate of mean sea level rise of about 1.78 mm/year has occurred, (Figure 1) This is similar to average rates experienced throughout the Pacific of between 1 mm/year and 2 mm/year over the last century and is close to the global average sea-level rise (Douglas, 2001).

The El Niño - Southern Oscillation (ENSO) results in weaker easterly trade winds during periods of El Niño. Under strong El Niño conditions (high negative Southern Oscillation Index, SOI) there is a general reduction in monthly mean sea levels, although with a slight lag (Figure 2).

![Figure 1: Annual mean sea level variation between 1957 and 2001 for the Pago Pago tide gauge.](image-url)
Figure 2: Correlation between monthly mean sea level and monthly Southern Oscillation Index between 1967 and 2001. Note: large negative SOI for El Niño events.

The trade winds result in approximately 70% of wave conditions between June and November occurring from the south-eastern quadrant (90° to 180°), (Sea Engineering Inc & Belt Collins, 1994). For the rest of the year, approximately 75% of the waves occur from between north-east to south-east (45° to 135°).

Wave data collected for the Samoa region by Oceanor (Norway) as part of their wave energy studies for SOPAC (Barlow & Hau, 1994) were re-assessed within Oceanor’s World Wave Atlas system to provide further information of the offshore wave climate around American Samoa.

Wave height data were collated over the period between October 1986 to July 2000, (with a gap of three years between 1989 and 1992) from moored buoy data, GEOSAT and TOPEX / Poseidon satellite data and UK Met Office Global Wave Model data. Whilst the data were collected for Western Samoa, they also covered the American Samoa region and are likely to be representative. However, wave period and directional information was collected over a shorter time frame and are unlikely to be totally representative of annual conditions. Frequency plots of significant wave height, mean and peak wave period, and mean wave direction are shown in Figures 3 to 6.
Figure 3: Frequency distribution of significant wave height (i.e., the average of the highest 33% of wave heights).

Figure 4: Frequency distribution of mean wave period.
Figure 5: Frequency distribution of peak wave period.

Figure 6: Frequency distribution of mean wave direction.

Offshore wave conditions are dominated by the south easterly trades, typically with a significant wave height of between 1.5 m and 2.5 m and mean wave period of 5.5 to
7.0 seconds. Over 80% of offshore wave conditions have a wave steepness of less than 0.03 reflecting the dominance of oceanic generated swell conditions.

Extreme offshore wave conditions based on a three parameter Weibull distribution, are plotted in Figure 7 below. However, this may under predict significant wave height slightly as cyclonic conditions may not be adequately represented due to the resolution of the global wave model from which the wave height statistics have been derived.

Figure 7: Return periods for extreme significant wave heights.

2.3 Tropical storms and cyclones

In the South Pacific tropical cyclones develop during the wet season, usually between November and April with peak cyclone activity typically occurring in January (see Appendix 1). For the southwest Pacific a tropical cyclone is a tropical low-pressure system with an organised wind circulation intense enough to produce sustained gale force winds (at least 34 knots or 63 km/hr) near its centre, with a severe tropical cyclone producing sustained hurricane force winds (at least 64 knots or 118km/hr), and corresponds to the hurricanes or typhoons of other parts of the world (NIWA, 2003).

Whilst cyclone activity most commonly occurs over New Caledonia, Vanuatu, Fiji, Tonga and Niue, the movements of individual cyclones can be unpredictable. Figures 8 to 10 below show the individual tracks of cyclones affecting the South Pacific over
the last five years, including the track of Cyclone Heta that recently occurred on the 4-5 January 2004 and caused substantial damage on American Samoa.

![Cyclone Tracks](image)

**Figure 8:** Individual cyclone tracks for the South Pacific for the years 2000 to 2004 (Joint Typhoon Warning Centre, 2004).

Annual tropical cyclone occurrence for the years 1972 to 2001 with an intensity of greater than 25 knots is shown in Figure 9 below. Monthly statistics are summarised in Appendix 1 to this report.

