11. Appendix 1: Terms of Reference

Terms of Reference

Information for Climate Risk Management
(KAP II Component 1.4.0)
Procurement Plan ref. FS5

Kiribati Adaptation Program – Pilot Implementation Phase (KAP II)

1. General background

Kiribati is one of the most vulnerable countries in the world to the effects of climate change and sea level rise. Most of the land in urban Tarawa is less than 3 meters above sea level; the island has an average width of only 450 meters, rendering retreat adaptation options untenable. This situation is typical of most islands in the country. The islands are exposed to periodic storm surges and droughts, particularly during La Niña years, although they lie outside the cyclone path. Already, Kiribati is becoming increasingly vulnerable to climate events due to its high population concentration, accelerated coastal development, shoreline erosion, and rising environmental degradation. By 2050, if no adaptation measures are undertaken, Kiribati could face economic damages due to climate change and sea level rise of US$8-$16 million a year, equivalent to 17-34 percent of its 1998 GDP.

To address these rising risks, the Government of Kiribati is undertaking an Adaptation Program, supported by the World Bank, the Global Environmental Facility, AusAID and NZAID, the Japan PHRD Climate Change Fund, UNDP, and a parallel project by the EU. The key goal is to reduce Kiribati's vulnerability to climate change, climate variability and sea level rise. This Kiribati Adaptation Program (KAP) is planned to be implemented in three phases:

- **Phase I: Preparation** (2003-2005, completed). This phase began the process of mainstreaming adaptation into national economic planning and identified priority pilot investments for Phase II. It also involved an extensive process of national consultation. The project was closely linked with the preparation of the 2004-07 National Development Strategy and Ministry Operational Plans.

- **Phase II: Pilot Implementation** (2006-2009). This current phase is the focus of this TOR. Its objective is to implement pilot adaptation measures, and consolidate the mainstreaming of adaptation into national economic planning.

- **Phase III: Expansion** (2009-2015). This phase would gradually scale up the investments piloted under Phase II to cover all major islands and vulnerable sectors of Kiribati.

The key objective of the current Pilot Implementation Phase, KAP II, is to develop and demonstrate the systematic diagnosis of climate-related problems and the design of cost-effective adaptation measures, while continuing the integration of climate risk awareness and responsiveness into economic and operational planning. Lessons learned from KAP-II would be used to plan the long-term national response to climate change envisaged for 2009/10 onwards. KAP II includes the following components:

Component 1: Policy, planning, and information. This component supports three core elements of all adaptation efforts in Kiribati. The first element is awareness raising and consultation. The second element is policy coordination and planning, including support to the new National Strategic Risk Management Unit in the Office of Te Beretitenti; continued mainstreaming into Ministry Operational Plans; and integration of adaptation into population and resettlement programs. The third element is to generate scientific climate risk information and refurbish the capacity of the Meteorological Office.

Component 2: Land use, physical structures, and ecosystems. This component will contribute to reducing the vulnerability of the coastline including key public assets and ecosystems, shifting the coastal management practice from a reactive, single technique approach to repairing damage as it occurs, to a preventative and more technically varied risk mitigation strategy, including more attention for environmental sustainability. More specifically, the component would support the development and application of improved risk diagnosis and response methods, and improvements in planning and permitting processes to guide coastal zone activities, including regulatory adjustments, awareness raising and enforcement, and economic and environmental monitoring. Secondly, the component will produce design and construction guidelines, and apply them to a sample of public assets that are at risk, including the national hospital and vulnerable coastal areas. Thirdly, the component includes monitoring and pilot activities to protect and restore coastal ecosystems and biodiversity affected by climate change, climate variability and sea level rise, including the detrimental effects of current adaptation practices.

Component 3: Freshwater resources. This component supports the development and management of freshwater resources to reduce their vulnerability to climate variability and climate change. It will provide assistance to update the national water policy, improve water resource management, and revise building codes to enhance opportunities for rainwater catchment and storage. Given that water management problems are most acute on the central island, Tarawa, the component will also support the preparation of a master plan for water resources on Tarawa, pilot projects to identify and increase water resources in freshwater lenses, and a public awareness and education campaign to change user attitudes. On the outer islands, the component focuses on water resource assessments and improvements in the water supply system in selected locations, including attention for non-polluting sanitation systems.

Component 4: Capacity at island and community level. This component provides assistance to the Ministry of Internal and Social Affairs (MISA) to include adaptation in the Outer Island Profiles, and training on climate risk management for local governments. Furthermore, it supports a program of small-scale adaptation investments in two selected outer islands, identified through participatory planning and implemented directly by communities.

Component 5: Program management. This project component provides overall support to the project, including program management, accounting, procurement, and running costs of the Program Management Unit. It will also support the evaluation of KAP-II in view of the design of the next phase of GoK adaptation efforts.

2. Specific background for this assignment

Adaptation to the impacts of climate change in atoll countries requires evaluation of a range of physical and planning measures and subsequent implementation of optimal solutions, by the government and other stakeholders.

For coastal management, Kiribati currently relies on a narrow range of engineering solutions (seawalls) to coastal hazards that are under-engineered with regard to future climate change and construction techniques. In the water sector, climate risks are not included in problem diagnosis, options analysis, and design of system upgrades. Building codes do not reflect climate standards.

Constraints to improving the range and technical robustness of engineered solutions include: limited technical design expertise; limited awareness and testing of alternative options; current construction practices; but also the lack of technically defensible design parameters that take account of present and future climate change (e.g., storm surge, wave height, maximum water levels, and return period of extreme rainfall events and droughts).

3. Objective of the assignment

The objective of this assignment is to develop climate risk information to be adopted as national standard for options analysis and technical design work ("climate proofing parameters"), particularly regarding coastal and water related issues.

4. Tasks

It is expected that the TA will establish, through data analysis, fieldwork and modelling, a range of extreme water levels and drought and flood return periods that underpin adaptation designs. The analysis should certainly cover Tarawa (for which data are most readily available, but to the extent possible also other islands (for instance those with a long-term meteorological data record).

The analysis should include:

1. Analysis and estimates of storm surge that accord with the 1%, 2% and 10% annual exceedence probability (AEP). Such analysis should give explicit consideration of:
    a. The inverse barometric effect.
    b. Wind stress.
    c. Wave setup.
2. Analysis and estimates of maximum at-shoreline wave heights that correspond with the 1%, 2% and 10% AEP.
3. Analysis and estimates of maximum wave run-up levels for a range of differing foreshore slope angles.
4. Generation of storm surge, wave height and run-up estimates for a range of different island exposures that should at least include:
    a. Windward ocean shoreline.
    b. Leeward ocean shoreline.

   c. Windward lagoon shoreline.
   d. Leeward lagoon shoreline.
   e. Gross differences in reef platform width.

5. Analysis of intensity of extreme rainfall events with a return period of 10, 50 and 100 years, as well as droughts with a return period of 10, 50, and 100 years.
6. Identify and procure relevant datasets (e.g., wind, atmospheric pressure, sea level) to support analysis and collect new data (e.g., waves) where appropriate.
7. In collaboration with the GoK CCST, identify combined scenarios of sea level change, extreme water levels, the risk of extreme rainfall, as well as drought, for three time horizons 2025, 2050 and 2100.
8. All estimates of water level heights, extreme rainfall and droughts should be generated with reference to a known survey datum.
9. Conduct in-house trainings to GoK CCST on the tools and methods needed for analysis of data and generation of climate data trends.
10. Conduct a workshop to all stakeholders to present conclusions of his assignment.
11. Work with Govt agencies to develop a user-friendly database framework for data storage and updating.
12. Work with Awareness Technical Assistants to integrate climate risk information into awareness products.

5. Outputs

A document describing all the information listed above, to be discussed with all government agencies that would be using such information (and those who would be collecting the data to update it). Information must be presented in a very user-friendly way, focusing only on the essentials and including an explanation of how they could be applied in different contexts. Scientific details should only be inserted in technical annexes.

A draft report will be presented to all key agencies for questions and comments, so that the contents as well as the presentation can be fine-tuned to the needs of the end users of the information.

A Database framework to archive, manage and update data gathered in this assignment.

6. Arrangements

Responsible to: KAP II Project Director

Cooperating/Collaborating with the following Government of Kiribati agencies: National Strategic Risk Management Unit; Climate Change Study Team; Ministry of

Public Works and Utilities; Meteorological Service; as well as the Tidal Facility in Betio.

