Pacific Adaptation Strategy Assistance Program

Report on Water Security & Vulnerability to Climate Change and Other Impacts in Pacific Island Countries and East Timor

prepared by

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on behalf of GHD Pty Ltd for

Department of Climate Change & Energy Efficiency

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List of Acronyms and Abbreviations

ABoM	Australian Bureau of Meteorology
ACP States	African, Caribbean and Pacific Group of States
ADB	Asian Development Bank
AIDAB	Australian International Development Assistance Bureau (predecessor to AusAID)
AusAID	Australian Agency for International Development
CGPS	Continuous global-positioning system
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Cv	Coefficient of variation (= standard deviation divided by mean)
DCCEE	Department of Climate Change and Energy Efficiency
DWSP	Drinking Water Safety Plan
ENSO	El Niño Southern Oscillation
EU	European Union
FSM	Federated States of Micronesia
GCM	Global Climate Model (or General Circulation Model)
GEF	Global Environment Facility
GIS	Geographical information system
GWP	Global Water Partnership
HELP	Hydrology for the Environment, Life and Policy
ICU	Pacific Islands Island Climate Update
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Intertropical Convergence Zone
IWRM	Integrated Water Resources Management
JASL	Joint Archive for Sea Level
JICA	Japan International Cooperation Agency
KAP	Kiribati Adaptation Programme
kL/day	kilolitres per day
L/p/day	Litres per person per day
MDG	Millennium Development Goals

MSL	Mean sea level
NGO	Non-governmental organisation (also called civil society organisation)
NIWA	National Institute of Water and Atmospheric Research (New Zealand)
NMS	National Meteorological Service
NOAA	National Oceanic and Atmospheric Administration (USA)
NZAID	New Zealand International Aid & Development Agency (now called New Zealand Aid Programme, NZAP)
NZAP	New Zealand Aid Programme (formerly called New Zealand International Aid & Development Agency, NZAID
PACC	Pacific Adaptation to Climate Change Project
Pacific HYCOS	Pacific Hydrological Cycle Observing System
Pacific RAP	Pacific Regional Action Plan on Sustainable Water Management
PASAP	Pacific Adaptation Strategy Assistance Program
PCCSP	Pacific Climate Change Science Program
PIC	Pacific Island Country
PICCAP	Pacific Islands Climate Change Assistance Programme
PI-CPP	Pacific Islands Climate Prediction Project
PNG	Papua New Guinea
PRIF	Pacific Region Infrastructure Facility
PWWA	Pacific Water and Wastes Association
RMI	Republic of Marshall Islands
RO	Reverse osmosis
SCOPIC	Seasonal Climate Outlook for Pacific Island Countries
SOI	Southern Oscillation Index
SOPAC	Pacific Islands Applied Geoscience Commission (formerly South Pacific Applied Geoscience Commission and now the Applied Geoscience and Technology Division of SPC since January 2011)
SPC	Secretariat of the Pacific Community
SPC-SOPAC	Applied Geoscience and Technology Division of SPC
SPCZ	South Pacific Convergence Zone
SPREP	Secretariat of the Pacific Regional Environment Programme (formerly South Pacific Regional Environment Programme)
SPSLCMP	South Pacific Sea Level and Climate Monitoring Project
SRES	Special Report on Emission Scenarios
SST	Sea surface temperature
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
USAID	United States Agency for International Development
USGS	United States Geological Survey
WHO	World Health Organization
WHYCOS	World Hydrological Cycle Observing System
WMO	World Meteorological Organization

Executive Summary

Introduction

This report has been prepared for the Department of Climate Change and Energy Efficiency as part of the Pacific Adaptation Strategy Assistance Program (PASAP). The objective of the report is to provide an overview of the vulnerability of water resources and water supply systems in 14 Pacific Island Countries (PICs) and East Timor to climate change impacts in addition to current stresses caused by climate variability, population pressures, pollution, geological hazards and other factors.

Summary and Conclusions

Diversity between the selected countries

There is considerable diversity between and within the 15 selected countries in physiographic, geological, demographic and hydrologic characteristics, all of which have impacts on water resources availability and water supply systems. The land masses vary from large, mountainous islands with considerable surface water and groundwater resources to small, low-lying coral sand and limestone islands with very limited groundwater resources and no surface water resources. The populations of each country vary from 1,500 to over 6.7 million. Average country-wide population densities vary from 20 to 500 people/km^2 with some urban areas having very high densities of over 10,000 people/km^2. The percentage of urban and rural populations in the 15 countries varies from 80% rural to 100% urban.

Freshwater sources and use

The main sources of freshwater throughout the region are naturally occurring groundwater and surface water and rainwater harvested from roofs and other surfaces. Surface water is only available in some countries but fresh groundwater is available, even in limited quantities, in all countries. Desalination is not common and is only used as a primary source of water in one country. Some countries use desalination as an emergency source in droughts for urban centres. Importation of water to some small islands occurs via pipeline as a regular source of water or via barge or boat in droughts.

Water resources availability is most critical in the small coral sand and limestone islands within the region, especially in densely populated areas on some atoll islands.

The main consumptive use of freshwater in the selected countries is water supply for urban and rural communities. The conjunctive use of rainwater, when available, for potable purposes and other sources for non-potable purposes is common in some islands. Brackish water and seawater are used in some islands as a source of supplementary water for some non-potable uses.

Only 50% of the total population across all the selected 15 countries had access to improved water supplies in 2010 which is significantly less than the world average of 86%. For individual countries, the access to improved water supplies varies from about 40% to 100%.

Freshwater is also used for agriculture (mainly for subsistence crops but some irrigated agriculture), industry (limited in most countries) and mining (limited to some larger countries) and hydroelectricity generation (some countries only).

Current water security issues

Water security in the selected countries is impacted at present to various degrees from current climate variability, geological hazards and human factors. The most vulnerable groups include densely populated urban and peri-urban settlements and remote communities.

Droughts associated with El Niño and La Niña episodes are a major problem for many countries, causing severe water shortages in some. For some of the smaller islands, emergency measures such as use of desalination and importation of water via barge or boat is required. Droughts also severely impact on agriculture in many islands and can also cause major reduction in hydroelectricity generation (e.g. Fiji).

Floods caused by tropical storms and cyclones are a major problem in some of the countries, particularly for urban centres located near major rivers.

Volcanic eruptions, earthquakes and resulting tsunamis and landslides have caused major short to medium-term impacts in some countries. Resulting destruction and damage of infrastructure including water supply systems, and temporary salinisation of groundwater resources has occurred in small islands and coastal areas of larger islands.

Human factors are already having a large impact on water security, particularly in urban and peri-urban areas where rapidly increasing populations place increasing demands on water resources. Inadequate water supply systems, often suffering from large pipeline losses, mean that many people do not have access to safe water in adequate quantities. High population densities and inadequate sanitation facilities lead to pollution of nearby groundwater and surface water resources and resultant water quality degradation. Population pressures mean that adjacent areas reserved for water resources development are also polluted due to human activity and settlement within them. As a result, the incidence of water-borne disease is high in some countries. The incidence rate of diarrhoeal diseases in the PICs, linked to contaminated drinking water and poor sanitation conditions, is about four to five times higher than in developed countries such as Australia and New Zealand.

Other sources of pollution include oil and fuel leaks and spills and agricultural chemical on rural land. Over-pumping causing salinisation of groundwater is a problem in some islands

Damage to water infrastructure, particularly associated with land disputes between land owners and government authorities, is another human-induced problem in some countries.

Poor water governance and management is also a major factor in decreasing current water security. Problems include lack of water policy, plans and legislation and ineffective coordination and administration of water sector agencies. Most countries suffer from insufficient knowledge of national water resources due to limited effort and resources being applied to water resources assessment and monitoring. Ineffective or no water source protection measures increase the vulnerability of water resources to contamination from human settlements and activities. Human and financial resource capacity limitations often prevent even essential tasks from being undertaken. Insufficient training, education and ongoing development of water sector personnel and loss of such personnel to more lucrative positions within or outside the country are ongoing problems.

Lack of, or limited community education, awareness and participation in freshwater management, conservation and protection are additional problems which impact on water security.

Climate change projections

The impacts of projected climate change and associated mean sea level rise on water resources and water supply systems have been considered to the year 2030 based on interim climate projections provided by the Pacific Climate Change Science Program (PCCSP). These interim projections are based on “most likely” and ““largest change” conditions from the outputs of 18 global climate models (GCMs). The parameters of most relevance for water security are mean rainfall, rainfall intensity, mean temperature and mean sea level change. No projections are available yet from PCCSP for other relevant parameters i.e. evaporation and tropical cyclone activity. Also, El Niño Southern Oscillation (ENSO) activity, the main driver of current climate variability in the selected countries, is assumed by PCCSP to remain the same as at present due to a lack of consensus in the GCMs.

The PCCSP interim projections to 2030 for the 15 countries are summarised below.

<u>Mean annual rainfall</u>

- For the “most likely” condition, three countries (Tonga, Vanuatu and East Timor) show relatively small reductions. Nine countries (Cook Islands, FSM, Fiji, Niue, Palau, RMI, Samoa, Solomon Is and Tuvalu) show relatively small increases and three countries (Kiribati, Nauru and PNG) show larger increases.

- For the “largest change” condition, five countries (Fiji, Niue, Tonga, Vanuatu and East Timor) show small to moderate reductions while the other ten countries show small to large increases.

Mean dry season rainfall

- For the “most likely” condition, four countries (Fiji, Tonga, Vanuatu and East Timor) show small to moderate reductions and a further two countries (Palau and Solomon Islands) show very small reductions. The other nine countries showed small to large increases with the highest increases indicated for Kiribati, Nauru and parts of PNG.
- For the “largest change” condition, four countries (Fiji, Niue, Tonga and Vanuatu) show relatively small reductions while East Timor shows a large reduction.

Mean wet season rainfall

- For the “most likely” condition, all 14 PICs show small to moderate increases. East Timor shows a very small reduction.
- For the “largest change” condition, four countries (Fiji, Niue, Tonga and Vanuatu) show small reductions while the other 11 countries show small to large increases. The largest increases are shown for Kiribati and Nauru.

Mean monthly rainfall intensity

- For the “most likely” condition, most countries show increases in either all or most months. Where decreases are shown, these are relatively small. Vanuatu and East Timor show the most months with decreases.
- For the “largest change” condition, most countries again show increases in either all or most months. The largest changes are shown for PNG (moderate to high increases in all months) and East Timor (small to moderate decreases in most months).

Mean monthly temperature

- For the “most likely” condition, all 15 countries show increases between 0.6ºC and 1.1ºC.
- For the “largest change” condition, all 15 countries show increases between 0.6ºC and 1.2ºC. The highest increases are shown for Kiribati and Nauru.

Mean sea level

- Increases are shown to be in the range from 0.03 m to 0.17 m within the 15 countries.

Projections made in some other studies were also reviewed and the results are presented in the report.

Climate change impacts on water resources by 2030

Impacts on surface and groundwater resources availability due to projected changes to rainfall, temperature and mean sea level rise were assessed. This was done by assessing impacts on streamflow and groundwater recharge, the main drivers of (or inputs to) these water resources, using water balance approaches.

Emphasis was placed on the five countries showing a reduction in mean rainfall under the “most likely” or “largest change” conditions (i.e. Fiji, Niue, Tonga, Vanuatu and East Timor). The other 10 countries are projected to have small to large increases in mean rainfall which will have beneficial effects on water resources.

Key findings regarding projected impacts on streamflows, and hence surface water availability, are:

- Small mean annual streamflow reductions (up to 5%) for Tonga, Vanuatu and East Timor under the “most likely” condition and a small increase for Fiji. Higher reductions of up to 15% under the “largest change” condition for the three PICs and nearly 40% for East Timor.
- Significant reductions in mean dry season streamflow (up to about 25%) for East Timor under the “most likely” condition and much higher reductions under the “largest change” condition (60% to 100%, with the latter value appearing unreasonably high).

- Lesser reductions in mean dry season streamflow for Fiji, Tonga and Vanuatu of up to 15% and 20% for the “most likely” and “largest change” conditions, respectively.

Key findings regarding projected impacts on groundwater recharge, and hence groundwater availability, are:

- Small reductions in mean annual groundwater recharge for Tonga, Vanuatu and East Timor (up to 2%) under the “most likely” condition.
- Moderately significant reductions in mean annual groundwater recharge for Fiji, Niue, Tonga and Vanuatu (up to 12%) and significant reductions for East Timor (20%) under the “largest change” condition

The estimated streamflow and recharge changes due to projected mean rainfall changes are rather coarse. However, such estimates are considered reasonable given the uncertainties inherent in the interim projections of rainfall and the scale at which they are available, the lack of projections regarding evaporation and the assumption that climate variability due to ENSO activity will be the same as at present.

Impacts from projected increases in rainfall intensity in most countries are likely to be:

- Increased flooding and consequent problems including damage to infrastructure (including water infrastructure), increased land erosion, especially in cleared, steep catchments, and sedimentation of downstream reaches of streams and rivers and the coastal environment.
- Beneficial impacts due to enhanced groundwater recharge to freshwater lenses on coral sand and limestone islands and to coastal aquifers in high islands.
- Beneficial effects for lakes and larger water storages on high islands from higher streamflows.

It is not possible to estimate impacts on streamflow and recharge conditions at catchment scale given the resolution of the projected rainfall conditions (2.5° of latitude x 2.5° of longitude or approximately 280 km x 280 km at the equator). This scale is larger, and in most cases much larger, than the size of the islands within the study region except for the main island of PNG.

Mean sea level impacts on groundwater resources by 2030

The impact of projected mean sea level rises is not expected to have a significant impact on groundwater resources in small islands and coastal areas of larger islands except where land surface elevations are currently very low. Rising sea levels will not adversely impact on groundwater resources unless there is loss of land. Groundwater modelling studies have shown that a loss of land width by say 20% would lead to about 30% loss in groundwater storage.