Since 1970, the Samoan islands have experienced on average 1.4 tropical cyclone events per year that have passed within 100 km of the islands, as shown in Figure 10 (NIWA, 2003). The El Niño-Southern Oscillation (ENSO) also influences cyclone occurrence with a slightly lower risk during neutral ENSO (1.3 times per year) and La Niña phases and generally higher risk of cyclones occurring during the El Niño phases.
Figure 9: Average number of best track positions in 1° by 1° cells for all years between 1972 and 2001 (Joint Typhoon Warning Centre, 2004).

Figure 10: Tropical cyclone occurrence, of events that pass within 100km per year for neutral ENSO periods October – June, 1970/71 to 2001/02 (NIWA, 2003).
3. Impacts of climate variability and change

3.1 Introduction

Future climate change will have a significant impact on small islands such as American Samoa. This section briefly summarizes some of the impacts that future climate variability and change will have on coral reef ecosystems, with reference to the coastal protection functions of these systems. Much of the information is based on the latest IPCC (2001) guidance on global climate changes in the context of American Samoa, the report Preparing for a changing climate (Shea et al. 2001), and the recently published Climate Variability and change and sea level rise in the Pacific Island Region (Hay et al. 2003).

3.2 Potential future impacts

Increased temperatures of between 0.6°C and 3.5°C in this century in the Pacific Region, and increased carbon dioxide concentrations in the atmosphere, are two of the most commonly accepted changes likely to occur. It is also generally accepted that such global climate changes will result in increased stresses on coral reef ecosystems. Buddemeier et al. (2004) summarised the likely impacts of increasing temperature and carbon dioxide concentrations on coral reef ecosystems over the next century as:

- Increases in ocean temperatures associated with global climate change will increase the number of coral bleaching episodes. If the frequency or severity of coral bleaching events increases, this will decrease the capacity for coral species to recover from such events, resulting in a reduction in local and regional coral biodiversity as more sensitive species are eliminated.

- Increases in atmospheric concentrations of carbon dioxide (CO₂) from fossil fuel combustion will drive changes in surface ocean chemistry. Higher CO₂ concentrations in the atmosphere, and hence dissolved in the surface ocean, decreases the ability of corals to extend their calcium carbonate skeletons and/or form skeletons of lower density. This will affect the reef ecosystem’s ability to respond to sea level rise (see below), increase susceptibility to both physical breakdown and bioerosion, and reduce the ability to recover from stress events such as bleaching.
The effects of global climate change will combine with more localised stressors to further degrade coral reef ecosystems. Whilst coral reefs will be adversely affected by climate change, these effects will also result in the reef ecosystem being more susceptible to degradation due to natural climate variability (such as El Niño events) as well as localised stressors (such as sedimentation and pollution).

Accelerated global mean sea level rise is a further, reasonably well accepted, feature of future climate change. Over the past century global sea level has been rising at an average rate of about 1.8 mm per year (Douglas, 2001), which is similar to the rate (1.78 mm/year) recorded at the Pago Pago tide gauge over the last fifty or so years. Table 1 summarises the "most likely" projections, from the latest IPCC (2001) report, for global average sea level rise by 2050 and 2100.

Table 1:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>SLR by 2050</th>
<th>SLR by 2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Pago Pago trend of +1.78 mm/year continues</td>
<td>0.089 m</td>
<td>0.178 m</td>
</tr>
<tr>
<td>IPCC (2001) &quot;most likely&quot; mid-range</td>
<td>0.14 – 0.18 m</td>
<td>0.31 – 0.49 m</td>
</tr>
<tr>
<td>IPCC (2001) Uncertainty range</td>
<td>0.10 – 0.24 m</td>
<td>0.21 – 0.71 m</td>
</tr>
<tr>
<td>Intermediate zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPCC (2001) Uncertainty range</td>
<td>0.05 – 0.31 m</td>
<td>0.09 – 0.88 m</td>
</tr>
<tr>
<td>Upper and lower extreme zones</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 11 shows the above global projections, relative to 1990, with the mean annual sea level data since 1957 at Pago Pago superimposed.