7. Timing

Three months work have been allocated for this activity. It is envisaged that the activity will require at least a 3-4 week visit to Kiribati to undertake field data collection where appropriate and to liaise with relevant agencies. At the end of this visit, a workshop will be organized with key users of the information to inform them of some preliminary results and have an exchange of ideas about the uses and packaging of the information. This should include the international technical assistant working on the development of a risk diagnosis and response process for coastal management (component 1.3.2) and if possible the technical assistant working on risk analysis and design capacity for coastal hazard protection of key public assets (2.2.1).

The activity is scheduled for the fourth quarter of 2007 and first quarter 2008.

Annex B: Consultant's Personnel

Name	Position
1. Mr. Douglas Ramsay	Leading Consultant (NIWA)
2. Dr. Rob Bell	Consultant (NIWA)
3. Dr. Richard Gorman	Consultant (NIWA)
4. Mr. Craig Thompson	Consultant (NIWA)
5. Dr. Scott Stephens	Consultant (NIWA)

Annex C: Consultant's' Reporting Obligations

The Consultant shall submit to the Client the reports in the form and within the time periods specified in Annex C, "Consultant's Reporting Obligations"

1. **Provide technical analysis and report on climate risk information as detailed.** ***Timing Month 2***
    a. Analysis and estimates of storm surge that accord with the 1%, 2% and 10% annual exceedence probability (AEP). Such analysis should give explicit consideration of:
        a. The inverse barometric effect.
        b. Wind stress.
        c. Wave setup.
    b. Analysis and estimates of maximum at-shoreline wave heights that correspond with the 1%, 2% and 10% AEP.
    c. Analysis and estimates of maximum wave run-up levels for a range of differing foreshore slope angles.
    d. Generation of storm surge, wave height and run-up estimates for a range of different island exposures that should at least include:
        a. Windward ocean shoreline.
        b. Leeward ocean shoreline.

c. Windward lagoon shoreline.

d. Leeward lagoon shoreline.

e. Gross differences in reef platform width.

e. Analysis of intensity of extreme rainfall events with a return period of 10, 50 and 100 years, as well as droughts with a return period of 10, 50, and 100 years.

f. In collaboration with the GoK CCST, identify combined scenarios of sea level change, extreme water levels, the risk of extreme rainfall, as well as drought, for three time horizons 2025, 2050 and 2100.

g. All estimates of water level heights, extreme rainfall and droughts should be generated with reference to a known survey datum.

2. Identify and procure datasets and develop user-friendly database framework for data storage and updating

Timing Month 2

h. Identify and procure relevant datasets (e.g., wind, atmospheric pressure, sea level) to support analysis and collect new data (e.g., waves) where appropriate.

i. Work with Government agencies to develop a user-friendly database framework for data storage and updating.

3. Conduct training and workshop

Timing Month 3

j. Conduct in-house trainings to GoK CCST on the tools and methods needed for analysis of data and generation of climate data trends.

k. Conduct a workshop to all stakeholders to present conclusions of his assignment.

12. Appendix 2: Glossary

Adaptation to climate change	Undertaking actions to minimise threats or to maximise opportunities resulting from climate change and its effects.
Adaptive capacity	The ability of a human system or ecosystem to: adjust or respond to *climate change* (including both variability and extremes); moderate potential damages; take advantage of new opportunities arising from climate change; or cope with and absorb the consequences.
Adaptive responses	See *Adaptation to climate change*.
Aerosols	A collection of airborne solid or liquid particles, with a typical size between 0.01 and 10 microns, which reside in the atmosphere for at least several hours. Aerosols may be of either natural or *anthropogenic* origin.
Anomaly	A difference from the long-term average climate (e.g., of a climate element). For example, the El Niño summer rainfall anomaly is the difference between the rainfall averaged over summers when El Niño conditions are present and the rainfall averaged over all summers.
Anthropogenic	Produced by human beings or resulting from human activities.
Anthropogenic emissions	Emissions of *greenhouse gases*, greenhouse gas *precursors* and *aerosols* associated with human activities. These activities include burning fossil fuels for energy, deforestation, and land-use changes that result in a net increase in emissions.
AOGCM	Acronym for *atmosphere–ocean general circulation model*.
AR4	Acronym for the three-volume IPCC *Fourth Assessment Report, 2007.*
Atmosphere–ocean general circulation model (AOGCM)	A comprehensive *climate model* containing equations representing the behaviour of the atmosphere, ocean and sea ice and their interactions.
Carbon dioxide (CO_2)	A naturally occurring gas, also a by-product of burning fossil fuels. It is the principal anthropogenic greenhouse gas.
Climate	The 'average weather', over a period of time ranging from months to thousands or millions of years. The classical period for calculating a 'climate normal' is 30 years.
Climate change	A statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer).
Climate model	A numerical representation (typically a set of equations programmed into a computer) of the *climate system*. The most complex and complete climate models are known as *General Circulation Models* (below).
Climate prediction	An attempt to provide a most likely description or estimate of the actual future evolution of the *climate*.
Climate projection	A potential future evolution of the climate in response to an emission or concentration *scenario* of *greenhouse gases* and *aerosols*. Often based on a simulation by a *climate model*.

Climate system	The interacting system comprising the atmosphere, hydrosphere (liquid water in lakes, rivers, seas, oceans), cryosphere (snow, ice, permafrost), land surface and biosphere (ecosystems and living organisms) that determines the earth's *climate*.
Climate variability	Variations of the *climate* (e.g., of the mean state, standard deviations and extremes) on all temporal and spatial scales beyond those of individual weather events.
Coastal accretion	A long-term trend of shoreline advance and/or gain of beach sediment volume over several decades. In many cases, accretion is beneficial and creates a buffer against future coastal hazards.
Coastal erosion	A long-term trend of shoreline retreat and/or loss of beach sediment volume over several decades. 'Cutback' is a more suitable term for a dynamically 'stable' shoreline to describe the temporary loss of beach volume or shoreline retreat during a storm (before the volume gets replenished over ensuing weeks and months).
Downscaling	Deriving estimates of local climate elements (e.g., temperature, wind, rainfall), from the coarse resolution output of *global climate models*. Statistical downscaling uses present relationships between large-scale climate variables and local variables. Nested regional climate modelling uses the coarse resolution output from a global climate model to drive a high resolution *regional climate model.*
El Niño	A significant increase in sea surface temperature over the eastern and central equatorial Pacific that occurs at irregular intervals, generally ranging between 2 and 7 years. Associated changes occur in atmospheric pressure patterns and wind systems across the Pacific. These can lead to changes in seasonal rainfall and temperature in parts of Australia and New Zealand.
El Niño Southern Oscillation (ENSO)	Term coined in the early 1980s in recognition of the intimate linkage between *El Niño* events and the *Southern Oscillation*, which, prior to the late 1960s, had been viewed as two unrelated phenomena. The interactive global ocean–atmosphere cycle comprising El Niño and La Niña is often called the 'ENSO cycle'.
Extreme weather event	An event that is rare at a particular place. 'Rare' would normally be defined as rare as or rarer than the 10th or 90th percentile.
ENSO	Acronym for *El Niño–Southern Oscillation*.
General Circulation Model (GCM)	A global, three-dimensional computer model of the *climate system*, which can be used to simulate the general circulation and climate of the atmosphere and ocean, and particularly human-induced climate change. GCMs are highly complex and they represent the effects of such factors as reflective and absorptive properties of atmospheric water vapour, greenhouse gas concentrations, clouds, annual and daily solar heating, ocean temperatures and ice boundaries. GCMs include global representations of the atmosphere, oceans and land surface.
GCM	Acronym for *General Circulation Model* or *Global Climate Model.*