Hence, the main issue is whether or not land will be lost. An inundation study for Bonriki island (the current major groundwater resource for South Tarawa, Kiribati) showed some loss of land by 2030. Based on this, a recent water master plan study for Tarawa assumed a reduction in groundwater sustainable yield of 20%. However, these estimates are based on interpolation of existing relatively coarse topographical information. It also assumes that natural accretion and/or coastal protection works would not be implemented as adaptation measures.

Further work is required to assess the vulnerability of shorelines to erosion due to mean sea level rise. Erosion of shorelines due to extreme events such as major waves from storms or cyclones is more likely to affect low-lying coastal areas and small islands than a gradual change in sea level. A better understanding of the processes and impacts on coastlines due to sea level rise is required, particularly on small islands.

Climate change impacts on water demand by 2030

Projected air temperature increases are unlikely to have a significant impact on water demand especially when compared with the water demand increase due to population increases and losses in pipe networks. An increase in water demand of 2% due to projected temperature increase was used in a recent water master plan study for Tarawa, Kiribati.

Comparisons of risks to water security by 2030

Key findings from an analysis and comparison of risks to water security due to climate and non-climate related factors are:

- In general, the highest risks to water security are from increasing water demands due to population increase and other activities and pollution of water resources.
- Increasing water demands based on current annual population growth rates in some urban areas have the potential to increase water demands in 2030 by between 70% and 240%. These increases are higher than those due to reductions in streamflow and groundwater recharge, especially under the "most likely" condition where the worst scenario is a 25% reduction in streamflow in East Timor.
- The loss of freshwater resources due to pollution is hard to quantify. In most cases, water treatment systems can be installed to improve the water quality so the impact is one of additional cost rather than total loss of the resource.
- Contamination of fresh groundwater due to seawater intrusion from over-pumping is reversible if pump rates are reduced to sustainable levels. The main impact would be the cost of developing additional water sources once the pump rates were reset in order to meet the required water demand.
- The reduction in water resources availability due to mean sea level rise is hard to quantify. If the assumption made for Tarawa of a 20% reduction in groundwater sustainable yield is applied to other similar small islands, the impact of this projected climate change is again significant but relatively small compared to the large demand on water resources due to population increase.
- Leakage from many urban pipe distribution systems is 50% or higher. This loss of potential usable freshwater is greater than the effect of projected climate change impacts on streamflow, groundwater recharge and the assumed loss of 20% of groundwater resources on low islands.
- The impact of temperature rise on water demand based on the 2% increase used for Tarawa is insignificant compared with the other impacts.
- Impacts of natural hazards such as overtopping waves due to cyclones and tsunamis, while devastating in the short to medium-term, may not lead to a long-term loss in groundwater resources unless major changes in landform are experienced. Also, damaged infrastructure can be repaired or new infrastructure installed if communities have and use the opportunity to resettle to higher ground.
- Impacts from poor water governance and management are considered to be moderate to high on overall water security. While these factors do not directly lead to a loss of water resources, they can lead to poor decisions about water resources development and protection. This can cause further water quality degradation on existing developed water resources due to lack of action regarding encroachment onto water protection areas. Poor governance can also lead to other problems including delays in implementing much needed water augmentation works for existing populations.
- Impacts from vandalism are also considered to be moderate on overall water security. Vandalism can cause damage to infrastructure with temporary loss or reduction in water supply services. Damaged infrastructure can be repaired or replaced but this can be expensive and time consuming.
- Impacts from works that alter existing coastlines making them more vulnerable to erosion, or gravel mining that exposes shallow groundwater to direct evaporation can potentially lead to a loss of groundwater resources due to man-induced erosion of land or increased evaporation.

In summary, non-climate related factors of increasing water demand due to increasing population and leakage from pipe systems pose the greatest risks to water security.

Water security implications for vulnerable groups

The main vulnerable groups of people in terms of water security from both climate and non-climate related factors are those living in:

- Crowded urban and peri-urban areas, which are at major risk because of lack of adequate water supply and the need to use polluted sources for some water uses.
- Remote islands, which are at risk during droughts if the local water resources are depleted (e.g. rainwater tanks) or become saline (groundwater) and require importation of water.
- Remote parts of larger islands, which are at risk during droughts if water resources are depleted and food crops fail, due to the difficulty of access for emergency assistance and the time taken to regrow crops once rainfall returns to normal.
- Very low level parts of islands, which are at risk of overtopping, erosion and temporary salinisation of groundwater from waves caused by cyclones or tsunamis in addition to potential inundation from projected sea level rise.

Review of experiences to improve water security

The report outlines major regional water sector programmes and initiatives in the Pacific region within the past decade. Most of these have been co-ordinated through SPC-SOPAC Division (formerly SOPAC). Country-based programmes and activities are also considered with reference to those in East Timor and in Kiribati (the Kiribati Adaptation Programme).

Many recent programmes and initiatives in the water sector have been implemented with recognition of potential climate change impacts but with a primary focus on more immediate needs such as providing improved water supplies to cater for population growth and development. Many projects have focused on water governance, water resources assessment, water supply development and management, capacity building and training, and community education and awareness. These improvements are required regardless of the additional stresses imposed due to climate change. The ultimate aim of these projects is the improvement of water supply for rural and urban communities, agriculture and, in some cases, hydroelectricity generation for the current and future populations. Other projects have been or are being implemented to install new water supply systems or reconstruct/rehabilitate existing systems for communities devastated by natural disasters.

Water sector projects which aim to improve water security through proper planning, design and implementation and which cater for current climate variability are also building resilience into physical and human systems which can assist in coping with future climate change.

Some examples of good and poor practices are presented.

Practical strategies to improve water security

A number of strategies for managing the implications of climate change in addition to existing stresses on water security for the countries in the study region are outlined in the report under the following categories:

- Water governance
- Assessment and monitoring of water resources
- Management and protection and of water resources
- Appropriate water supply systems
- Demand management
- Drought and flood planning
- Capacity building and training
- Community education, awareness and participation
- Other water supply strategies for specific circumstances.

Key principles for these strategies are:

- Ensuring that the water sector in each of the selected countries is resilient to current climate variability, in addition to major pressures from increasing water demand and stresses from water pollution associated with human settlements, is the most effective overall adaptation strategy to cope with future climate change.
- Strategies to reduce vulnerability of the water sector to climate change and, thus, increase water security are essential components of good water management practice, and are required whether climate changes or not.
- There are “no simple technical fixes” or no single action that will improve water security. Rather a range of strategies are required including improved water governance; effective assessment, development, management, protection and conservation of water resources; effective operation, maintenance and management of water supply systems and other water development schemes; enhanced community participation in the water sector and improved community education and awareness.
- Although there are some regional similarities between countries, each country is different and some have wide variations in water resources and water security between different parts of the country (e.g. high islands and low islands). The mix of potential strategies to improve water security must be adapted to suit local circumstances taking account of population growth and the pattern of settlement and development.
- Introduction of new technologies requires parallel investment in training, education and awareness to gain community and government acceptance.
- In specific circumstances, particularly in countries with limited land and water resources (e.g. crowded low-lying islands and remote islands), there are a number of options to assist in development and management of water resources.

Identification of gaps and future needs

Information gaps and research needs, aimed at a better understanding of the implications of climate change on water security, are identified according to the following categories:

- Climate change projection deficiencies and needs
- Water resources data deficiencies and needs
- Other data deficiencies and needs
- Research into impacts on surface water and groundwater resources
- Further development of effective water supply technologies.

1. Introduction

This report has been prepared for the Department of Climate Change and Energy Efficiency as part of the Pacific Adaptation Strategy Assistance Program (PASAP).

The objective of the report is to provide an overview of the vulnerability of water resources and water supply systems in 15 selected countries to climate change impacts in addition to current stresses caused by climate variability, population pressures, pollution, geological hazards and other factors.

The 15 selected countries are the 14 Pacific Island Countries (PICs), which are members of the Pacific Forum, and East Timor (Timor-Leste). The 14 PICs are Cook Islands, Federated States of Micronesia (FSM), Fiji, Kiribati, Nauru, Niue, Palau, Papua New Guinea (PNG), Republic of Marshall Islands (RMI), Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu.

The Scope of Services for the report is provided in Annex A.

2. Overview of Water Resources and Water Supply Systems

2.1 Outline of the selected countries

Figure 1 shows the region of the 15 countries (the “study region”) which extends from latitude 15ºN to 23ºS and longitude 125ºE to 157ºW. This region is one of immense diversity in geography, climate, hydrology, biodiversity, demography, culture and language.

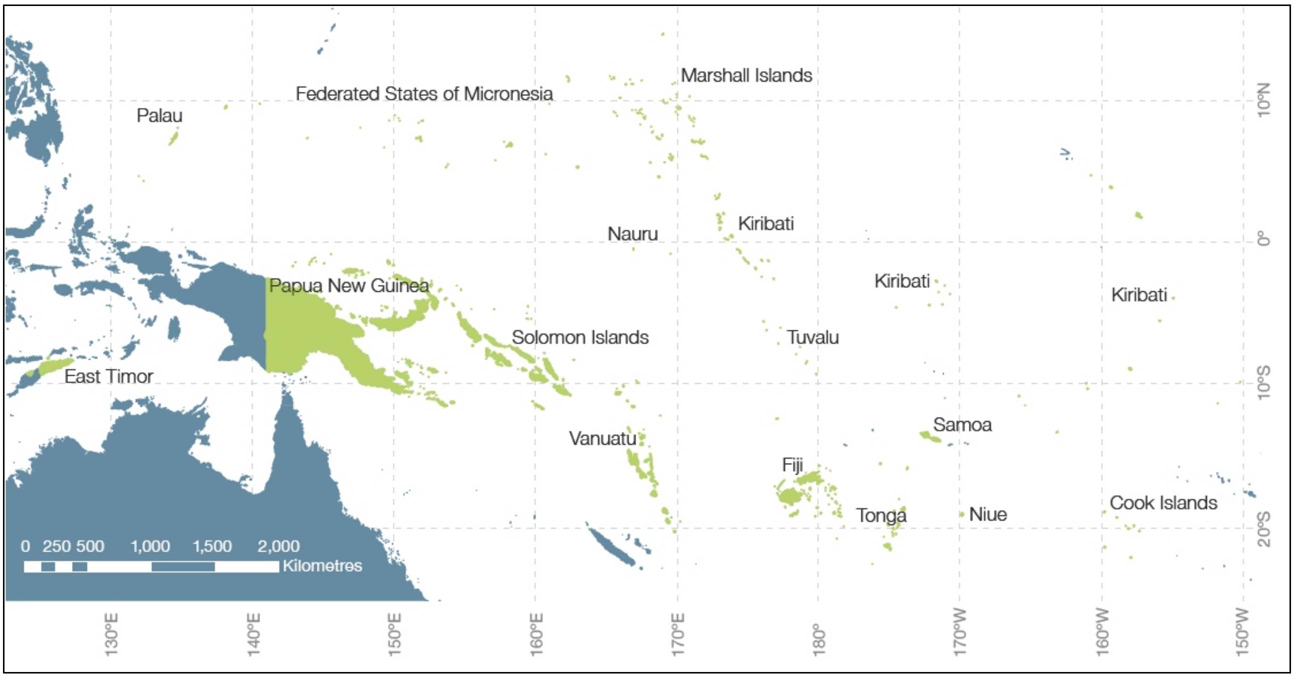


Figure 1 Map showing the locations of the 15 countries (from PCCSP, 2010a)

A summary of key physiographic, geological, demographic and hydrologic characteristics which are relevant to the availability and use of water resources are provided in this section. This information shows the very wide diversity between the countries in terms of total land area, topography, number of islands, geology, rainfall, total population and the distribution and density of the population. All of these characteristics, together with climate variability, have impacts on water resources availability and water supply systems in each country. Climate variability under current conditions and impacts of this variability on water resources are covered in section 3.2.

2.2 Physiographic and geological characteristics

Table 1 presents a summary of key physiographic and geological characteristics for each of the 15 countries. Figure 2 and Figure 3 show the range of land areas and highest elevations, respectively. Figure 2 uses a logarithmic scale owing to the large range in land areas.

Table 1 Summary of physiographic and geological characteristics for the 15 countries

Country	Total land area (km^2)	Number of islands or atolls	Island type according to geology	Highest elevation (m)
Cook Is	237	15	Volcanic, limestone, atolls, mixed	652
FSM	701	607	Volcanic, atolls, mixed	791
Fiji	18,273	322	Volcanic, limestone, atolls, mixed	1,324
Kiribati	811	33	Atolls & reef islands, limestone island	87
Nauru	21	1	Limestone	71
Niue	259	1	Limestone	68
Palau	444	Approx. 250	Volcanic, some with limestone	213
PNG	462,840	Approx. 600	Volcanic, limestone, atolls, reef islands, mixed	4,509
RMI	181	34	Atolls & reef islands	10
Samoa	2,785	10	Volcanic	1,857
Solomon Is	30,407	922	Volcanic, limestone, atolls & reef islands	2,335
Tonga	650	176	Volcanic, limestone, reef islands, mixed	1,033
Tuvalu	26	9	Atolls	5
Vanuatu	12,281	82	Volcanic with coastal sands and limestone	1,877
East Timor	14,922	3	Mixed igneous, metamorphic & sedimentary	3,030

Notes: Land areas for (a) PICs are from SPC (2011a) and for (b) East Timor is from Wallace et al. (2010a). Data regarding number of islands and highest elevations are from various sources. It is noted that there are differences in numerical values between sources.