The relative rate of sea level rise at any location also depends on vertical land mass movements, e.g., due to earthquakes, subsidence or plate movements. However, the observation that the trend in sea level rise in American Samoa is comparable to other long term rates throughout the Pacific (and indeed globally) suggests that, until proved otherwise, the global rates of sea level rise presented above would appear to provide as reliable an estimate as is presently available.

There is no evidence yet to suggest that the rate of increase in high tide or extreme water levels will differ from that of mean sea levels. Hence, all things being equal, present day extreme water levels will be attained more frequently. In American
Samosa, the main cause of storm surge is attributed to tropical cyclones (see below). Any increase will depend on changes in the frequency or intensity of such events and as yet there is no clear evidence as yet whether changes in the behaviour of these systems will result in changes in storm surge magnitudes.

Figure 11: IPCC (2001) global mean sea level rise projections (tied back to 1990) with the mean annual sea level data since 1957 at Pago Pago (black line) superimposed. Note that the green lines correspond to the upper and lower bounds of the most likely range of sea-level rise, the blue lines to the intermediate zone, and red lines to the upper and lower extreme zones.

There is no evidence that global warming will result in an increase in occurrence of tropical cyclones (IPCC 2001). However, studies have indicated that there will likely be changes in the intensity of tropical storms (by 10-20%), e.g., more Heta type cyclones, as well as changes in the genesis area and tracks of such cyclones. There is also no indication that the present relationship between cyclone distribution and ENSO would change.

Current predictions indicate little change or a small increase in the magnitude of El Niño events over the next 100 years but there is some evidence of more frequent El Niño-like events. However, confidence in the projections of the frequency, magnitude and spatial patterns of El Niño events throughout the Pacific are relatively low due to the general limitations of how the El Niño and La Niña events are simulated within the complex climate models used to make future predictions.
Whilst a modest rise in sea level (within the projected rates of future mean sea level rise) would be beneficial for coral reef growth on most reef systems due to increased water circulation, the degree of protection provided by the reef system is likely to be reduced. The main impacts are outlined below.

3.3 Impacts on coastal erosion and inundation

In general, increased sea level will result in increased wave energy propagating over the reef flat and reaching the shoreline resulting in increased storm damage, longshore transport potential, wave run-up and inundation. The relative magnitude will vary considerably depending on the exposure of the coastline, the changes to nearshore wave processes, the geomorphology controlling beach face shape response (pocket beach, barrier spit, flood deltas, mangrove and coastal wetland etc.), and the characteristics of the beach sediments themselves (sand, shingle, cobble etc.).

Approximately 20% of the coast (about 26 km) of Taitua is fronted by beaches. Typically these tend to be pocket beaches bounded by rocky headlands and arculate in plan shape. The coastal plains tend to be a mixture of both terrestrially derived sediments (to the landward) and marine (carbonate) sediments (to the seaward side). Such coastlines, in their natural state, can be relatively resilient to beach changes (compared to more open coastlines), changes caused by changes to the hydraulic forcing processes likely to occur due to climate change. This is because they tend to be relatively closed systems, i.e., little sediment enters or leaves the beach system due to natural processes. Some landward retreat of the coastline will occur as “leakage” of sediment from these pocket beach systems under storm events is more likely to occur than sediment accretion.

Unfortunately there are very few ‘natural’ beach systems remaining on Taitua. Large lengths of the coastline are fronted by engineering structures intended to protect the land backing them. Such structures interfere with the natural cycles of beach response preventing the natural beach system from fluctuating in response to extreme (erosional) and fair-weather (accretionary) events. It can be expected that beach loss adjacent to such structures will continue, resulting in a continued loss of beach area and potentially greater risk of damage and lower standard of protection provided by the engineering structures (see below).

In other places, such as around headlands, the beaches are thin and sinuous, often a thin layer of sand and cobbles overlying basalt outcrops of boulders with a narrow coastal plain backing it. This type of coastline generally exhibits a long-term erosional
pattern but normally at a very slow rate with erosion events typically related to episodic storm events and characterised by erosion scars at the coastal edge. Increased sea levels will potentially result in an increased rate of erosion, but this will depend on the morphology of the basalt outcrops with there tending to be an increased “hardening” of the shoreline as more basalt becomes exposed as the coastline retreats.