Global Climate Model (GCM)	The same as *General Circulation Model.*
Global surface temperature	The global surface temperature is the area-weighted global average of: (i) the sea surface temperature over the oceans (i.e., the subsurface bulk temperature in the top few metres of the ocean), and (ii) the surface-air temperature over land at 1.5 m above the ground.
Global warming	Generally used to refer to the rise of the earth's surface temperature predicted to occur as a result of increased emissions of *greenhouse gases*.
Greenhouse effect	An increase in the temperature of the earth's surface and the lowest 8 km or so of the atmosphere, caused by the trapping of heat by *greenhouse gases*. Naturally occurring greenhouse gases cause a greenhouse effect at the earth's surface of about 30^{o}C. Further temperature increases caused by *anthropogenic emissions* are termed the enhanced greenhouse effect.
Greenhouse gases	Gases in the earth's atmosphere that absorb and re-emit infrared (heat) radiation. Many greenhouse gases occur naturally in the atmosphere, but concentrations of some (such as *carbon dioxide*, methane and nitrous oxide) have increased above natural levels because of *anthropogenic emissions*.
Hazard	A source of potential harm to people or property. Examples are coast erosion or inundation. Note a hazard does not necessarily lead to harm or damage.
Interdecadal Pacific Oscillation (IPO)	A long timescale oscillation in the Pacific Ocean–atmosphere system that shifts climate every one to three decades. The IPO has positive (warm) and negative (cool) phases. Positive phases tend to be associated with an increase in *El Niño*, and negative phases with an increase in *La Niña events*.
Intergovernmental Panel on Climate Change (IPCC)	The body established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) to objectively assess scientific, technical and socioeconomic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation.
IPCC	Acronym for *Intergovernmental Panel on Climate Change*.
IPO	Acronym for *Interdecadal Pacific Oscillation.*
Kyoto Protocol	The Kyoto Protocol to the *United Nations Framework Convention on Climate Change* (UNFCCC) was adopted at the Third Session of the Conference of the Parties (COP) to the UNFCCC, in 1997 in Kyoto, Japan. It contains legally binding commitments on countries included in Annex B of the Protocol (most OECD countries and some others) to reduce their *anthropogenic greenhouse gas emissions* to some (negotiable) value below 1990 levels in the commitment period 2008 to 2012.

La Niña	A significant decrease in sea surface temperature in the central and eastern equatorial Pacific that occurs at irregular intervals, generally ranging between 2 and 7 years. La Niña is the cool counterpart to the *El Niño* warm event, and its spatial and temporal evolution in the equatorial Pacific is, to a considerable extent, the mirror image of El Niño. Like El Niño, there are associated changes in atmospheric pressures and wind systems across the Pacific, and related changes can occur in temperature and rainfall in parts of Australia and New Zealand.
Limitation adaptations	Adaptations aimed at lessening or minimising the consequences of the most adverse effects of climate change as they arise over time.
Low-regrets adaptations	Low-cost policies, decisions and measures that have potentially large benefits.
Mean High water Spring (MHWS)	Mean high water spring is traditionally the level of the average spring tides just after full or new moon.
Mean Level of the Sea (MLOS)	The actual level of the sea over a certain averaging period (days, weeks, years, decades) after removing the tides (not to be confused with mean sea level or MSL, which usually refers to a set vertical survey datum).
Mean Sea Level (MSL)	Land based survey datum generally based on the measured mean level of the sea over a defined period in time.
Mitigation (of climate change)	Activities undertaken to reduce the sources or increase the sinks of *greenhouse gases.*
Natural hazard	Any atmospheric or earth- or water-related occurrence (including earthquake, tsunami, erosion, volcanic and geothermal activity, landslip, subsidence, sedimentation, wind, drought, fire or flooding), the action of which adversely affects or may adversely affect human life, property or other aspects of the environment
Natural variability	Non-anthropogenic climate variability that may be irregular or quasi-cyclic. *El Niño-Southern Oscillation* is probably the best-known example of a natural oscillation of the climate system, but there are many others. Changes caused by volcanic eruptions and solar variations can also be considered ‘natural’.
No-regrets adaptation	Those adaptations that generate net social, economic and environmental benefits whether or not there is anthropogenic climate change, or adaptations that at least have no net adverse effects.
Percentile	Used to give an observed value a ranking within the historical record. For example, only 5% of observations lie *below* the 5th percentile (i.e., the coldest 5% of the temperature record) and 5% of observations lie *above* the 95th percentile (i.e., the warmest 5% of that record).
Regional Climate Model (RCM)	A *climate model* that is run at high resolution over a ‘region’ (e.g., the eastern part of Australia, Tasman Sea plus New Zealand) to describe climate at the regional scale. RCMs are typically driven with data from *Global Climate Models,* which run at lower resolution and therefore do not accurately simulate, for example, the effects of the Southern Alps on New Zealand’s climate.

Relative sea level	Sea level measured by a tide gauge with respect to the land upon which it is situated. Mean Sea Level (MSL) is normally defined as the average relative sea level over a period, such as a month or a year, long enough to average out transient fluctuations such as waves.
Return period	The average time period between repetition of an *extreme weather event*, such as heavy rainfall or flooding, in a stationary climate (that is, a climate without global warming or other trends). In the case of rainfall, a return period is always related to a specific duration (e.g., 50-year return period of 24-hour extreme rainfall).
Risk	The chance of an 'event' being induced or significantly exacerbated by climate change, that event having an impact on something of value to the present and/or future community. Risk is measured in terms of *consequence* and *likelihood*.. It also has an element of *choice* by humans.
Scenario	A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces.
Sea-level rise	Trend of annual mean sea level over timescales of at least three or more decades. Must be tied to one of the following two types: *global*—overall rise in absolute sea level in the world's oceans; or *relative*—net rise relative to the local landmass (that may be subsiding or being uplifted).
Significant wave height	The average height of the highest one-third of waves during a short recording interval (typically 10–20 minutes). Generally, considered the height that a trained observer would report for a given sea state.
SOI	Acronym for *Southern Oscillation Index*.
Southern oscillation	A multi-year low-latitude seesaw in sea level pressure, with one pole in the eastern Pacific and the other in the western Pacific/Indian Ocean region. This pressure seesaw is associated with a global pattern of atmospheric *anomalies* in circulation, temperature, and precipitation. Its opposite extremes are the *El Niño* and *La Niña* events.
Southern Oscillation Index (SOI)	An index calculated from *anomalies* in the pressure difference between Tahiti and Darwin. Low negative values of this index correspond to *El Niño* conditions, and high positive SOI values coincide with *La Niña* episodes.
SRES scenarios	A set of *greenhouse gas* and *aerosol* emissions *scenarios* developed in 2000 by Working Group III of the *IPCC* and used, among others, as a basis for the climate projections in the IPCC's 2001 Third Assessment Report.
SST	Acronym for *Sea Surface Temperature* (see *Global surface temperature*).
Storm surge	The temporary excess above the level expected from the tidal variation alone at a given time and place. The temporary increase in the height of the sea is caused by extreme meteorological conditions such as low atmospheric pressure and/or strong winds.

Storm tide	The total elevated sea height at the coast above a datum during a storm combining storm surge and the predicted tide height. Note that *wave set-up* and *wave run-up* need to be added to the storm tide level at any locality to get the final storm inundation level.
Sustainability	'... development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Bruntland Report, *Our Common Future, Report of the World Commission on Environment and Development* 1987).
Unitary authorities	Territorial authorities that also have regional council responsibilities.
United Nations Framework Convention on Climate Change (UNFCCC)	The Convention was adopted on 9 May 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community. Its ultimate objective is the 'stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. It contains commitments for all parties. Under the Convention, parties included in Annex I aim to return greenhouse gas emissions not controlled by the *Montreal Protocol* to 1990 levels. The convention entered into force in March 1994. See also *Kyoto Protocol*.
Wave run-up	The ultimate height reached by waves (storm or tsunami) after running up the beach and coastal barrier (see also *wave set-up*).
Wave set-up	The super-elevation in water level across the surf zone caused by energy expended by breaking waves (see also *wave run-up*).

13. Appendix 3: Analysis methodologies

13.1 Sea-level data analysis

13.1.1 Analysing the measured sea level record

Sea level records from 4 separate gauges were combined as described in Chapter 2, to produce a near-continuous hourly record from 31 May 1974 to 31 August 2007 (Figure 5).

This 33.25-year sea level record was decomposed into the following components: astronomical tide, Mean Level of the Sea (MLOS) and storm surge. The sea level was decomposed by first calculating the astronomical tide and then subtracting it from the raw sea levels to give a residual sea level. The residual sea levels were then filtered using a band-pass wavelet filter to provide MLOS (768-hour low-pass cut-off) and storm surge (24–384 hour band-pass).

In merging the records it has been assumed that the sea level characteristics from the Bairiki sea-level gauge deployment are not significantly different to those at the Betio site (Table 1). However, geographical differences are likely to modify some characteristics of tidal propagation, amplification and wind set-up and set-down, in particular. This was alleviated by calculating the astronomical tidal component (the major component of water level variation) on an annual basis – thus separate harmonic analyses were performed for the time when the record was measured at Bairiki. In Section 4.3 it is observed that difference due wind set-up is relatively minor between the 23 sites around Tarawa Lagoon. Furthermore, the annual maxima are not noticeably subdued for the period of deployment at Bairiki. Thus we are satisfied that that merged 33-year record can be reliably used for extreme-value analysis.