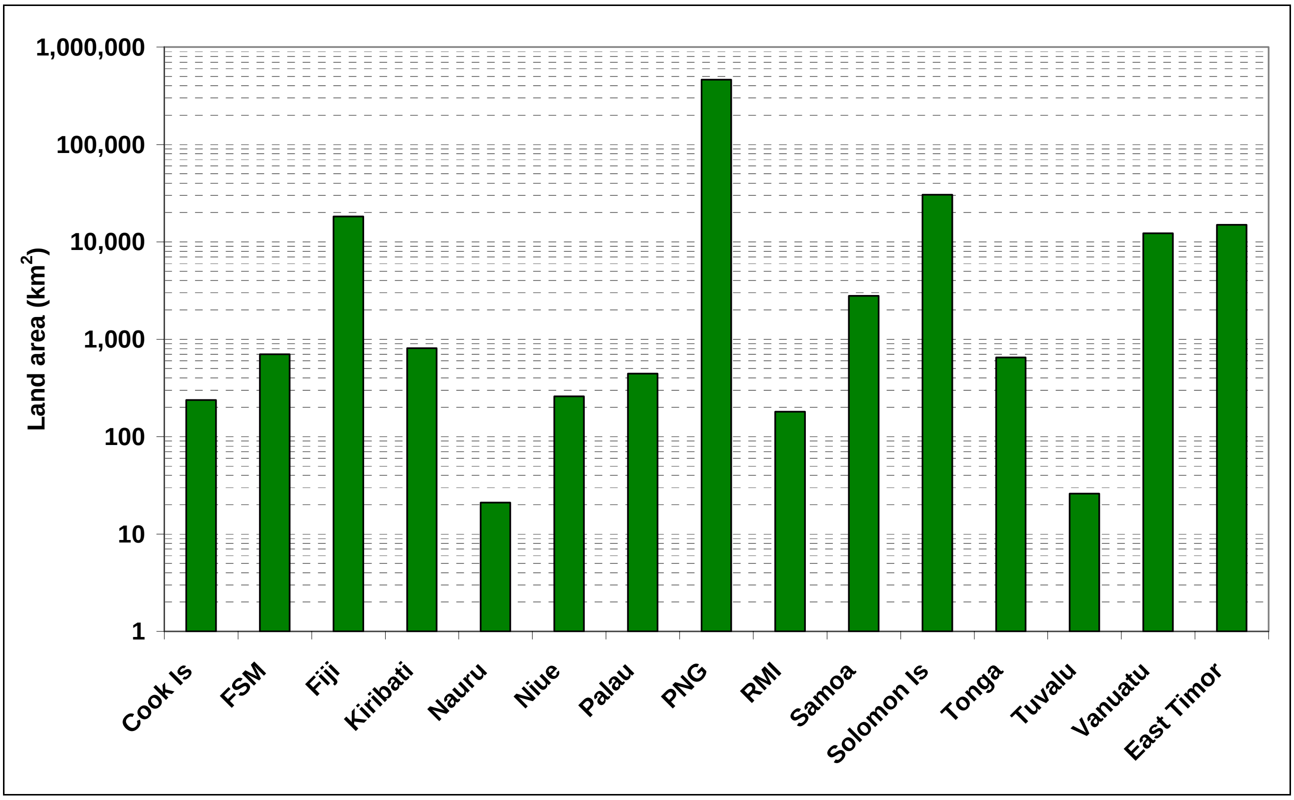


Figure 2 Land areas for each of the 15 countries

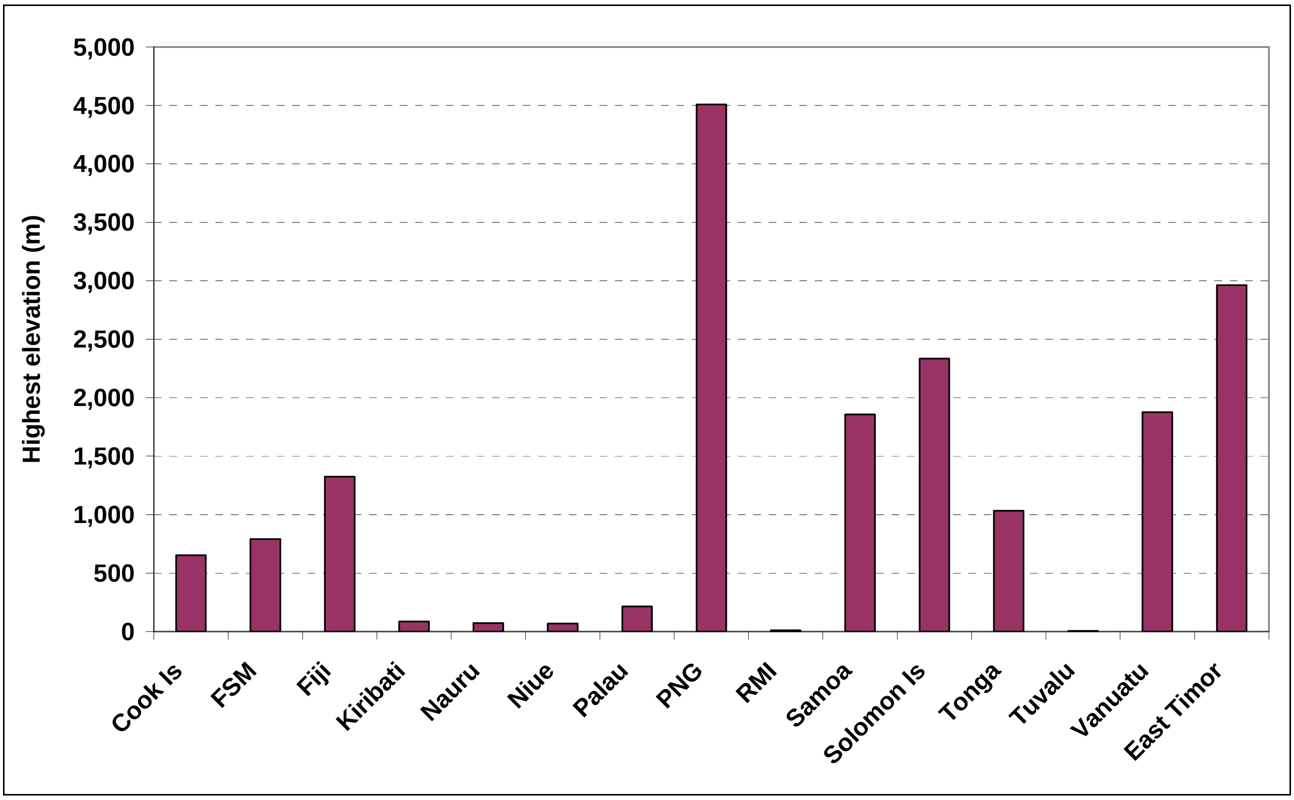


Figure 3 Highest elevations for each of the 15 countries

The following observations are made about the diverse physiographic and geological characteristics of the selected countries:

- The total land area of each country varies from over 460,000 km^2 (PNG) to 26 km^2 (Tuvalu) and 21 km^2 (Nauru). The vast bulk of the land area is within PNG followed by the other three Melanesian countries and East Timor. The percentages of the total land area for these five countries are Fiji (3.3%), PNG (85%), Solomon Islands (5.6%), Vanuatu (2.2%) and East Timor (2.7%) giving a total of 99%. Hence, the other ten PICs, all in Polynesia and Micronesia, have a combined land area of only 1% of the total for the 15 countries.
- The number of islands in each country varies from nearly 1,000 (Solomon Islands) to one (Nauru and Niue).
- It is noted that the main land components of PNG and East Timor are parts of larger islands. PNG consists of the eastern part of the large island of New Guinea (the world's second largest island) and numerous small to medium size islands. The western part of New Guinea island comprises two Indonesian provinces, Papua and West Papua. East Timor consists of the eastern part of Timor island, the enclave of Oecussi within Indonesian West Timor and the islands of Atauro (north of the capital Dili) and Jaco (at the eastern end of the country). For the purposes of this report, the term "island" refers to not only distinct islands within each country but also the main land masses of PNG and East Timor.
- Geological features of the 15 countries vary considerably from atoll islands made from coral sand and underlying limestone (e.g. most of Kiribati, and all of RMI and Tuvalu) to large 'high' islands with volcanic and metamorphic rocks and high mountains, the highest being about 4,500 m in PNG. Nauru and Niue are raised limestone islands. Many islands are of mixed geology comprising limestone, volcanic and other rock types. Some typical island types are shown in Figure 4.
- Topography within and between the 15 countries also varies considerably from the small, low-lying atoll islands ('low' islands) with maximum elevations of 2 m above mean sea level, to large 'high' islands with volcanic rocks and high mountains, the highest being about 4,500 m in PNG.

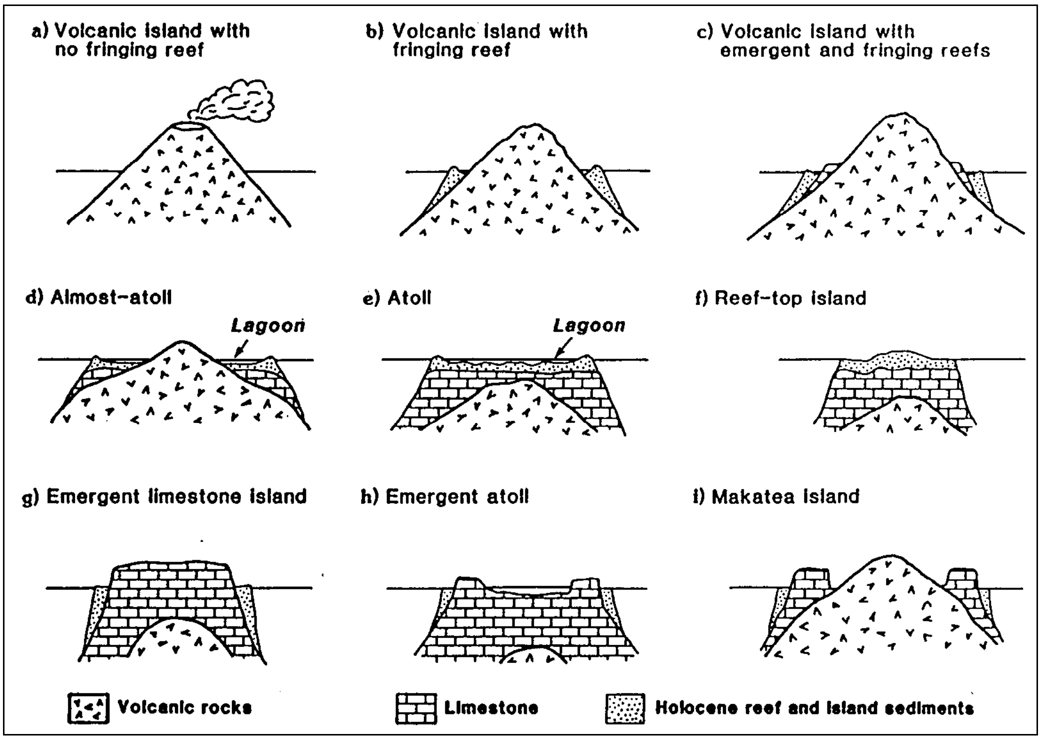


Figure 4 Typical island types (after Scott & Rotondo, 1983; Woodroffe, 1989)

2.3 Hydrologic characteristics

Table 2 presents a summary of key characteristics related to rainfall, the main influence on water resources, and the types of water resources for each of the 15 countries. Figure 5 shows the variations of annual mean (average) rainfall within and beyond the study region. Figure 6 shows the mean annual rainfall for the capital in each country and the mean, minimum and maximum annual rainfall in each country. Figure 6 also shows the coefficient of variation (Cv) of annual rainfall, a measure of annual rainfall variability, for the capital in each country.

Key observations about the rainfall characteristics over the study region are:

- The spatial distribution of rainfall varies considerably between and within countries, as shown in Table 2 (columns 2 and 4) and Figure 5. Mean annual rainfall varies from 900 mm or less in parts of eastern Kiribati, within the dry equatorial part of the Pacific, to over 8,000 mm in elevated parts of FSM, PNG and Solomon Islands. The mean annual rainfall at the capitals of each of the 15 countries varies between relatively low values of 900 mm and 1,100 mm for Dili, East Timor and Port Moresby, PNG, respectively, to high values of 4,700 mm and 3,500 mm for Pohnpei, FSM and Funafuti, Tuvalu, respectively. It is noted that the spatially averaged rainfalls over East Timor and PNG are much higher than at the capitals (about 2,000 mm and 3,000 mm, respectively).
- Within high islands, rainfall is highly variable from coastal zones to mountainous areas. This effect is mainly evident on larger islands such as the main island of PNG but is also evident on much smaller islands such as Pohnpei, FSM and Rarotonga, Cook Islands. These rainfall differences are largely due to orographic effects (lifting of cloud masses due to mountains) resulting in higher rainfall on windward sides and lower rainfall on leeward sides of islands. For instance, orographic effects on the predominant south-east trade winds due to the central mountains in the island of Viti Levu, Fiji, result in higher mean annual rainfall in Suva (approximately 3,000 mm) on the eastern side of the island than in Nadi on the western side of the island (approximately 1,900 mm).

Table 2 Summary of hydrologic characteristics for the 15 countries

Country	Mean annual rainfall (mm) at the capital	Coefficient of variation (Cv) of annual rainfall at the capital	Range of mean annual rainfall in country (mm)	Main freshwater resources
Cook Is	2,000	0.20	1,800 – 4,500	SW, GW, RW
FSM	4,700	0.12	2,600 – 8,200	SW, GW, RW
Fiji	3,000	0.19	1,500 – 6,000	SW, GW, RW, D (tourist resort only)
Kiribati	2,000	0.47	900 – 3,100	GW, RW
Nauru	2,100	0.54	2,100	D (regular use), RW, GW (limited)
Niue	2,100	0.24	2,100	GW, RW
Palau	3,700	0.13	3,200 – 4,300	SW, GW, RW
PNG	1,100	0.24	900 – 9,000	SW, GW, RW
RMI	3,300	0.15	2,200 – 3,300	RW, GW, D (emergency)
Samoa	2,900	0.20	2,500 – 7,500	SW, GW, RW
Solomon Is	2,000	0.20	1,800 – 9,000	SW, GW, RW
Tonga	1,700	0.24	1,700 – 2,500	GW, RW, SW (limited)
Tuvalu	3,500	0.20	2,400 – 4,000	RW (primary), GW (limited), D (emergency)
Vanuatu	2,100	0.27	2,000 – 4,000	SW, GW, RW
East Timor	900	0.32	700 – 3,000	SW, GW, RW

Notes: Rainfall data was obtained from several sources including water resources reports and national meteorological services in some PICs. Mean annual rainfalls are shown to the nearest 100mm. The coefficient of variation (Cv) of annual rainfall (= standard deviation/mean) is a measure of temporal variability of annual rainfall with higher values indicating greater variability. The range of mean annual rainfall, obtained from all available raingauges, illustrates the spatial variation of rainfall in each country. SW = surface water, GW = groundwater, RW = rainwater; D = desalination.