Other features likely to be sensitive to the impacts of climate change include the barrier spit system in the Pala Lagoon and Coconut Point area. The morphology of the spit suggests that it has developed from northeast to southwest by longshore sediment movement. Erosion of the southwest edge of the spit has been ongoing for a long time and further changes to longshore sediment transport rates due to subtle changes in nearshore wave climate or reduction in the supply of sediment to the shoreline are likely to have a serious impact on the stability of this feature in the future. This coastline is likely to experience some of the highest future rates of erosion on Tanailla.

The impact on the many flood deltas, formed where streams have deposited terrestrially derived sediments during periods of high rainfall on the reef flat, is difficult to assess. An important factor will be the volumes of terrestrial sediments being deposited at the coast at each particular river outlet, which will depend on future rainfall event intensity and frequency. Increased sea levels and resulting larger wave conditions at the shoreline may result in an increased winnowing of finer sediment from these deltas, i.e., the beach material becomes gradually coarser. Increased wave action may also increase the occurrence of short-term damming of the river mouths, potentially leading to an increased risk of fluvial flooding of low lying areas within the coastal hinterland.

Between Logologo Point and Fogagogo, the shoreline is characterised by a lava sea cliff of relatively recent origin. Sea level changes may result in a minor increase in the rate of erosion of the cliff sections of coastline but this is unlikely to a significant slope. In sections where coastal deposits do occur (generally these are perched on the basalt bench above high tide and are likely to have been deposited during storm conditions), these may serve as a slight retreat of the beach as it re-adjusts to increased sea levels.

In terms of inundation the following general climate-change impacts will occur:

- More frequent, possibly permanent inundation, of those areas currently experiencing occasional inundation.
- Episodic inundation of new areas which were previously just above sea flooding levels.
Increased inundation is likely to impact most on the coastal wetlands. On American Samoa these are characterised by coastal marsh and mangrove forest. The coastal marshes tend to be in isolated depressions with fresh to slightly brackish water (Richmond, 1995). Increased sea levels may well increase the salinity within these marshes, leading to ecological changes. However, unless there is significant change in the forcing hydraulic processes, e.g., wave energy reaching these marsh areas, it is unlikely that there will be any substantial erosion.

Mangroves, despite being relatively limited in extent on American Samoa, are located in open brackish or saline environments. Where they are found, they are important in maintaining shoreline stability. The importance of sediment flux and vertical rates of sedimentation in determining how mangroves respond to sea level is well recognised, and where sediment supply is low, mangrove accretion may not be able to keep up with future sea level rise. However, it is also noted that in appropriate coastal areas, inundation of low-lying land may increase potential areas for mangrove expansion.

3.4 Impacts on existing coastal defences

Increased sea levels and more frequent inundation events will tend to lead to a reduction in the standard of coastal defence provided by existing structures. With increased wave energy at the shoreline and higher water levels there is the potential for significantly higher wave run-up and overtopping of defences leading to increased inundation and damage to human infrastructure and property located behind the defences.

There will also be considerable increase in the potential for damage to the existing defences themselves. For example with rock structures, the size of rock required is directly proportional to the cube of the significant wave height. Hence even a small increase in wave conditions at the shoreline can result in a large increase in the size of rock armour required to achieve the same stability. Given that many of the coastal defences found around the coast of American Samoa have been poorly designed or constructed, the impacts of climate change are expected to result in much more frequent damage to these defences and lower standard of protection to the land backing it. Similarly if defences have been designed for a particular ‘design life’, this is unlikely to be fulfilled if climate change considerations have not been factored into the design.

Increased wave energy may also result in increased wave reflections from solid defence structures exacerbating the seaward transport of beach and reef flat sediment.
4. References


Appendix 1: Average number of best track positions in 1° by 1° box per month between 1972 and 2000 (Joint Typhoon Warning Center, 2004).

January

February

March

Review of oceanographic models by Australian Saints
April

May

June

Review of oceanographic conditions in American Samoa
Review of oceanographic conditions in American Samoa
October

November

December

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