Sea level can be best summarised by a Fourier power spectrum (Figure A1), which shows how the energy or power spectral density (PSD) of the signal varies with period (or frequency). In Figure A1 we have plotted the PSD for the year 2005. The various phenomena that are labelled in Figure A1 are defined as follows:

Inter-month	Variation of sea level on a month-to-month basis, it can be thought of as variation in the Mean Level of the Sea (MLOS).

Storm surge	response of the ocean level to changing weather conditions over periods of several days, especially atmospheric pressure and wind.
Diurnal tides	once-daily tides (which are small in Kiribati).
Semi-diurnal tides	twice-daily tides dominate the sea level record, the main one being due to the influence of the Moon (called the M_2 tide) at a cycle period of 12.42 hours.
Shallow-water tides	tides resulting from the nonlinear interaction of diurnal and semi-diurnal tides as they propagate into shallow waters such as the lagoon.
Seiche	chaotic oscillations of lagoons at their natural frequency, in response to nonlinear interaction between weather and tides, the local bathymetry and shoreline.

It is seen that the astronomical tide has by far the largest influence on sea level followed by long-term fluctuations in mean level of the sea (MLOS), with storm surge having the smallest influence.

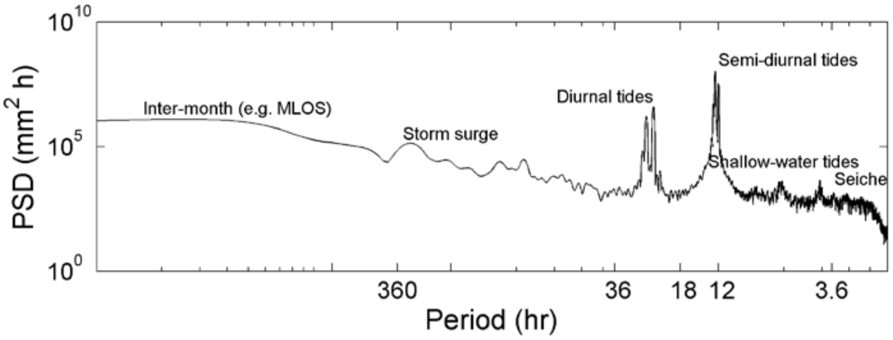

Figure A1: Fourier power spectrum for the Tarawa sea level record for the year 2005.

13.1.2 Astronomical tides

Tidal analysis is the process of identifying the amplitude and phase (i.e., half-range and timing of high water) of over 100 individual tides, each being associated with a particular astronomical phenomenon or shallow-water interaction between tides. For the Kiribati region, the three most important tides are all twice-daily tides (indicated by subscript “2”):

- M_2, the semi-diurnal lunar tide at 12.42 h periods, caused by the direct gravitational attraction of the Moon on Earth’s waters;

- S_2, the semi-diurnal solar tide at exactly 12 h periods, caused by the direct gravitational attraction of the Sun on Earth’s waters;

- N_2, the semi-diurnal elliptic tide at 12.66 h periods, resulting from the elliptical orbit of the Moon around Earth over a 27.5 day cycle.

Of these, M_2 is by far the strongest, followed by S_2 then N_2. The results of tidal analysis are presented in Table A1.

Classical tidal harmonic analysis was undertaken using the Matlab-based software of Pawlowicz et al. 2002. Tidal harmonics were analysed on an annual basis, to account for inter-annual variation and provide a more accurate time-varying tidal time series. The *Sa* (annual MLOS cycle) and *Ssa* (bi-annual seasonal cycle) were included in the harmonic analysis to remove any seasonal trends from the residual dataset. The minimum, maximum, mean and standard deviation of the annual cycle were 13, 444, 66 and 73 mm respectively over the 33-year record. The annual amplitudes and phases of the 25 constituents with a signal-to-noise ratio larger than 10 were averaged to give tidal constituents used to calculate the exceedances in Chapter 4.

The astronomical tides were subtracted from the raw sea levels to give a residual non-tidal sea level component.

Table A1: Average tidal harmonic constituent amplitude and phase from annual analysis of 33-years of sea level data.

Harmonic	Amplitude (mm)	Phase (° GMT)	Harmonic	Amplitude (mm)	Phase (° GMT)
M_2	580.4	140	$2N_2$	17.9	129
S_2	303.4	152	S_1	15.8	105
N_2	124.2	139	Q_1	11.7	27
K_1	91.8	69	EPS_2	6.1	139
K_2	85.4	149	ETA_2	5.8	157
SA	65.7	286	PSI_1	5.8	203
O_1	59.7	42	LDA_2	5.7	124
P_1	31.1	74	R_2	5.2	147
SSA	30.4	176	J_1	4.7	89
NU_2	22.3	140	OO_1	3.6	129
T_2	20.5	157	M_6	1.8	294
MU_2	20.2	141	SK_3	1.7	254
L_2	18.0	137			

13.1.3 Variability in mean level of the sea (MLOS)

Mean level of the sea (MLOS) is the actual level of the sea upon which tide oscillates about. MLOS itself is a continuously varying mean sea-surface level that includes the effects of long-period (seasonal and >1 year) fluctuations in sea level. These include the annual cycle (due to seasonal heating/cooling, which is minimal in Kiribati), the 2 to 4 year El Nino-Southern Oscillation (ENSO) effects and long-term sea level trends due to climate change effects. In this case analysis we incorporated the annual and bi-annual heating/cooling cycle into the tidal harmonic analysis, so they are not included in the calculated MLOS.

Mean level of the sea was obtained from the raw sea level measurements by first subtracting the astronomical tidal component and then low-pass wavelet filtering using a 32-day cut-off, to give the MLOS component. A Generalised Extreme Value (GEV) model (see section 11.1.5 for details) was fit to 30 annual maxima values of MLOS and annual exceedance probabilities extracted (Figure A2 and Table A2).

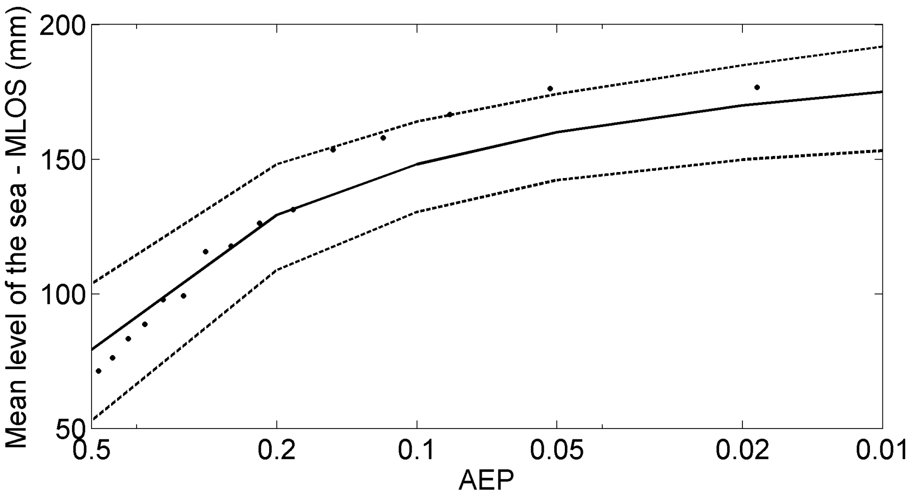

Figure A2: GEV model fit to 30 MLOS annual maxima, 1974–2006, showing predicted storm tide return heights for given Annual Exceedance Probabilities (AEP). The dots mark the measured annual maximum MLOS. The solid line is the best-fit, while upper and lower dashed lines mark 95% and 5% tolerance limits respectively.

Table A2: Predicted MLOS heights (m) for given Annual Exceedance Probabilities (AEP), based on the GEV model fit shown in Figure A2.

AEP	10%	2%	1%
Mean	0. 148	0.170	0.175
5% tolerance interval	0.130	0.150	0.153
95% tolerance interval	0.164	0.185	0.192

13.1.4 Storm surge

Storm surge is the response of the ocean level to changing atmospheric pressure and wind. The combined effect of a high storm surge and a high tide is called a storm tide.

In the deep ocean, changing atmospheric pressure results in the inverted barometer (IB) effect on sea level:

- a 1 hPa fall in pressure results in a 1 cm rise in sea level; and
- a 1 hPa rise in pressure results in a 1 cm fall in sea level.