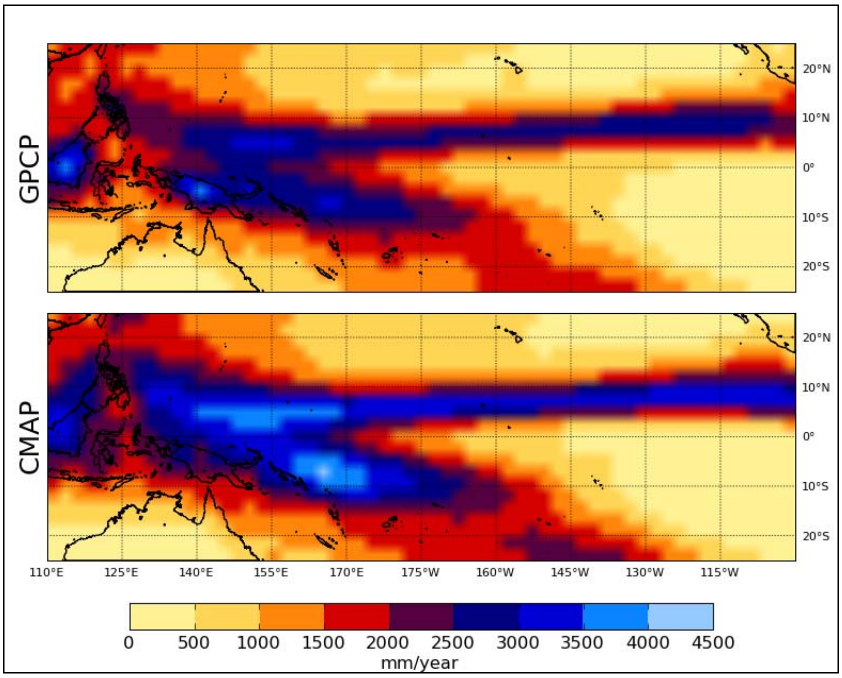


Figure 5 **Mean annual rainfall (mm/year) for the study region using GPCP and CMAP datasets for the period 1979-1999**

Notes: The mean annual rainfall maps in Figure 5 covers a region within and beyond the 15 countries. The two maps were derived from rainfall datasets that blend satellite and gauge estimates of precipitation from (a) the Global Precipitation Climatology Project (GPCP) and (b) the Climate Prediction Center of the National Weather Service, and called Climate Prediction Center Merged Analysis of Precipitation (CMAP). Both methods give similar spatial patterns with CMAP estimating slightly higher rainfalls than GPCP. Further information is contained in Xie and Arkin (1997), Adler et al. (2003) and Yin et al. (2004). Figure 5 was kindly produced for this report by CSIRO Marine and Atmospheric Research as part of the PCCSP.

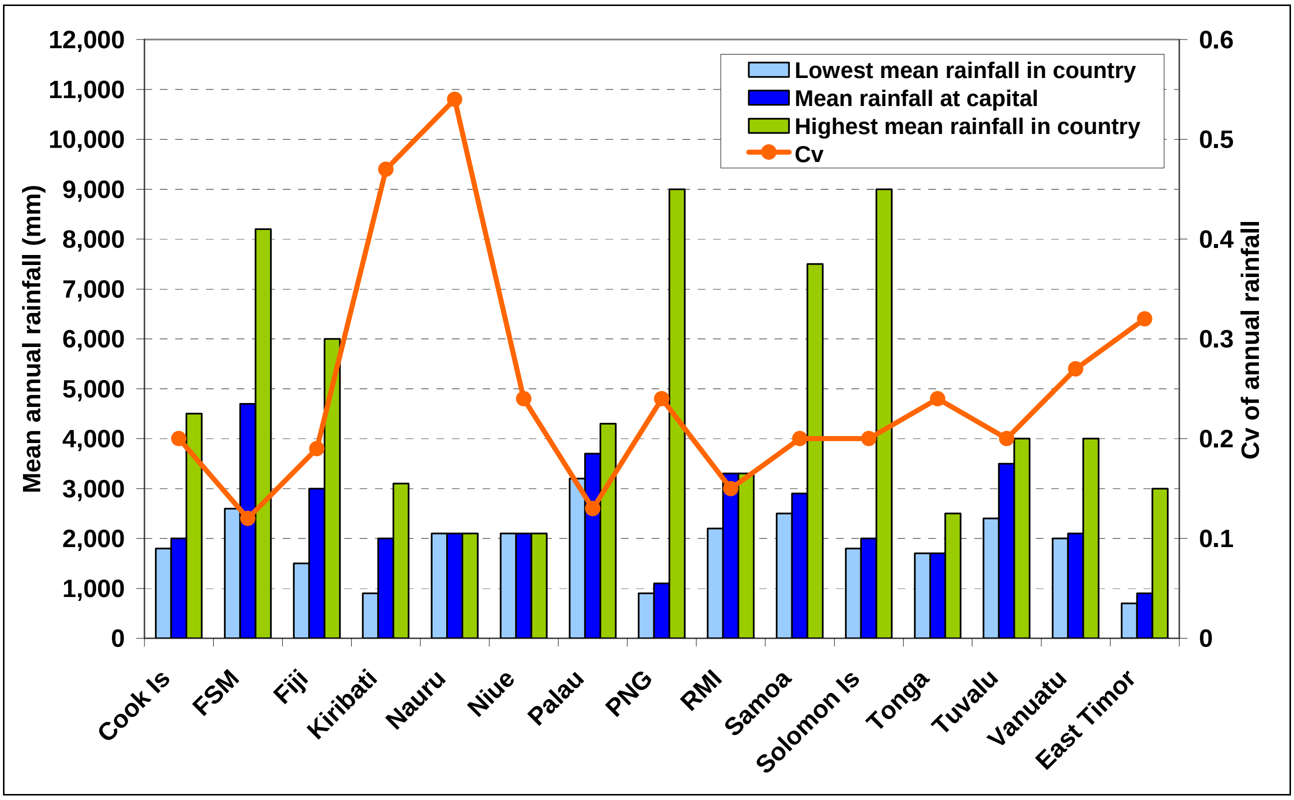


Figure 6 Rainfall characteristics for each of the 15 countries

- Rainfall also displays considerable temporal variability within and between the countries. For example, the Cv of annual rainfall (at the capitals varies from lows of 0.12 and 0.13 for Pohnpei, FSM and Melekeok, Palau, respectively, to highs of 0.47 for Tarawa, Kiribati and 0.54 for Nauru. The highest Cv's are associated with countries showing relatively low mean rainfall (e.g. Kiribati and Nauru) and, conversely, the lowest Cv's are associated with relatively high mean rainfall (e.g. FSM and Palau)
- High temporal variability due to major influences from El Niño and La Niña episodes (refer section 3.2.2).

Evapotranspiration is also a very important component of the hydrological cycle and of significance to water resources availability. It comprises the processes of evaporation from open surfaces and transpiration from vegetation and is dependent on many factors including solar radiation, temperature, humidity, wind speed and carbon dioxide levels. Potential evapotranspiration occurs when there is an adequate supply of moisture available at all times. Actual evapotranspiration from a land mass is dependent not only on the potential evapotranspiration but also on the availability of moisture in the soil and type and density of vegetation.

The variation in mean annual potential evapotranspiration over the region is summarised in Figure 7. The estimates of potential evapotranspiration in Figure 7 were made by Nullet (1987) for selected low-lying islands (to remove the effects of altitude on evapotranspiration in high islands) using the Priestley-Taylor method (Priestley and Taylor, 1972). Although the contours in Figure 7 cover a wide part of the Pacific Ocean, they are not intended to be representative of open ocean evaporation.

From Figure 7, the potential evaporation values within the study region range from about 1,600 to 1,800 mm/year (4.4 to 4.9 mm/day on average). The contours tend to run parallel with the equator although potential evaporation increases along the equatorial zone from west to east. Estimates of potential evaporation in other studies using the Penman equation show values which are reasonably similar or somewhat lower. For example, Thompson (1986a) provides a potential evaporation estimate of 1,460 mm/year for Tongatapu which is about 10% less than the approximate 1,600 mm/year from Figure 7. For the Cook Islands, Thompson (1986b; 1986c) estimated potential evaporation in the range from about 1,800 mm/year (averaged over four northern islands) to about 1,500 mm/year for (averaged over four southern islands). The estimate for the northern Cook Islands matches very well with Figure 7 while the estimate for the southern Cook Islands is about 7% less than the approximate 1,600 mm/year from Figure 7. For Kiritimati in eastern Kiribati (near the equator and south of the Hawaiian islands), Porteous and Thompson (1996) estimate potential evaporation from pan evaporation data (using a pan factor of 0.7) to be approximately 1,900 mm/year. This value is again reasonably consistent with Figure 7. For Tarawa in western Kiribati, a potential evaporation estimate of about 1,800 mm/year was made in Falkland (1992) based on pan evaporation data for 1981-1991 and a pan factor of 0.8. Measurements on Tarawa using a climate station and the assumption that equilibrium evaporation is more applicable in tropical climates than the Priestley-Taylor method used by Nullet (1987) suggest a lower potential evaporation rate of 1,420 mm/year (White et al., 1999), which is about 25% lower than in Figure 7.

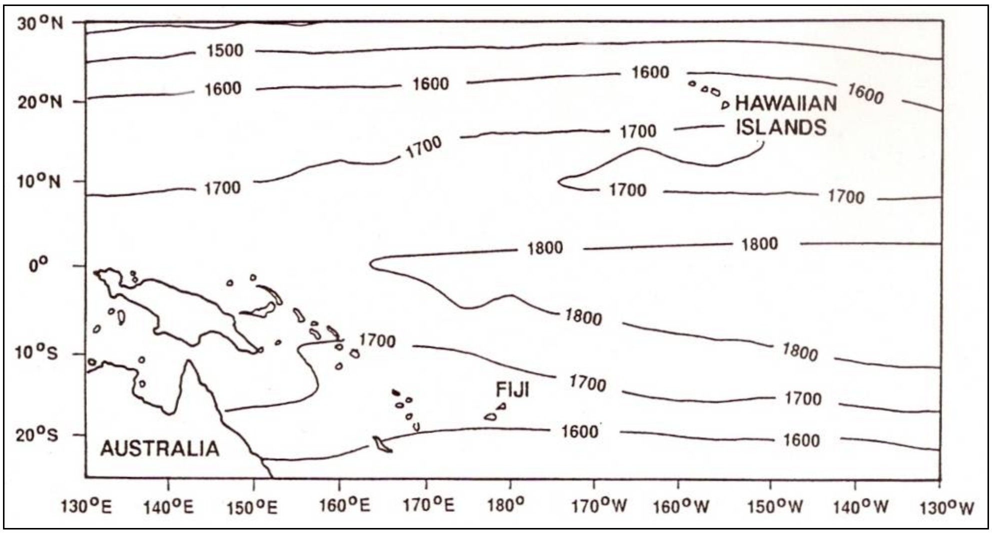


Figure 7 Mean annual potential evapotranspiration contours (mm/year) for the study region (from UNESCO, 1991; modified from Nullet, 1987)

For East Timor, various estimates of “evaporation” and potential evapotranspiration have been made for lowlands, midlands and highlands. These are summarised in Yance (2004) based on earlier reports by SNC-Lavalin (2001) and Souza (1972). Of most relevance, Yance (2004) refers to potential evapotranspiration estimates of 1,400 to 1,500 mm/year based on data from two climate stations. Higher potential evaporation estimates, in the range from 1,730 to 1,970 mm/year, are also tabulated in Yance (2004).

A summary of water resources within the selected countries is presented in section 2.5.

2.4 Demographic characteristics

Table 3 presents a summary of key demographic characteristics for each of the 15 countries. Figure 8 and Figure 9 show total (national) populations and average population densities, respectively. Figure 8 uses a logarithmic scale owing to the large range in populations.

The following observations are made about the diverse demographic characteristics of the selected countries:

- Country populations vary by more than four orders of magnitude from about 1,500 in Niue to over 6.7 million in PNG. The total estimated population in the 14 PICs in mid-2010 was approximately 9 million and the total estimated population in all 15 countries was about 10 million. The vast majority of these people live in PNG (6.7 million) followed by the other three Melanesian countries and East Timor. The percentages of the total population for these five countries are Fiji (8.4%), PNG (67%), Solomon Islands (5.5%), Vanuatu (2.4%) and East Timor (10.6%) giving a combined percentage of 94% of the total population. The other ten PICs have a combined percentage population of about 6% of the total for the 15 countries.

Table 3 Summary of demographic characteristics for the 15 countries

Country	Estimated population in mid-2010	Average population density (people/km^2)	Population growth rate (%)	Urban population (%)	Rural population (%)
Cook Is	15,700	66	0.3	72	28
FSM	111,000	158	0.4	22	78
Fiji	848,000	46	0.5	51	49
Kiribati	101,000	125	1.8	44	56
Nauru	9,980	475	2.1	100	0
Niue	1,480	6	-2.3	36	64
Palau	20,500	46	0.6	77	23
PNG	6,740,000	15	2.1	13	87
RMI	54,400	301	0.7	65	35
Samoa	183,000	66	0.3	21	79
Solomon Is	550,000	18	2.7	20	80
Tonga	103,000	158	0.3	23	77
Tuvalu	11,100	427	0.5	47	53
Vanuatu	245,000	20	2.6	24	76
East Timor	1,070,000	72	2.4	30	70

Notes: Population estimates (shown to three significant figures), growth rates and urban & rural populations for (a) PICs are from SPC (2011a and 2011b) and for (b) East Timor are from NSD (2010). Population densities are based on population estimates above and land areas in Table 1. Countries with population densities greater than 100 people/km2 are shaded orange. It is noted that some of the above data differs slightly from national census data. For example, the preliminary result from the 2010 national census in Kiribati gave a total population of 103,466, which is different by only 2.5% from the value shown above.

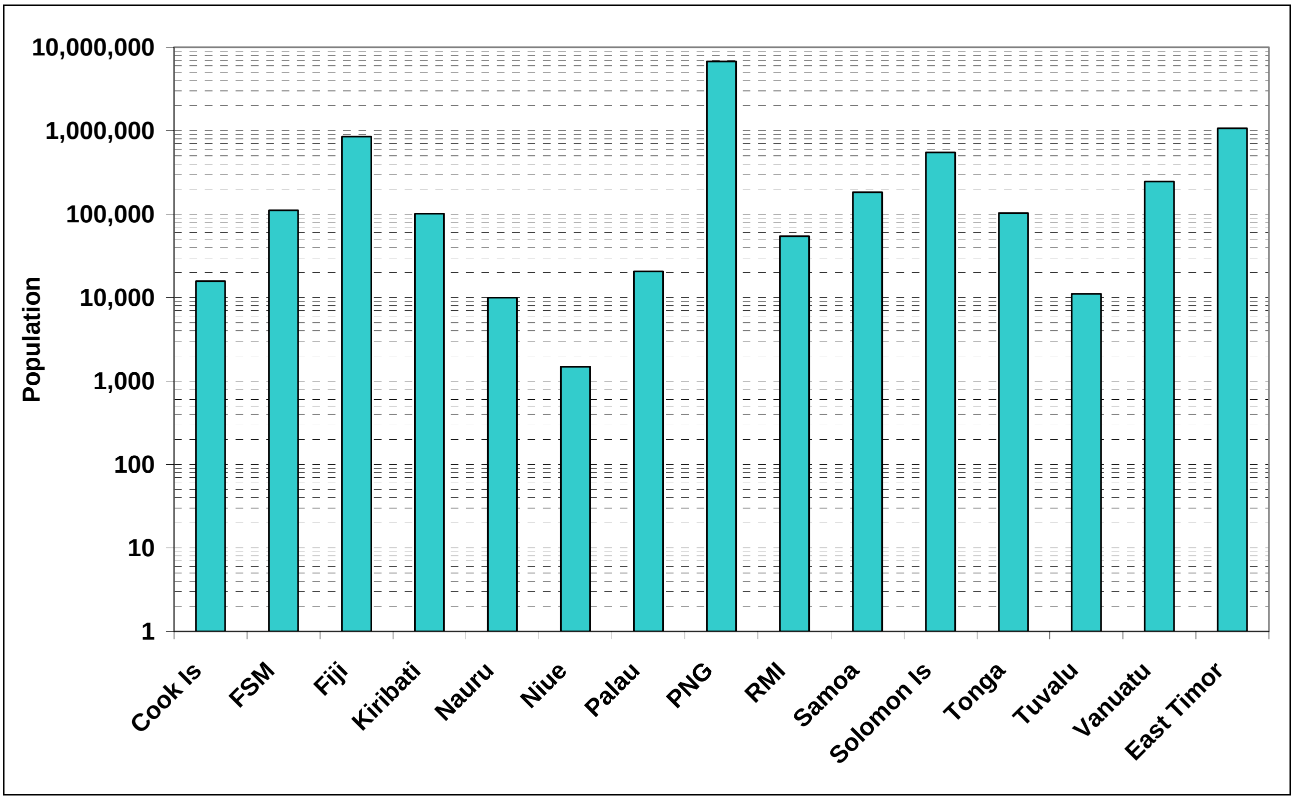


Figure 8 Total populations for each of the 15 countries

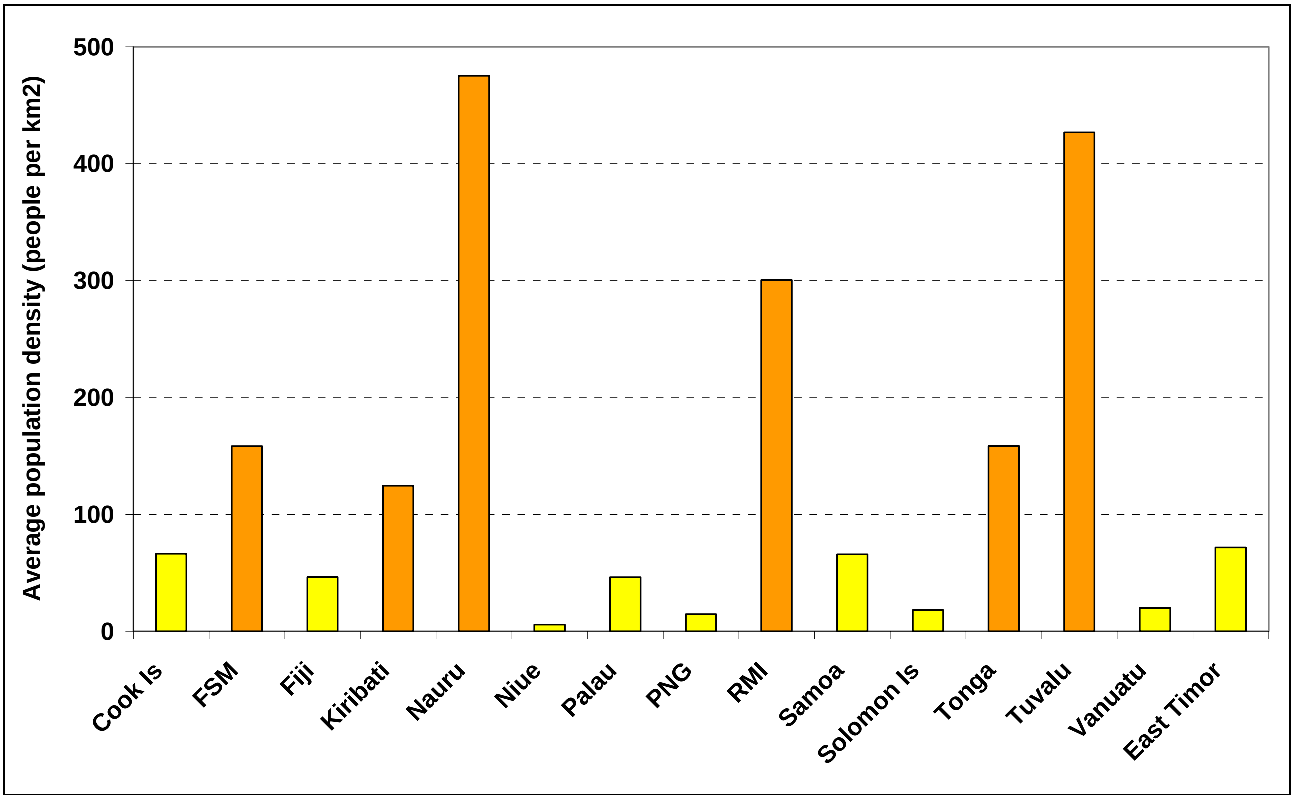


Figure 9 **Average population densities for each of the 15 countries**

- Annual population growth rates vary considerably from lows of -2.3% in Niue and +0.3% in Cook Island, Samoa and Tonga (all in Polynesia) to +2.1%, +2.6% and +2.7% in PNG, Vanuatu and Solomon Islands (all in Melanesia), respectively (SPC, 2011a). The average growth rate in 2010 for the whole population in the 15 countries was 2%.
- Average population densities vary considerably between the countries. Apart from Niue with 6 people/km^2, the larger Melanesian countries have the lowest average population densities (15, 18 and 20 people/km^2 for, respectively, PNG, Solomon Islands and Vanuatu). By comparison, the smaller PICs show the highest average population densities. For example, the average population densities for Nauru, RMI and Tuvalu are 475, 301 and 429 people/km^2, respectively. The six countries with average population densities greater than 100 people/ km^2 (the three above plus FSM, Kiribati and Tonga which are shaded orange in Table 3 and Figure 9) all consist of small islands only.
- In urban areas, the population densities are higher and, in some cases, much higher than the national averages. For instance, from Table 3 the average population density for Kiribati is 125 people per km^2. This average population density is distorted by the relatively large area (approximately 350 km^2) and low population (5,900 in 2010) of one island, Kiritimati (Christmas Island) in eastern Kiribati, giving a population density for that island of only 17 people per km^2. By comparison, the population density of urban South Tarawa is approximately 3,200 people per km^2, or about 25 times larger than the national average (based on the area of 16 km^2 and a preliminary population estimate of 50,010 from the 2010 census). Population densities in some parts of South Tarawa are even higher, with the most densely populated areas being on the islands of Betio and Nanikai (10,000 and 14,000 people per km^2, respectively). Population densities of these magnitudes on small atoll islands have major impacts on the limited groundwater resources through increasing demands for water and pollution from human settlements built over much of the available groundwater.
- The proportion of urban to rural populations also varies considerably. In Nauru, the whole population is classified as urban. Other relatively high urban populations are found in the Cook Islands (72%), Palau (77%) and RMI (65%). Relatively high rural populations are

found in PNG (87%) and Solomon Islands (80%). Other countries with 70% or greater rural populations (from (SPC, 2011b) are Samoa (79%), FSM (78%), Tonga (77%), Vanuatu (76%) and East Timor (70%). Overall, the rural population in the 15 countries was about 80% of the total showing the predominantly rural nature of these countries.

- Urban growth rates also vary considerably. From SPC (2011b), urban growth rates over 2.5% are found for Cook Islands (2.6%), PNG (2.8%), Solomon Islands (4.7%), Vanuatu (3.5%) and East Timor (4.8%). The urban growth rate in SPC (2011b) for Kiribati is shown as a relatively low 1.9% which is only 0.1% higher than the national average. However, a detailed water master plan study for Tarawa shows the urban (South Tarawa) growth rate to be a more realistic 3.4% using census data for the period 1985 to 2010 (White, 2011a; 2011b). Hence, the highest growth rates are found (in descending order) for East Timor (Dili), Solomon Islands (Honiara), Vanuatu (Port Vila) and Kiribati (South Tarawa).

The planning horizon for this report is 20 years into the future (i.e. the year 2030) as advised by DCCEE (Martin Sharp, pers. comm., June 2011). This is also the selected year for climate change projections made available to PASAP from the Pacific Climate Change Science Program (PCCSP) as presented in section 4.

Using the national population growth rates for mid-2010 from Table 3, the changes in population (in numerical and percentage terms) and the estimated total population by 2030 were calculated as shown in Table 4. Figure 10 shows the estimated percentage changes in populations from 2010 to 2030. These results assume that current percentage changes in national population will apply over the next 20 years.

Table 4 Summary of estimated population changes and total populations by 2030

Country	Population estimates in mid-2010	Estimated change in population to 2030	Estimated change in population to 2030 (%)	Estimated population in 2030
Cook Is	15,700	1,000	6%	16,700
FSM	111,000	9,000	8%	120,000
Fiji	848,000	89,000	10%	937,000
Kiribati	101,000	43,000	43%	144,000
Nauru	9,980	5,140	52%	15,100
Niue	1,480	-550	-37%	930
Palau	20,500	2,600	13%	23,100
PNG	6,740,000	3,470,000	52%	10,200,000
RMI	54,400	8,100	15%	62,500
Samoa	183,000	11,300	6%	194,000
Solomon Is	550,000	387,000	70%	937,000
Tonga	103,000	6,300	6%	109,000
Tuvalu	11,100	1,200	10%	12,300
Vanuatu	245,000	164,000	67%	409,000
East Timor	1,070,000	649,000	61%	1,720,00

Notes: Population estimates and increases are shown to three significant figures. Countries with percentage increases in population between 2010 and 2030 of greater than 40% are shaded dark orange. Niue is the only country to show a decrease.

From Table 4 and Figure 10, the following observations are made:

- Six countries show an estimated increase in population of greater than 40% (those shaded dark orange). These countries are two Micronesian countries (Kiribati and Nauru), the three largest Melanesian countries (PNG, Solomon Islands and Vanuatu) and East Timor. The largest percentage increase is for the Solomon Islands (70%) followed by Vanuatu (67%).
- Only Niue shows an estimated decrease in population by 2030.

- The other eight countries show relatively smaller percentage increases of between 6% and 15%.
- The results here assume that the current estimated population growth rates apply over the next 20 years. Obviously, this assumption may not be correct. One independent check was made of the estimated population increase. White (2011b) provides an estimate of 147,000 for the total population of Kiribati in 2030 based on a detailed analysis of available census data and growth rates. The estimate here of 144,000 is similar (within 2%) to the estimate in White (2011b).