Wind also raises or lowers sea level in two ways, depending upon the direction it blows relative to the shore:

- an onshore wind piles up water against the shore (set up), and an offshore wind draws water away from the shore (set down); This process is likely to occur inside atoll lagoons;

- at mid-latitudes, an alongshore wind results in a temporary change in water level due to Coriolis effects if the landmass is sufficiently large in comparison to the wind system. However, for the small atolls and low latitudes of the Kiribati Islands, this effect is negligible.

For wind to generate storm surge along open coasts, it must be sustained for several hours or days over a wide area. Thus, sea breezes do not generate storm surge. Within an atoll lagoon, where the downwind passage of water is constrained, local wind set up can occur over shorter timeframes.

Storm surge for Tarawa was calculated by estimating the tide using tidal harmonic analysis, and subtracting it from the measured sea level to compute a residual difference. A band-pass filter was then applied to the residual (between 24–384 hours) to remove: a) any leftover tide; b) the high-frequency signal (seiche etc.); and c) long-period (inter-month) effects. The same process was performed on atmospheric pressure data to produce the inverted barometer (IB) component of storm surge. Whilst some correlation between inverted barometer and storm surge was observed, the correlation was low, with storm surge having greater than 5 times the variance (energy) of the IB. This means that local wind effects have a stronger influence on storm surge than barometric pressure. The minimum, maximum and standard deviation of the storm surge for the period of the SEAFRAME gauge record were -104, 115 and 22.5 mm respectively.

Extreme-value predictions for the storm surge component of sea level are given in Figure A3 and Table A3.

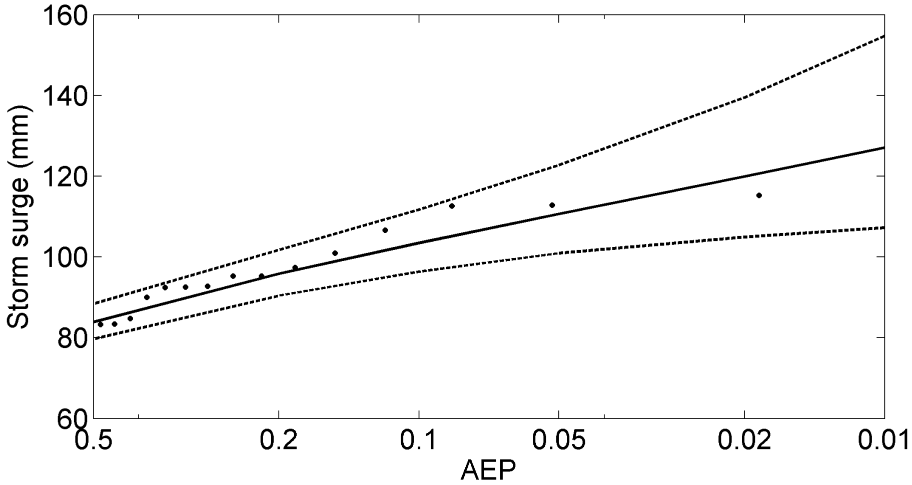

Figure A3: GEV model fit to 30 storm surge annual maxima, 1974–2006, showing predicted storm surge return heights for given Annual Exceedance Probabilities (AEP). The dots mark the largest 15 measured annual maximum storm surges. The solid line is the best-fit, while upper and lower dashed lines mark 95% and 5% tolerance limits respectively.

Table A3: Predicted storm surge heights (mm) for given Annual Exceedance Probabilities (AEP), based on the GEV model fit shown in Figure A3.

AEP	10%	2%	1%
Mean	0.103	0.120	0.127
5% tolerance interval	0.096	0.105	0.107
95% tolerance interval	0.112	0.139	0.155

13.1.5 Storm tide level analysis

Extreme sea levels (storm tides) are usually predicted by fitting an extreme-value model such as the generalised extreme value model, to a subset of independent maxima from an existing sea-level record (Coles, 2001). In this way the very largest events in the record are extrapolated to estimate even larger events that may occur over a longer timeframe.

The accuracy of the storm tide level predictions depends on:

1. the quality of the input data, including: (a) the accuracy of the measured or simulated sea level maxima; and (b) suitable historic coverage—the longer the available record the more reliable the estimates. Increased reliability results from improved statistical precision of the estimates and from decreased error associated with climate variability; and

2. the degree of fit between the "true" distribution of the sea levels, and the fitted statistical distribution (e.g., Generalised Extreme Value or GEV model) used to extrapolate to the extreme values.

For Tarawa, the ~33-year record is sufficiently long to reliably estimate expected 1% AEP levels at the sea-level gauge site. Hence classical extreme-value methods were applied to this dataset in the study. The results of GEV analysis are shown in Figure A4 and Table A4. Of note is the flat nature of the curve for low AEP's, for example there is only a 2.5 cm difference between the 10% and 1% AEP storm tide level. Storm tide levels are strongly bounded by dominance of the astronomical tide and small magnitude of the storm surge component.

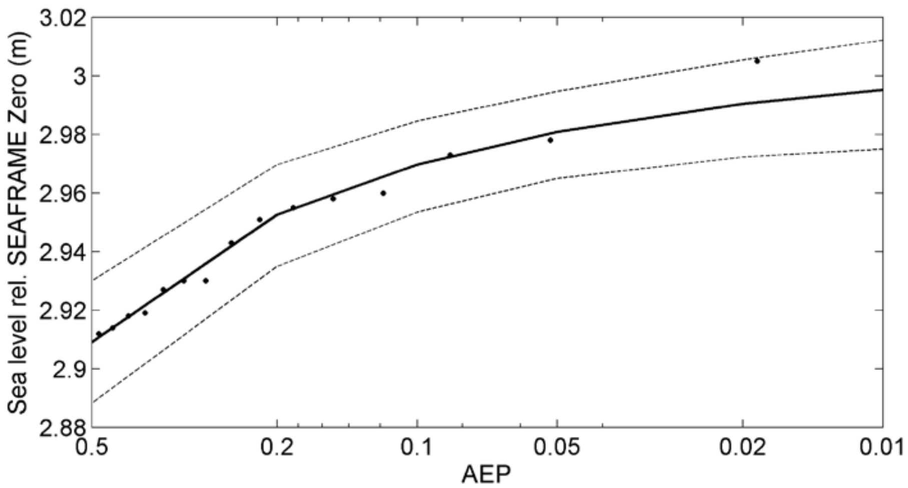

Figure A4: Generalised extreme-value (GEV) model fit to 30 measured annual sea level maxima. The solid line marks the best-fit, dashed lines give 95% tolerance levels for the GEV fit, and dots show the largest 15 measured Annual Maxima plotted in their theoretical Gringorten plotting positions.

Table A4: Predicted storm tide levels from the measured sea level record for various Annual Exceedance Probabilities (AEP's).

AEP	0.1 (10%)	0.05 (5%)	0.02 (2%)	0.01 (1%)
Storm tide (m relative to SEAFRAME Gauge 0)	2.970	2.981	2.991	2.996
5% tolerance interval	2.954	2.965	2.972	2.975
95% tolerance interval	2.985	2.995	3.005	3.012

13.1.6 Simulating storm tide levels at sites where no measurements exist

The tidal range (and hence high tide level) and the characteristics of storm surge behaviour change with location within Tarawa lagoon, as the local bathymetry interacts with the tide and surge. Therefore at each of the 23 locations around Tarawa lagoon a unique dataset is required to generate extreme-value estimates. This necessitated that a sea level time series be synthesised for each location of interest away from the measurement gauge.

This process for deriving 1% AEP levels around the Tarawa lagoon is summarised as:

1. Predict extreme return levels at the sea-level gauge site using the measured data record (see above).

2. Simulate an artificial sea-level record at the sea-level gauge site, and predict extreme values using the simulated data.

3. Compare the simulated and measured datasets, and in particular, compare the extreme values predicted from both the measured and simulated data at the sea-level gauge site. This is to check our ability to simulate data to produce reliable extreme-value estimates. That way the methodology can be used to produce extreme sea level estimates for other areas of the coast.

4. Simulate time series of water levels at other locations around the Tarawa lagoon shoreline based on the variation in tidal amplification and wind set-up effects from the hydrodynamic modelling, and use these simulated time series to predict extreme sea levels from a Generalised Extreme Value (GEV) model fit to simulated annual maxima data.