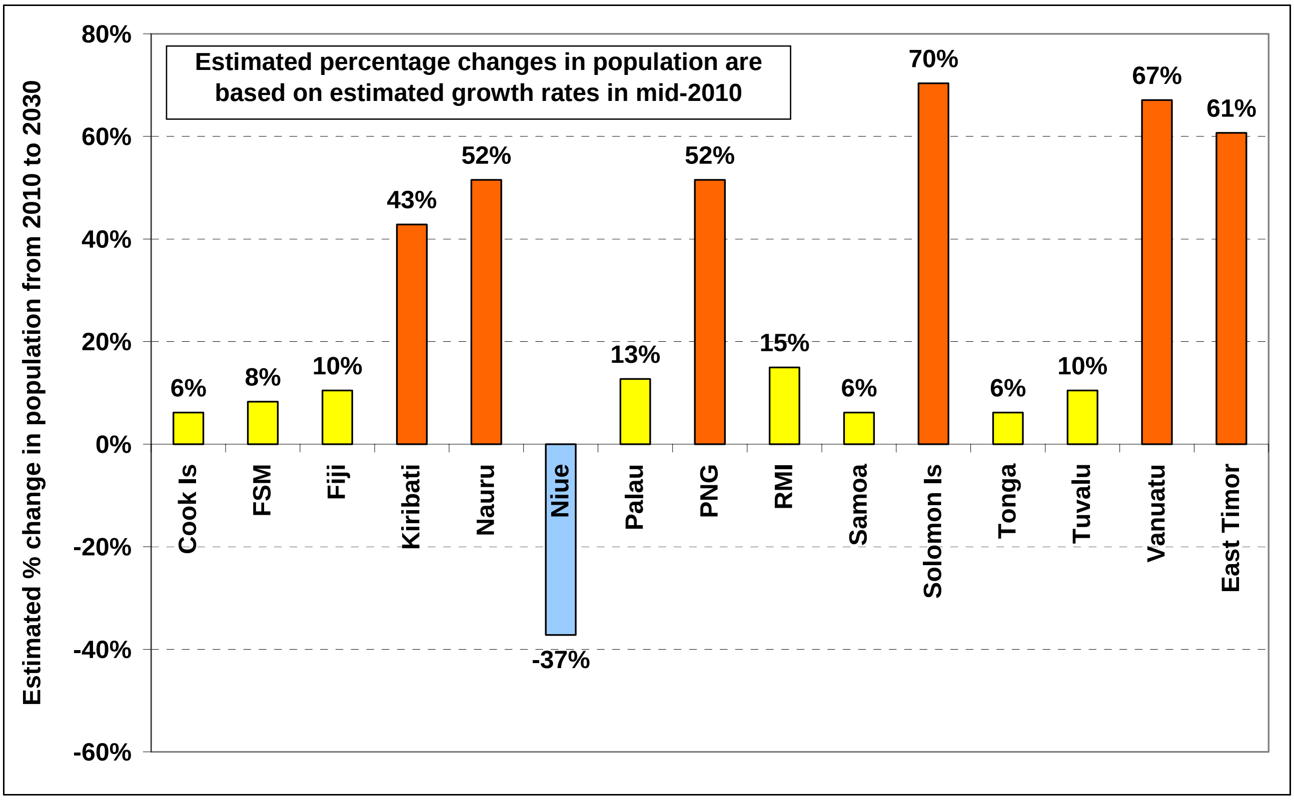


Figure 10 **Estimated percentage population changes by 2030 using current growth rates**

It is noted that the population increases apply to the total population in each country. It is most likely that population growth rates in urban areas will be significantly higher than the national population growth rates. This will have a large impact on the ability of water resources to meet urban water demands in many of the countries in the study region (refer section 3.5.1). For example, the population for urban South Tarawa in 2030 has been estimated at between 77,000 and 102,000 based on upper and lower bound growth rates (White, 2011b). When compared with the South Tarawa population estimate from the 2010 census of 50,010, these increases represent growth rates of about 2% and 3.5%, respectively, both of which are higher than the estimated national growth rate in 2010 of 1.8% (as per Table 3 in this report and in White, 2011b).

2.5 Types of water resources

2.5.1 Categories

Freshwater resources in the selected countries can be classified into two main categories:

- Naturally occurring water resources requiring a relatively low level of technology in order to develop them. This category includes surface water, groundwater and rainwater.
- Water resources involving a higher level of technology (sometimes referred to as “non-conventional” water resources). This category includes desalination, importation and the use of seawater or treated wastewater as a substitute for some uses.

As shown in Table 2, the naturally occurring water resources are the primary freshwater resources in all of the selected countries, except Nauru where desalinated water is the primary source of freshwater. In most of these countries, they are the only sources of freshwater. Fresh surface water is found in all of the 15 countries except the single island countries of Nauru and Niue. Fresh groundwater is found in all of the 15 countries, although it is very limited in Nauru, especially in droughts.

2.5.2 Surface water

Surface water can occur on 'high' volcanic islands in the form of ephemeral and perennial streams and springs, and as freshwater lagoons, lakes and swamps. Perennial streams and springs occur mainly in volcanic islands where the permeability of the rock is low. Many streams are in small, steep catchments and are not perennial. Low-lying coral islands and limestone islands rarely have fresh surface water resources except where rainfall is abundant. Many small island lakes, lagoons and swamps, particularly those at or close to sea level, are brackish.

2.5.3 Groundwater

Fresh groundwater occurs on many islands including small coral islands where there is an absence of surface water. Groundwater can be found as either 'perched' (high-level) or 'basal' (low-level) aquifers. Perched aquifers are found on many high volcanic islands above or behind relatively impermeable geological layers. These aquifers are the source of springs which occur mainly above sea level and sometimes below sea level. Basal aquifers occur at or below sea level and are found on many low islands of adequate size and rainfall and in the coastal margins of high volcanic islands. On many small coral islands and some limestone islands, the basal aquifer takes the form of a 'freshwater lens' (or 'groundwater lens'), which underlies the whole or most of the island. An example of a relatively thick freshwater lens is shown in Figure 11.

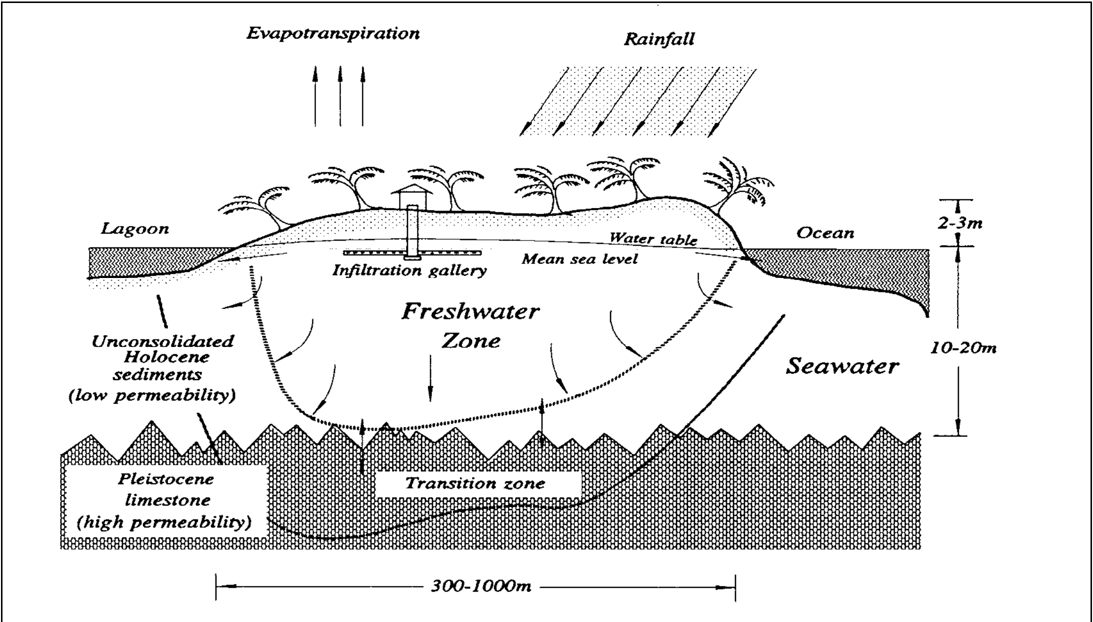


Figure 11 Cross section through a small coral island showing main features of a freshwater lens (exaggerated vertical scale) and location of an infiltration gallery

The term 'freshwater lens' can be misleading as it implies a distinct freshwater aquifer. In reality, there is no distinct boundary between freshwater and seawater but rather a transition zone as shown in Figure 11. Also, it is noted that diagrams such as that below exaggerate the vertical scale relative to the horizontal scale. In reality, the vertical scale is very small in comparison to the horizontal scale, often by a factor of 50 to 100.

Basal aquifers often tend to be more important than perched aquifers because they are more common and generally have larger storage volumes. Basal aquifers are, however, vulnerable to saline intrusion owing to the freshwater-seawater interaction, and must be carefully managed to avoid over-pumping, consequent seawater intrusion and salinisation of water supplies. The use of infiltration galleries (Figure 11) rather than conventional boreholes for groundwater pumping can avoid these problems.

2.5.4 Influences on occurrence of surface water and groundwater

The occurrence of surface water and groundwater on islands is dependent on many natural influences including the size of island or land mass, spatial and temporal distribution of rainfall, evaporation, soils, vegetation, geology and hydrogeology, topography and, for low-lying islands, sea level movements.

Human activities can also impact on the occurrence and distribution of fresh water resources primarily through the development of urban areas near or over groundwater resources, clearing of land for agriculture, forestry and mining and non-sustainable extraction of water particularly over-pumping of groundwater in coastal areas or small islands. Human activities can lead to biological and chemical contamination of both surface and groundwater due to urban and industrial development, soil erosion and consequent sedimentation of surface water systems due to inappropriate land clearing and saline intrusion into otherwise fresh groundwater due to over-pumping. Pollution problems associated with human settlement and activities are considered further in section 3.5.2.

2.5.5 Rainwater

Rainwater collection and storage (‘rainwater harvesting’) systems are common in many of the selected countries. In islands with high rainfall (e.g. Tuvalu), rainwater harvesting using the roofs of individual houses and some community buildings, is the primary source of freshwater (Taulima, 2002). In many countries, rainwater is used as a supplementary source to other water sources, especially groundwater. When rainfall is plentiful, rainwater is sometimes used for all household needs but limited to potable water needs (drinking, cooking and hand-washing) in dry periods. Common materials for rainwater tanks are ferrocement, fibreglass, steel and plastic (polyethylene). In recent years, polyethylene tanks have become popular for household rainwater collection in many islands.

Rainfall is sometimes collected from specially prepared ground surfaces. A prime example is the concrete runway on Majuro atoll, RMI, where surface runoff from rainfall is collected and pumped to large above-ground storages. This source of water is a major contributor to the water supply on Majuro (USAID, 2009). Simple rainwater collection systems consisting of containers (e.g. plastic barrels) located under the crown of coconut trees where rainfall is concentrated, are used in some islands (e.g. some outer islands of PNG).

2.5.6 Desalination

Desalination is used in a limited number of the selected countries as a primary or supplementary source of freshwater. Desalination is a relatively expensive and complex method of obtaining freshwater for small islands. The cost of producing desalinated water is almost invariably higher than developing groundwater or surface water due to the high energy and operating expenses. Desalination systems also require skilled operators to ensure the necessary operation and maintenance procedures are implemented.

Desalination using reverse osmosis (RO) units is used as the primary freshwater supply source on Nauru during droughts and as a supplementary source to rainwater and limited groundwater when rainfall is plentiful. RO desalination is used as the primary source of freshwater on Ebeye island, Kwajalein atoll, RMI. Other countries have installed RO units for emergency use during droughts (e.g. on the islands of Tarawa and Banaba, Kiribati; Majuro, RMI and Funafuti, Tuvalu). The long-term operational performance of these units has been generally poor. For example, most RO units installed in Kiribati during a serious drought from 1998 to 2000 failed after several months while one unit remained operational for only a few years. Eight RO units installed on Mauro atoll, RMI for public water supply after the 1998 drought are no longer operational (USAID, 2009). RO units are also used on a small number of tourist islands (e.g. in Cook Islands and Fiji).

2.5.7 Importation

Water is imported between islands in some countries, especially as an emergency measure during droughts. Water has been imported by sea transport (boats or barges) during droughts, for instance, to outer islands of Fiji, PNG and Tonga. During water shortages, people on some islands travel by boat or canoe to collect water from nearby islands with more plentiful water sources. Water is also piped to islands close to larger islands with more plentiful water resources. In Samoa, for example, freshwater is supplied by submarine pipeline over a distance of approximately 4 km from the western end of Upolo to Manono Island (UNICEF, 2009a).

In many small islands, bottled water has become an alternative source of drinking water. This is normally imported but in some islands has been produced from local desalination (RO) units (e.g. Tarawa atoll, Kiribati and Majuro atoll, RMI). The cost of bottled water is invariably much higher than for water supplied by local water authorities and is not used by most of the population.

2.5.8 Other sources

Seawater and brackish groundwater is used for non-potable purposes in a number of countries in order to conserve valuable freshwater resources especially on small islands. For example, reticulated seawater is used for toilet flushing and is a source of water for fire-fighting in densely populated parts of Tarawa, Kiribati and Majuro, RMI. Dual pipe systems are used to distribute freshwater and seawater to houses and other connections. Seawater or brackish groundwater from wells is used for bathing and washing purposes on some islands. Seawater is also used on some islands for cooling of electric power generation plants and for ice making.

Treated wastewater is not a common source of non-potable water in small islands, but is used for irrigation of garden and recreational areas at some tourist resorts and hotels (e.g. Fiji).

During severe drought conditions, or after natural disasters, coconuts have been used as a substitute for drinking water in some small areas. People on some of the smaller outer islands in Fiji, Kiribati, PNG and RMI, for instance, have survived on coconuts during drought periods. The coconut tree is very salt-tolerant and can continue to produce coconuts even when groundwater has turned brackish.

2.5.9 Further information

Further information on the water resources of the selected countries are presented in many publications. These include specific country water resources reports and other publications covering the wider region. Publications covering the 14 selected PICs and other islands in the Pacific Ocean include Carpenter et al. (2002), Falkland (2002a; 2002b) and Scott et al. (2003). Water resources reports for East Timor include Yance (2004), Furness (2004) and Wallace et al. (2010a; 2010b). Other publications covering the water resources of many islands within the Pacific Ocean as well as other parts of the world include UNESCO (1991), Vacher and Quinn (1997) and IETC (1998). Water resources publications specific to the most vulnerable countries (i.e. those with coral sand or limestone islands with only limited groundwater resources and rainwater) include White et al. (1999; 2007a; 2007b), USAID (2009) and White and Falkland (2010).

2.6 Water supply and use

2.6.1 General

The main consumptive use of freshwater in the selected countries is water supply for urban and rural communities.

Freshwater (direct from rainfall or from surface and groundwater sources) is also used for subsistence agriculture and for farm and domestic animals to support these communities. Small-scale irrigation of food crops occurs in a number of countries (e.g. diversion of streams for taro production). Swamp taro is also grown in pits dug below the groundwater table on many small coral islands in the Pacific. Larger-scale irrigation systems are restricted in the selected countries due to limited water resources and/or land availability. However, irrigated rice is grown in parts of East Timor (Javier et al., 2003; Wallace et al., 2010a) and to a lesser extent in Fiji.

Additional freshwater is used in some countries to support tourist facilities (e.g. some islands in Cook Islands, Fiji and Vanuatu) and limited industry. Overall, there is only minor utilisation of freshwater for industrial and mining purposes. Exceptions are found in some islands, for example, the volcanic island of Aniolam in the Lihir Islands, PNG, where a significant amount of water is used in gold processing. Groundwater is used for production of bottled water on some islands. An example is Fiji Water from the north-eastern part of the main island of Viti Levu.

Non-consumptive uses of surface water resources are hydroelectric power (hydropower) generation, transport and recreation. Hydroelectricity is generated in a number of islands within the selected PICs including Fiji, PNG, Samoa, Solomon Islands and Vanuatu. For Fiji, PNG and Samoa, about one third to one half of electricity is generated from hydropower stations (Marconnet, 2007). For Fiji, the percentage of electricity generation from hydropower generators has dropped from over 90% in the 1980s to about 60% (APCTT-UNESCAP, 2010) due to increasing demands for electricity. A hydropower plant was constructed in Pohnpei, FSM in the 1990s but is currently non-operational. A mini-hydropower plant supplies electricity to the city of Bacau and nearby areas in East Timor and others are planned for the future. Many high islands have the potential for hydroelectric power generation. Feasibility studies have been conducted for hydropower development on the Tina River, Guadalcanal, Solomon Islands (World Bank, 2010) and for rehabilitation of the existing plant and new hydropower development in Pohnpei, FSM (ADB, 2011). Feasibility studies are also being conducted in East Timor for a major expansion of hydropower generation from the proposed Iralalaru hydropower plant in the eastern part of the country.

Some rivers in the larger islands are used for transporting goods and people and for recreation (e.g. fishing).

2.6.2 Water supply for human settlements

Water supply systems and associated management approaches vary from household systems to community or centralised water supply systems in both rural and urban areas.

At household level, freshwater is generally obtained from a rainwater collection tank or other containers, groundwater withdrawal from wells and, on high islands, collection of water from nearby springs or streams. In addition to fresh (potable) water, brackish water and seawater are used in coastal areas on some islands for non-potable water in order to conserve valuable freshwater reserves. In some cases, water is extracted from shallow wells dug at low tide on the beach.

Typical community water supplies in rural areas have a distribution pipe network using water from surface or groundwater sources. Surface water systems normally use gravity flow pipelines from springs or streams to tanks or standpipes in the village. Groundwater systems often use petrol, diesel or solar pumps, which may be operated for a number of hours each day, to supply water to a storage tank feeding standpipes within the village. Rural water supply systems are often managed by village or island councils or community ‘water committees’. In some cases (e.g. village water supply schemes in Tonga) a small fee is charged to households benefiting from the water supply in order to cover operational expenses.

Urban water supply systems commonly consist of source works (e.g. groundwater pumping areas and/or surface water collection and storage), transmission pipelines and networks of distribution pipes to consumers. Urban water supply systems are generally run by either a water authority or a water division within a government department. In a limited number of cases (e.g. Port Vila and Luganville, Vanuatu), a private water company is responsible for water supply. Cost recovery by fixed fee or metered usage has been implemented in some countries.

On Fongafale island, the most populated island of Funafuti atoll, Tuvalu, rainwater is the primary freshwater resource and is collected in both household and community tanks. Where shortages are experienced at household tanks during extended dry periods, water is delivered by tanker from the community tanks. This service is provided by government and a fee is charged.

Per capita freshwater usage varies considerably between countries and within islands of the countries depending on availability, quality, type and age of water distribution systems, cultural and socio-economic factors and administrative procedures. Freshwater usage varies from low values of approximately 20-50 litres per person per day (L/p/d), where water is very limited, to more than 1,000 L/p/d on some islands where water resources are plentiful. Water usage tends to be higher in urban than in rural areas for a number of reasons, including the use of water consuming devices (e.g. washing machines) and leakage from pipe distribution systems. The latter can be 50% or more of the water supplied from sources (refer section 3.5.4). Typical per capita water usage in well-managed water supply systems is in the order of 50-200 L/p/d.

2.6.3 Access to improved water supplies

Table 5 provides estimates (mostly for 2006) of the percentage of people in urban and rural areas with access to improved drinking water sources in each of the 15 countries (from sources shown below Table 5). For the PICs, WHO & SOPAC (2008) indicate that this data might differ from the official statistics in PICs due to different criteria being used in defining access to drinking water or different methods in estimating coverage.

Table 5 Access to improved water supplies (%) in urban and rural areas of the 15 countries

Country	Urban (%)	Rural (%)	Total (%)
Cook Islands	98	88	95
FSM	95	94	94
Fiji	93	51	72
Kiribati	77	53	65
Nauru	100	-	100
Niue	100	100	100
Palau	79	94	89
PNG	88	32	40
RMI	98	97	99
Samoa	90	87	88
Solomon Islands	94	65	70
Tonga	100	100	100
Tuvalu	94	92	93
Vanuatu	87	52	60
East Timor	77	56	62

Notes: Data for 11 PICs and East Timor is for the year 2006 from UNICEF & WHO (2008). This report does not include data for Nauru at all or RMI or Vanuatu for 2006. Values for Nauru are for 2011 and are based on the fact that all people have access to either rainwater or desalinated water in limited quantities. Values for RMI are for 2007 from WHO & UNICEF (2010a). Values for Vanuatu are for the year 1999 from WHO & UNICEF (2008). The value of 43% for urban areas of Fiji in WHO & SOPAC (2008) is considered too low especially when compared with census figures for Fiji and with other urban values. A value of 93% was adopted for urban areas in Fiji from WHO & UNICEF (2010b).

WHO & SOPAC (2008) note the term “improved” rather than “safe” drinking water sources is used as a proxy to measure progress towards achieving the drinking water target of the Millennium Development Goals (MDGs) “to halve the proportion of people who are unable to reach or to afford safe drinking water” (United Nations, 2000) which became known as Target 7c after the World Summit in 2005. “Safe” drinking water means water that is safe to drink and available in sufficient quantities for hygienic purposes. National statistics do not normally have data based on this definition but rather have data associated with “improved” drinking water sources (e.g. piped water to standpipes or into houses, boreholes, protected springs or wells or rainwater catchments). Unimproved sources include unprotected wells and springs, water trucks, surface water including rivers, streams and lakes. Thus, “improved” drinking water sources are used as a proxy for “safe” drinking water sources. It is noted that many “improved” wells are not safe to drink. For instance, in low-lying sand islands, well improvements such as concrete surrounds and covers do nothing to prevent the movement of pathogens through the groundwater and into the well.

Access to an improved water source refers to the percentage of the population with reasonable access to an adequate amount of water from an improved source. Reasonable access is defined as access to at least 20 litres per person a day from a source within one kilometre of the dwelling.

The data in Table 5 shows a considerable range of conditions between the 15 countries. For urban areas, access to improved water supplies ranges from 77% (Kiribati and East Timor) to 100% (Nauru, Niue and Tonga). For rural areas, the range is from 32% (PNG) to 100% (Niue and Tonga). Overall, the range is from 40% (PNG) to 100% (Nauru, Niue and Tonga).

Assuming the percentages of people with access to improved water supplies shown in Table 5 and the estimated population data in Table 15 for 2010, only 50% of the total population in the 15 countries had access to improved drinking water sources. This included 88% of urban populations and 40% of rural populations. These percentages are similar to those for the PICs in 2006 from WHO & SOPAC (2008).

It is noted that the proportion of the global population (both urban and rural areas) with access to improved water supplies is much higher at 86% (WHO, 2009) than the 50% for the 15 selected countries. Figure 12 provides a graphical summary of the percentages of the population with access to improved water sources in each selected country, and compares these with the percentages for the total population in the 15 countries and for the world.

In addition, the MDG drinking water target for the combined 14 PICs will not be achieved by 2015 if past trends continue. Only six countries were on track in 2006 to meet their MDG drinking water target (WHO & SOPAC, 2008)

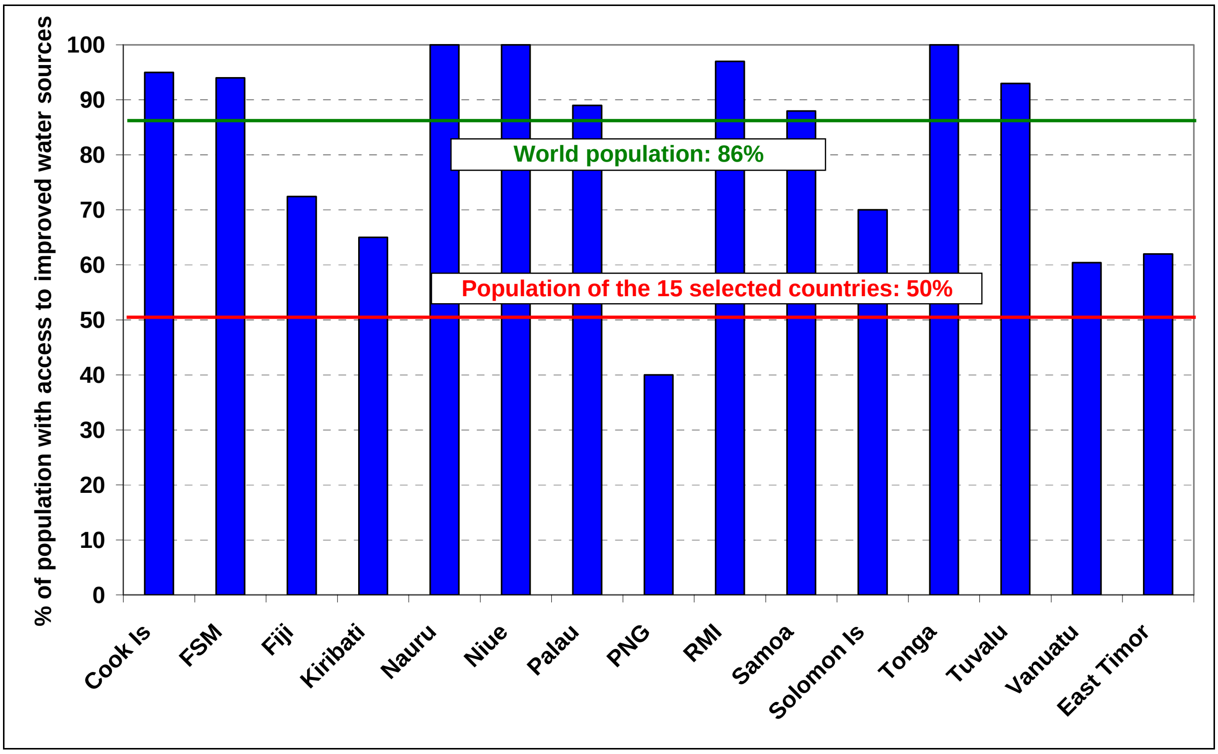


Figure 12 Percentages of populations with access to improved water sources

2.6.4 Implications of water supply and sanitation status on populations

Life expectancy is closely related to access to safe drinking water and basic sanitation (WHO & SOPAC, 2008). Using data from WHO (2009) for 2007, the life expectancy in the selected countries varied from 58 years (RMI) to 73 years (Cook Islands). The weighted average life expectancy taking account of populations in each country was 64 years, which is significantly lower than the average of 80 and 82 years for developed countries such as New Zealand and Australia (WHO & SOPAC, 2008).

The influence of drinking water, sanitation and hygiene on life expectancy is more prominent in the most vulnerable age groups, namely, children under five years and people over 60 years (WHO &

SOPAC, 2008). In the selected countries, the under-five mortality rate per 1,000 live births in 2007 (WHO, 2009) varied from 10 (Palau) to 97 (East Timor). The three highest under-five mortality rates in PICs were 63 (Kiribati), 65 (PNG) and 70 (Solomon Islands). The weighted average value for all 15 countries is 62 which is over ten times higher than the value of six for Australia and New Zealand.

Using global data as a reference for the 15 countries, the total number of deaths attributable to unsafe water, inadequate sanitation and insufficient hygiene is more than 20% of all deaths in children up to 14 years of age (Prüss-Üstün et al., 2008), and this number would be even higher for children under 5 years of age (WHO & SOPAC, 2008).

It is important to keep the human health aspects in mind when dealing with water resources and water supply systems, particularly in the 15 developing countries selected for this PASAP study. This aspect is further considered in section 3.5.2.

3. Current Water Security Issues

3.1 Main categories

This section provides an overview of current or "baseline" water security issues across the 15 countries. These water security issues are presented according to the following main categories:

- Current climate variability
- Geological hazards
- Human factors.

3.2 Current climate variability and impacts

3.2.1 Main features of current climate

The current climate and weather of the study region is largely influenced by three large-scale climatic features, El Niño and La Niña episodes and short-term tropical cyclones. The large-scale climatic features are the Intertropical Convergence Zone (ITCZ), South Pacific Convergence Zone (SPCZ) and West Pacific Monsoon (also called the East Asian Monsoon) which drive seasonal rainfall variations in many of the countries. The average positions of these features in the period November to April (wet and dry seasons, respectively, in the southern and northern hemispheres) are shown in Figure 13 (from PCCSP, 2010b). These features are caused by winds converging over warm ocean water and meet in the West Pacific Warm Pool.