The nearest model output site to the Betio SEAFRAME gauge is site 1. A comparison between measured data and data simulated at site 1 is shown in Figure A5. It is seen that the simulated data over-predicts the extreme sea level heights by up to ~3 cm at 1% AEP. The shape parameters of the GEV fits are similar, as are the shape of the GEV fit curves. Given the strongly bounded nature of the extreme sea level curves, this is a reasonable match. The slight over-prediction from the simulated data arises due to differences in the simulated and measured storm surge characteristics, with simplifications in the wind set-up interpolations and modelled inverse barometer factor. The fact that the simulation-based extreme value predictions are larger than the measurement-based predictions builds in a small level of conservatism, i.e., it is safer to slightly over-predict sea level heights than to under-predict.

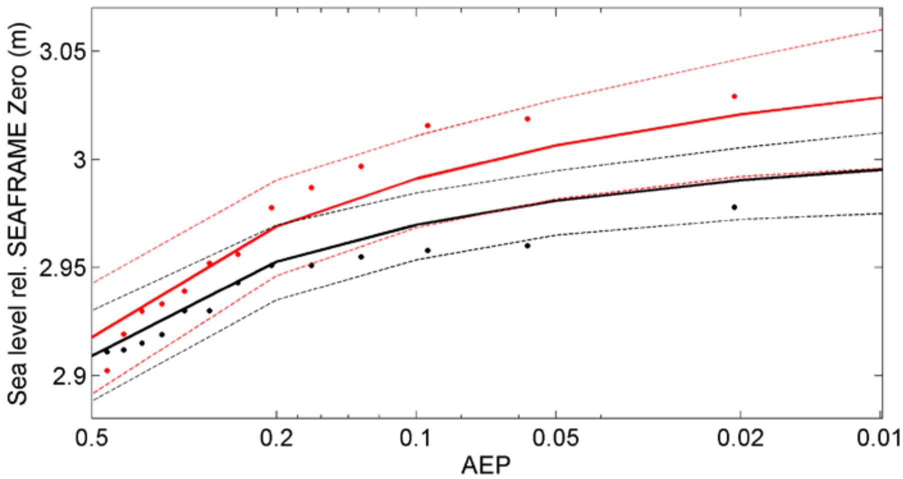

Figure A5: Comparison of annual maxima and GEV model fits to the measured and simulated water levels at the Betio SEAFRAME site. Black marks measured data, red marks simulated data.

The predicted extreme sea levels for all 23 sites are presented in Table A5 below.

Table A5: 10%, 2% and 1% Annual Exceedance Probability (AEP) storm tide levels (relative to SEAFRAME Gauge 0) at the 23 sites around Tarawa lagoon for the three sea level rise scenarios: present day, +0.48 m and +0.79 m.

Site	Location	Present day			+ 0.48 m SLR			+ 0.79 m SLR		
		10% (m)	2% (m)	1% (m)	10% (m)	2% (m)	1% (m)	10% (m)	2% (m)	1% (m)
1	Betio (West)	2.999	3.027	3.033	3.459	3.500	3.512	3.788	3.813	3.819
2	Betio (Central)	3.001	3.028	3.035	3.461	3.502	3.513	3.789	3.814	3.819
3	Betio (East)	3.002	3.029	3.036	3.462	3.503	3.514	3.791	3.815	3.821
4	Causeway	3.003	3.030	3.036	3.464	3.505	3.516	3.795	3.820	3.825
5	Bairiki	3.004	3.031	3.037	3.465	3.505	3.517	3.797	3.822	3.828
6	Nanikai	3.005	3.032	3.039	3.466	3.507	3.518	3.798	3.824	3.829
7	Taeoraereke	3.006	3.033	3.040	3.467	3.508	3.519	3.799	3.825	3.830
8	Banraeaba	3.008	3.035	3.041	3.468	3.509	3.520	3.800	3.826	3.831
9	Taborio (West)	3.008	3.036	3.042	3.469	3.510	3.521	3.801	3.826	3.832
10	Taborio (East)	3.010	3.037	3.043	3.470	3.511	3.522	3.801	3.827	3.833
11	Eita (West)	3.011	3.038	3.045	3.472	3.512	3.523	3.803	3.829	3.835
12	Eita (Central)	3.012	3.039	3.045	3.472	3.512	3.523	3.804	3.830	3.836
13	Eita (East)	3.013	3.040	3.046	3.472	3.512	3.524	3.805	3.831	3.837
14	Bikenibeu	3.014	3.041	3.047	3.473	3.513	3.524	3.806	3.832	3.837
15	Bonriki	3.015	3.042	3.048	3.473	3.513	3.524	3.806	3.832	3.838
16	Buota (South)	3.015	3.042	3.048	3.473	3.513	3.524	3.806	3.832	3.838
17	Buota (North)	3.015	3.041	3.047	3.473	3.513	3.524	3.806	3.832	3.838
18	Abato	3.014	3.041	3.047	3.473	3.513	3.524	3.805	3.832	3.837
19	Tabiteuea	3.014	3.041	3.047	3.471	3.512	3.523	3.805	3.831	3.837
20	Abaokoro	3.003	3.029	3.035	3.462	3.503	3.514	3.795	3.821	3.826
21	Ereti	3.002	3.028	3.034	3.461	3.501	3.513	3.794	3.820	3.825
22	Tearinibai	2.999	3.024	3.030	3.459	3.500	3.512	3.788	3.814	3.819
23	Buariki	3.000	3.026	3.031	3.459	3.500	3.512	3.788	3.813	3.819

13.2 Tarawa lagoon wave modelling

The SWAN model (Booij et al. 1999; Ris et al. 1999) is a wave model that simulates the development of wave conditions in coastal and estuarine environments. It is based on the concept of the wave spectrum, which describes the sea state in terms of the amount of energy in each band of wave frequency and propagation direction. The model computes the evolution of the wave spectrum in position (x, y) and time (t), explicitly taking into account the various physical processes acting on waves in shallow water. These include the effects of refraction by currents and bottom variation, and the processes of wind generation, white-capping, bottom friction, quadruplet wave-wave interactions, triad wave-wave interactions and depth-induced breaking. The model can incorporate inputs of relevant environmental conditions varying in both space and time, including winds, water levels, currents, and waves arriving from outside the model domain.

The SWAN model can be used for a direct simulation of wave conditions in a given coastal region, provided that adequate input data are available to represent the relevant environmental forcing conditions during the period of interest. However, computing limitations mean that such a fine-resolution simulation covering a large area is only feasible for relatively short time periods, typically up to several weeks. Less direct methods are required to simulate the multi-year time scales needed to provide information on seasonal and interannual variations in wave climate, and also allow the sensitivity of the wave climate to changes in wind climate to be readily investigated.

We describe here a method based on first running the SWAN model under a full range of nominal forcings, then applying the resulting transfer functions to long term records of observed winds and sea level, to derive nearshore wave conditions.

Wind conditions can be parameterised by wind speed U and wind direction ϕ at a suitably representative meteorological station, while sea level z can be provided by tidal predictions, using tidal components derived from tide gauge records or a tidal model. Wind and sea level data can be analysed to select a finite number of discrete values of each of the forcing parameters to adequately cover their range of observed values.

Wave climate at most of the sites of interest is dominated by short waves generated within the Tarawa lagoon by local winds. However, swell with a westerly component can propagate in through the exposed western side of the lagoon. Hence the environmental forcings considered in this study were offshore significant wave height, peak wave period, peak wave direction, wind speed and direction, and water level.

Each SWAN simulation was run with a combination of swell conditions, wind fields and water levels applied uniformly over the model grid of Tarawa lagoon. The output from each simulation will give a set of wave parameters at all positions (x, y) in the model grid, including significant wave height H_s, peak wave direction θ_p, peak wave period T_p, among others. This forms the basis of a “lookup table” describing wave conditions inshore for a limited set of forcing conditions.

Through a process of multi-linear interpolations, a set of numerical weighted values were derived from the separate weightings for swell conditions, wind and tide height.

These weights were then used to enter the “lookup table”, and compute wave values at each output location in the model grid. In this way, a time series of wave height, period and direction was simulated for each of the 23 sites of interest.

This method was therefore able to utilise a series of short, stationary SWAN simulations to predict wave conditions within Tarawa lagoon for any given swell, wind and sea level conditions. That is, an equilibrium sea state was computed as if the particular wind and tide conditions had been present for an indefinite time. This does not take into account the history of these forcings, which may, for example, result in the sea state being not fully developed in a strengthening wind, or remnant seas being left in a weakening wind. This is a relatively small limitation over short spatial scales and the whole approach is conservative in terms of extreme waves for engineering design. At typical wave speeds of 8 ms^{-1} (for 10 s period waves in deep-water), a 30 km domain is crossed in around 60 minutes. So only variations in the forcing at shorter time scales than this will be subject to these “hysteresis” errors. In any case, such variations will largely be averaged out in taking long-term climatic means.

13.2.1 Extreme wave analysis

Prediction of extreme significant wave heights was undertaken as follows:

- From each simulated significant wave height time series, a subset of wave height maxima were selected using the peaks-over-threshold method. Thus a series of independent wave maxima were obtained, with the number of maxima corresponding to ~5 events per year.

- The Generalised Pareto Distribution (GPD) was fitted to each of these wave maxima subsets, using maximum likelihood estimation (e.g., Coles, 2001).

- From the GPD fits, extreme significant wave heights were computed for 10%, 2% and 1% AEP at each site.

Results from these analyses are presented in Section 6.2.

13.3 Joint probability methodology

Figure A6 shows a scatter-plot of simultaneous significant wave height (H_s) and measured sea level at Site 1 at Betio (Figure 14). Correlation between high waves and storm tide levels may occur for two main reasons: 1) meteorological (but since the astronomical component (tide) of sea level is much larger than the storm surge component, any such correlation is modest); 2) shallow water wave transformations are dependent on water depth; waves may be depth-limited leading to strong correlation between large waves and high sea levels. In this case, no dependency is seen between the two variables. The observed band of larger waves of approximately 1 m height arises from swell that approaches from the western, open side of the lagoon.

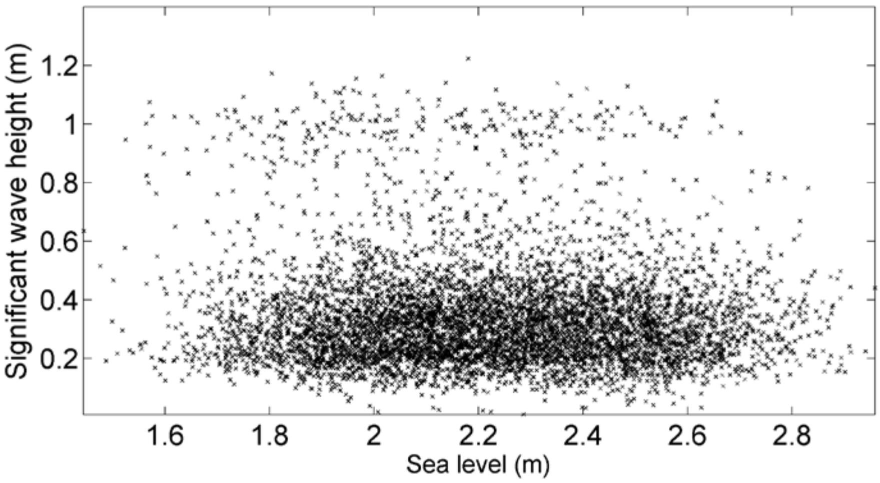

Figure A6: Simulated significant wave height (H_s) at Site 1 versus re-constructed sea level from 1997–2007.

We used the joint probability software package JOIN-SEA (HR Wallingford and Lancaster University, 2000) to calculate joint probabilities between storm tide level and wave height, for return periods of up to 100 years (1% AEP). The JOIN-SEA software needs a time series of sea level and wave height (and period) data that are matched in time. For each output site, the simulated sea level (Chapter 13.1.6) and simulated waves (Chapter 13.2) were matched in time for the period 1997–2007, corresponding to the duration of the simulated wave records.

Appendix 5 contains the output of the joint-probability analyses. It includes plots and tables of the wave and storm tide level combinations having a joint-probability of occurrence corresponding to return periods of 10, 50 and 100 years (i.e., AEP of 0.1, 0.02, and 0.01, or 10%, 2% and 1%).

14. Appendix 4: Tarawa Survey Datums: Relationship between University of Hawaii Tide Gauge 0, Mean Sea Level and SEAFRAME Tide Gauge 0.

Draft for discussion
May 2008

14.1 Introduction

This note has been produced to correct what we believe is an error in the assumption in the relationship between the University of Hawaii (U of H) Tide Staff 0 and SEAFRAME Tide Gauge 0 at Betio in Tarawa. It has been assumed by the South Pacific Sea Level and Climate Monitoring Project (SPSLCS) that Gauge 0 for the SEAFRAME gauge installed by the project is the same as Gauge 0 of the University of Hawaii Tide Gauge installed at Betio between May 1974 and December 1983 (Annex 1).

Our analysis suggests that this is not the case with the SEAFRAME Gauge 0 being 419 mm below that of the U of H Gauge 0, as summarised in Figure 1.

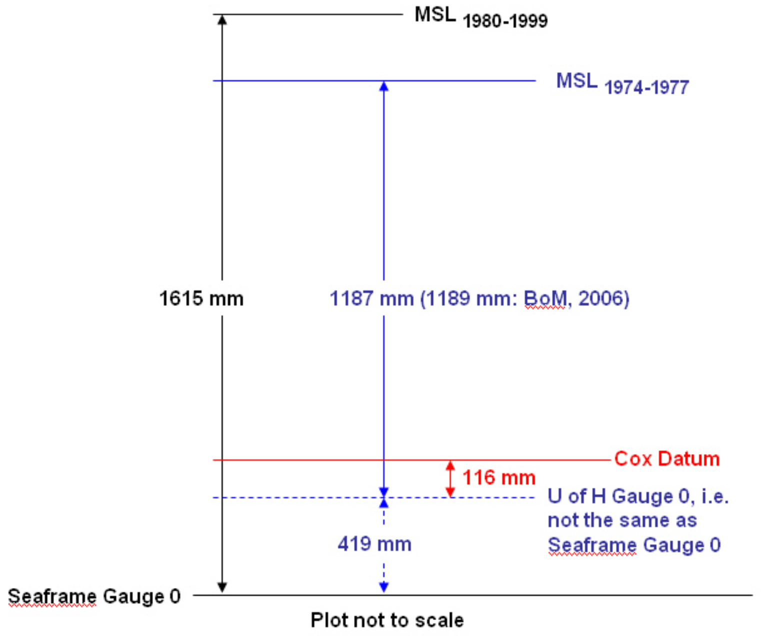

Figure 1: Suggested revised relationship between datums used on Tarawa.[4]

[4] We have included Cox datum for completeness based on the information provided in He (2001) but have not checked the accuracy of the information provided by He in relation to this datum.

14.2 Discussion

On Tarawa there are four different tide gauge records available extending back to May 1974 (Table 1) and Figure 2. The present SEAFRAME facility has been in place since 1993, with gauge 0 of this facility used as the reference level for tide predictions and sea-level recordings.

BoM (2006), summarised in Annex 1, state that: *"Sea levels in the NTC data are normally reported relative to "Chart Datum" (CD), thus enabling users to relate the NTC data directly to depth soundings shown on marine charts…... Unfortunately, at Tarawa the original benchmark used for the marine surveys is unrecoverable.….. In the absence of a known CD, NTC has chosen to refer sea level to the older UH datum, or "Tide Staff Zero". With this choice, the Mean Sea Level of either data set is close (though not necessarily identical). Mean Sea Level (MSL)……. is the average recorded level at the gauge over the three and a half year period 1974/1977. The 1974/1977 MSL at Tarawa was 1.189 metres above the UH Tide Staff Zero (and the SEAFRAME zero level).*

Our own analysis of the University of Hawaii (Tarawa A) dataset (Ramsay et al. 2008) gave a mean level of the sea of 1.187 m, i.e., almost identical to the earlier University of Hawaii analysis noted above. However, in plotting the four datasets, Figure 2, the Tarawa A dataset appears to be relative to a different datum than the subsequent datasets.

The overlapping portions of the four records were examined and the historical records were adjusted to SEAFRAME gauge Zero (Figure 3). In merging the records it has been assumed that the sea level characteristics from the Bairiki deployment (Tarawa B) are not significantly different to those at the Betio site. However, geographical differences may modify some characteristics of tidal propagation, amplification and wind set-up and set-down to some (probably relatively minor) extent.

Table 1: Sea level records available for Tarawa. The tabulated datum shift for each record based on consideration of the overlapping components of each record, is shown in the last column.

Name	Location	Start date	Finish date	Datum shift (mm)
Tarawa A	Betio	31 May 1974	31 Dec 1983	+419
Tarawa B	Bairiki	17 May 1983	10 May 1988	+23
Tarawa C	Betio	20 Jan 1988	31 Dec 1997	+23
SEAFRAME (D)	Betio	27 Mar 1993	Ongoing	0

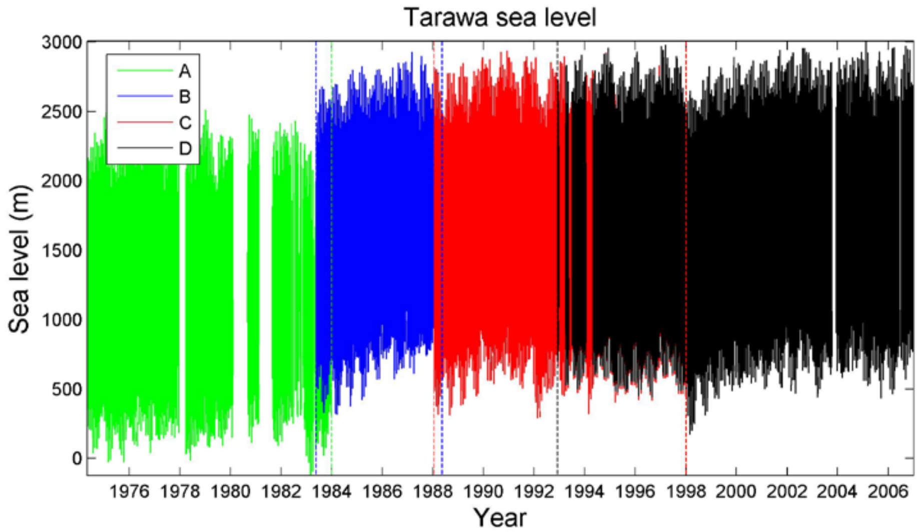

Figure 2: Plot of measured Tarawa sea levels between May 1974 to the present from the four available sea-level records (Table 1).

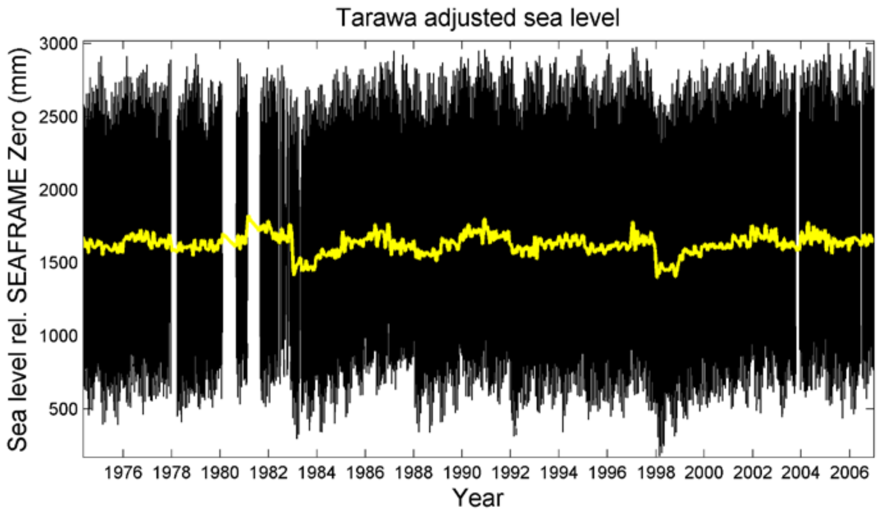

Figure 3: Plot of adjusted raw sea levels taking account of datum shifts note d in Table 1. The yellow line marks mean level of the sea. The datum is SEAFRAME gauge Zero.

14.3 Conclusions

It is suggested that the U of H Tide Gauge 0 and the SEAFRAME Gauge 0 are not the same datum with the actual relationship as shown in Figure 1. This has implications for previous assessments of coastal inundation that have utilised the SEAFRAME data.

The conversion between the datums can be summarised as

- To convert from SEAFRAME Gauge 0 datum to U of H Gauge 0 datum **subtract 0.419 m.**
- To convert from U of H Gauge 0 datum to SEAFRAME Gauge 0 datum **add 0.419 m.**

The following table summarises some key levels relative to both SEAFRAME Gauge 0 and U of H Gauge 0.

Table 2: Summary of some key levels relative to the UK and SEAFRAME Gauge 0 datums.

Sea level	Level (mm U of H)	Level (mm SEAFRAME)
Mean sea level (1974-1977)	1187 mm (1189 mm: BoM 2006)	1606 mm
Mean sea level (1980-1999) IPCC sea-level projection reference datum	1196 mm	1615.mm
Mean sea level (2007)	1218 mm	1637 mm

14.4 References

Bureau of Meteorology (2006). Sea level and climate: Their present state. Kiribati. June 2006.

He, C. (2001). Assessment of the Vulnerability of Bairiki and Bikenibeu, South Tarawa, Kiribati to accelerated sea-level rise. SOPAC Technical Report 322.

Ramsay, D.L.; Stephens, S.; Gorman, R.; Oldman, J.; Bell, R. (2008). Kiribati Adaptation Programme: Phase II: Information for climate risk management. Sea levels, waves, run-up and overtopping. NIWA Draft Client Report HAM2008-022, February 2008.

14.5 Contact details

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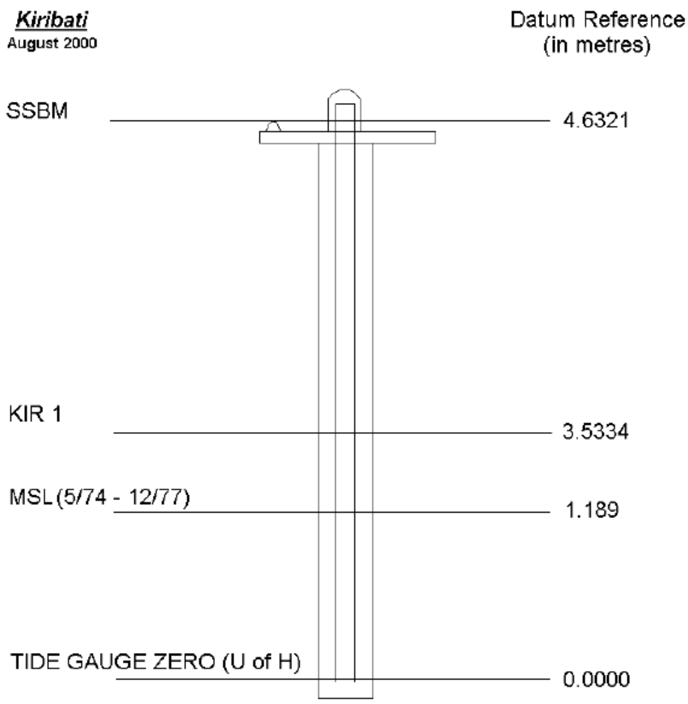
Annex 1: Summary of existing datum relationship contained within the South Pacific Sea Level and Climate Monitoring Project (SPSLCS) reports (e.g., BoM, 2006).

Definition of Datum and other Geodetic Levels at Tarawa

Newcomers to the study of sea level are confronted by bewildering references to "Chart Datum", "Tide Staff Zero", and other specialised terms. Frequently asked questions are, "how do NTC sea levels relate to the depths on the marine chart?" and "how do the UH sea levels relate to NTC's?"

Regular surveys to a set of coastal benchmarks are essential. If a SEAFRAME gauge or the wharf to which it is fixed were to be damaged and needed replacement, the survey history would enable the data record to be "spliced across" the gap, thereby preserving the entire invaluable record from start to finish.

Figure 22



The word "datum" in relation to tide gauges and nautical charts means a reference level. Similarly, when you measure the height of a child, your datum is the floor on which the child stands.

"Sea levels" in the NTC data are normally reported relative to "Chart Datum" (CD), thus enabling users to relate the NTC data directly to depth soundings shown on marine charts – if the NTC sea level is +1.5 metres, an additional 1.5 metres of water may be added to the chart depths. Unfortunately, at Tarawa the original benchmark used for the marine surveys is unrecoverable, so it is not possible to place CD on Figure 22. In the absence of a known CD, NTC has chosen to refer sea level to the older UH datum, or "Tide Staff Zero". With this choice, the Mean Sea Level of either data set is close (though not necessarily identical).

Mean Sea Level (MSL) in Figure 22 is the average recorded level at the gauge over the three and a half year period 1974/1977 (as indicated). The 1974/1977 MSL at Tarawa was 1.189 metres above the UH Tide Staff Zero (and the SEAFRAME zero level).