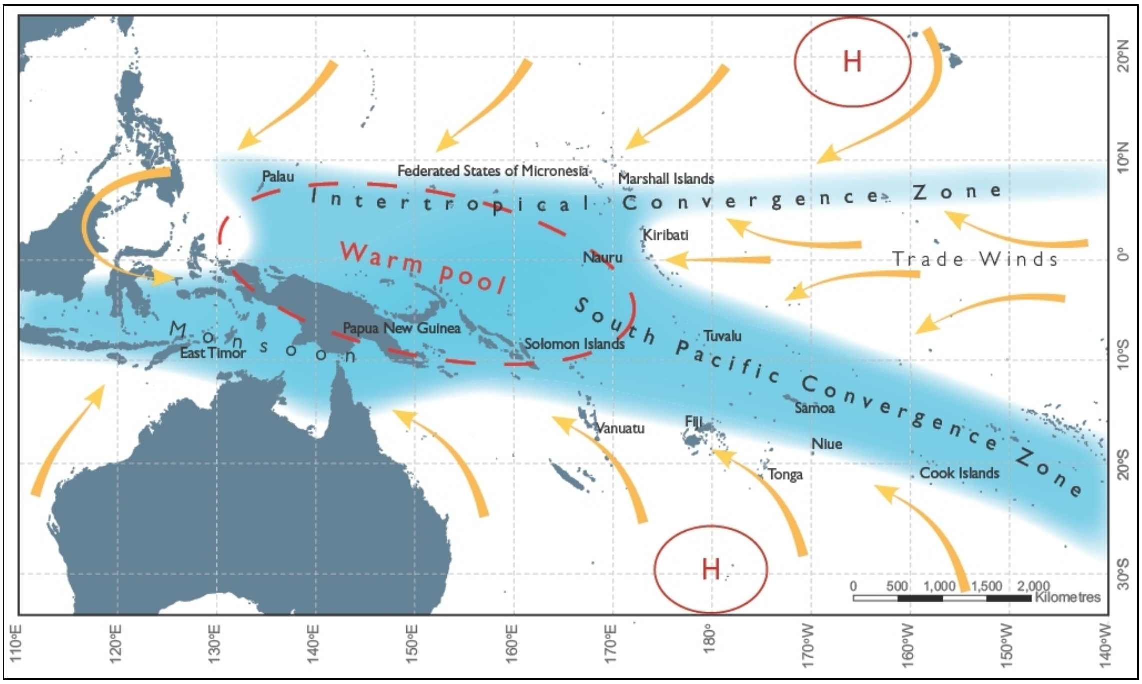


Figure 13 Map showing the average locations of main climatic features from November to April near the 15 countries (from PCCSP, 2010b)

The current climate, particularly rainfall, is highly variable both spatially and temporally across the study region. The spatial variability of annual rainfall over the region is shown in Figure 5 using two methods giving similar results. The data in Table 2 shows the large spatial and temporal variations in annual rainfalls between the 15 countries and within these countries. Spatial rainfall variations on high islands are generally due to orographic effects caused by uplifting of cloud masses over elevated terrain. On low islands, where topography does not influence rainfall patterns, rainfall still shows considerable spatial variation between islands. The islands of Kiribati are a good example, where all but one island are low-lying and where the mean annual rainfall varies from about 900 mm to 3,100 mm depending on island location.

As described in section 2.3, the temporal variability of rainfall in the 15 countries can be characterised by the coefficient of variation (Cv) of rainfall. The wide range of Cv's within the region is shown in Table 2.

3.2.2 Influence of ENSO

Inter-annual rainfall variability is due mainly to the effects of El Niño and La Niña episodes. These episodes, alternatively described as El Niño-Southern Oscillation (ENSO) events, occur at frequencies of approximately three to seven years. Figure 14 shows the average rainfall distribution over the Pacific Ocean and eastern Indian Ocean during El Niño and La Niña years (for the 12 month period from May through to April) for the period 1979-2008 (maps kindly supplied by ABoM). These show the major differences in average rainfall within the study region between El Niño and La Niña years. One significant feature is the major change in rainfall along the equator, near which Kiribati and Nauru are located.

El Niño episodes are responsible for droughts in most of the PICs and in East Timor, and cause heavy rainfall in the countries near the equator (i.e. Kiribati and Nauru) and some islands of other countries (e.g. southern FSM and northern Cook Islands) The opposite influences occur during La Niña episodes with major droughts being experienced in Kiribati and Nauru. Parts of other countries are also affected by La Niña droughts, for example Kapingamarangi atoll, the southernmost atoll in FSM (USAID, 2010) and the northern Cook Islands (Falkland, 2006).

Many PICs show a strong correlation with indices of ENSO activity including the Southern Oscillation Index (SOI) and the Niño Region 3.4 sea surface temperatures (SST) anomaly.

The major influence of ENSO events on Nauru's rainfall is shown, for example, in Figure 15. Annual rainfall has varied by a factor of more than 15 from 278 mm in 1950 (the year of a significant La Niña event) to 4,355 mm in 1954 (the year of a moderate El Niño event). The annual rainfall in Nauru is very closely correlated to the SOI (Figure 15) and the Niño Region 3.4 SST anomaly.

A similar close correlation between rainfall, the SOI and the Niño Region 3.4 SST anomaly is found for Kiribati (White and Falkland, 2010). Even in high rainfall islands such as Pohnpei, FSM, rainfall is closely correlated with ENSO events (Landers and Khosrowpanah, 2004).

There is a strong relationship between ENSO, particularly through its major impact on inter-annual rainfall, and surface water and groundwater resources. ENSO events have a significant impact on the frequency, severity and duration of droughts on high islands which can cause reduction and even depletion of streamflows and lowering and depletion of groundwater tables for perched aquifers leading to reductions or temporary cessations in spring flows. On low islands and the low-lying parts of high islands, droughts lead to contraction of the thickness, areal extent and hence volume of freshwater lenses and coastal aquifers. This causes normally fresh groundwater in some islands and parts of other islands to become brackish during and for some months after droughts.

van der Brug (1986) provides a detailed account of the severe impacts of the 1982-83 El Niño drought on rainfall, streamflows, groundwater and water supplies in several PICs within the study region (FSM, Palau and RMI) and others (Guam and the Commonwealth of the Northern Mariana Islands). The severe impacts of the major 1997-98 El Niño drought on streamflows, groundwater, water supplies and agriculture have been documented for a number of PICs including PNG and Solomon Islands (Barr, 1999), Fiji (Terry, 2002; Terry and Raj, 2002), Majuro atoll, RMI (Presley, 2005) and other countries including Cook Islands, Samoa and Tonga (Scott et al., 2003). A number of papers describe the impacts of the long 1998-2001 La Niña drought in Kiribati (e.g. White et al., 2007a, White and Falkland, 2010). In terms of total numbers of people affected, the drought of 1997-1998 affected over 70% of the PNG population at the time, or over three million people, with severe impacts on water, food, agriculture, education, health and other sectors (World Bank, 2009).

East Timor’s water resources are also significantly affected by droughts associated with El Niño episodes. These droughts impact significantly on streamflows and groundwater recharge with resulting impacts on available water resources for use in water supply and agriculture (Costin and Powell, 2006; Barnett et al., 2007; Wallace et al., 2010a).

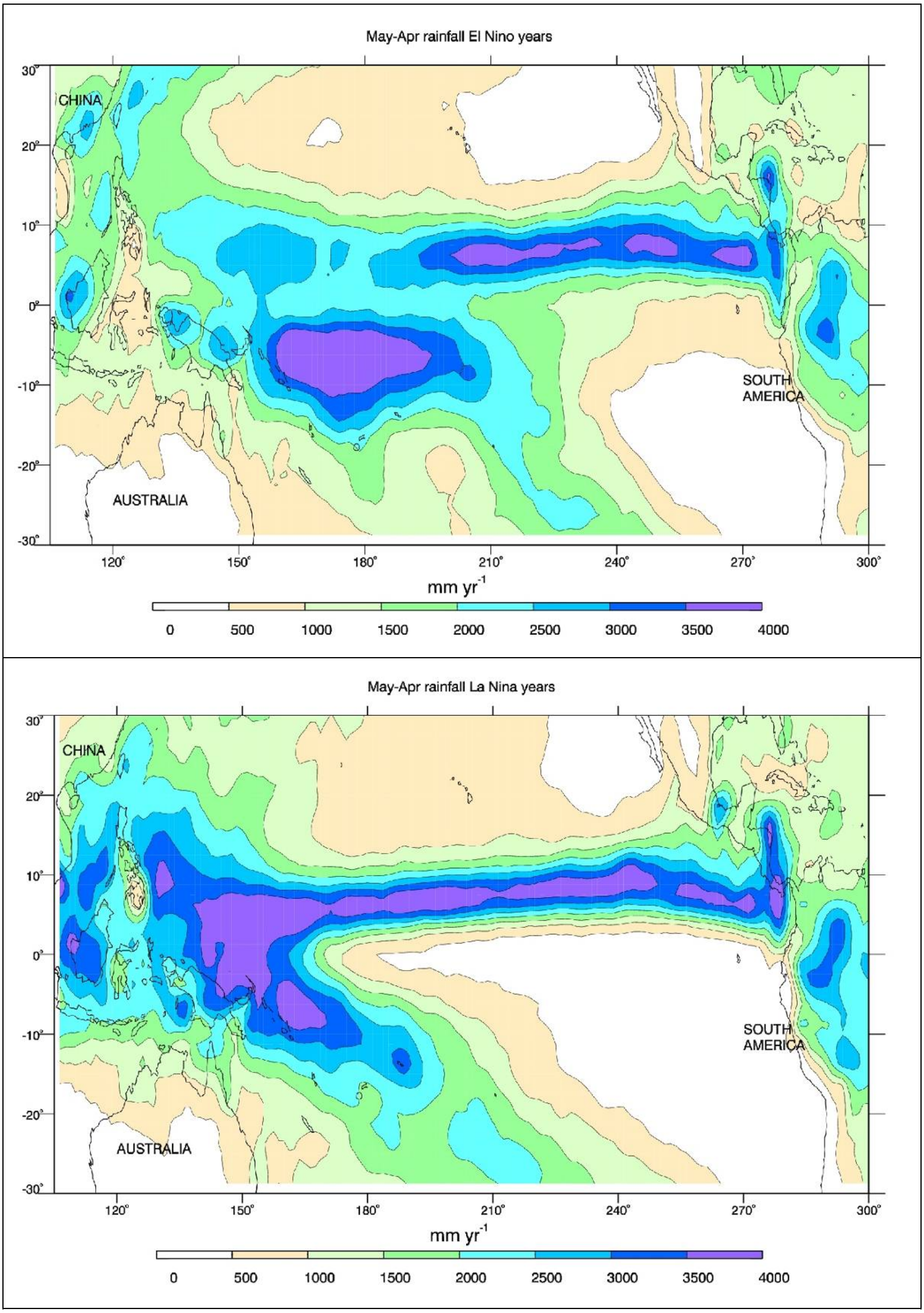


Figure 14 Rainfall distribution during El Niño (top) and La Niña episodes (bottom) for the periods December to February (left) and June to August (right)

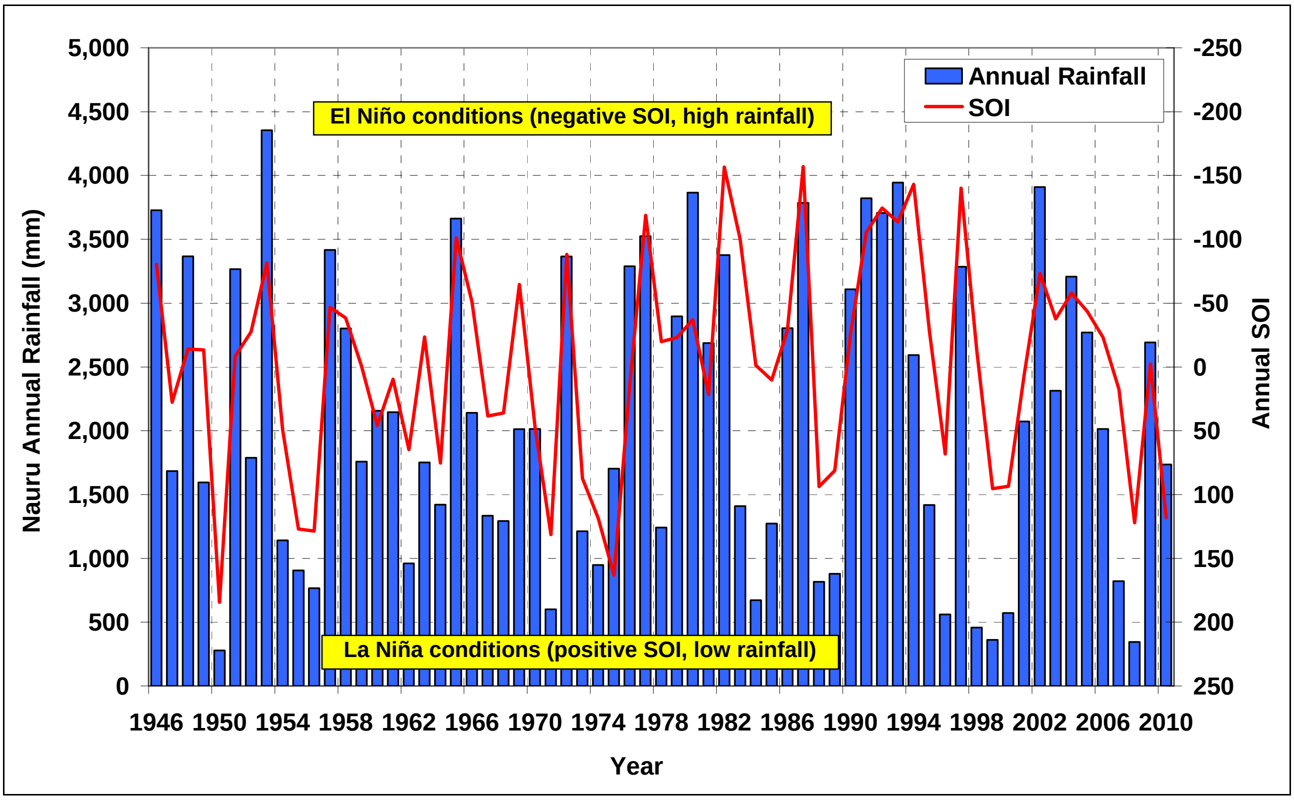


Figure 15 Annual rainfall for Nauru and annual SOI, 1946 - 2010

Droughts associated with El Niño episodes also significantly impact on electricity generation and costs in Viti Levu, Fiji. Low rainfalls cause low inflows into the Monosavu hydropower storage in the central mountains, lowering the storage level and reducing the hydropower output. As a result, the Fiji Electricity Authority has to rely heavily on diesel generators for electricity generation during drought periods at much greater cost (SOPAC, 2003).

High rainfall associated with La Niña episodes in most of the countries in the selected region (except Kiribati and Nauru) can result in high streamflows causing flooding and damage. It can also have the beneficial effect of increasing recharge to groundwater, resulting in replenishment of groundwater aquifers, raising of water tables and reductions in salinity for freshwater lenses and coastal aquifers.

3.2.3 Tropical storms

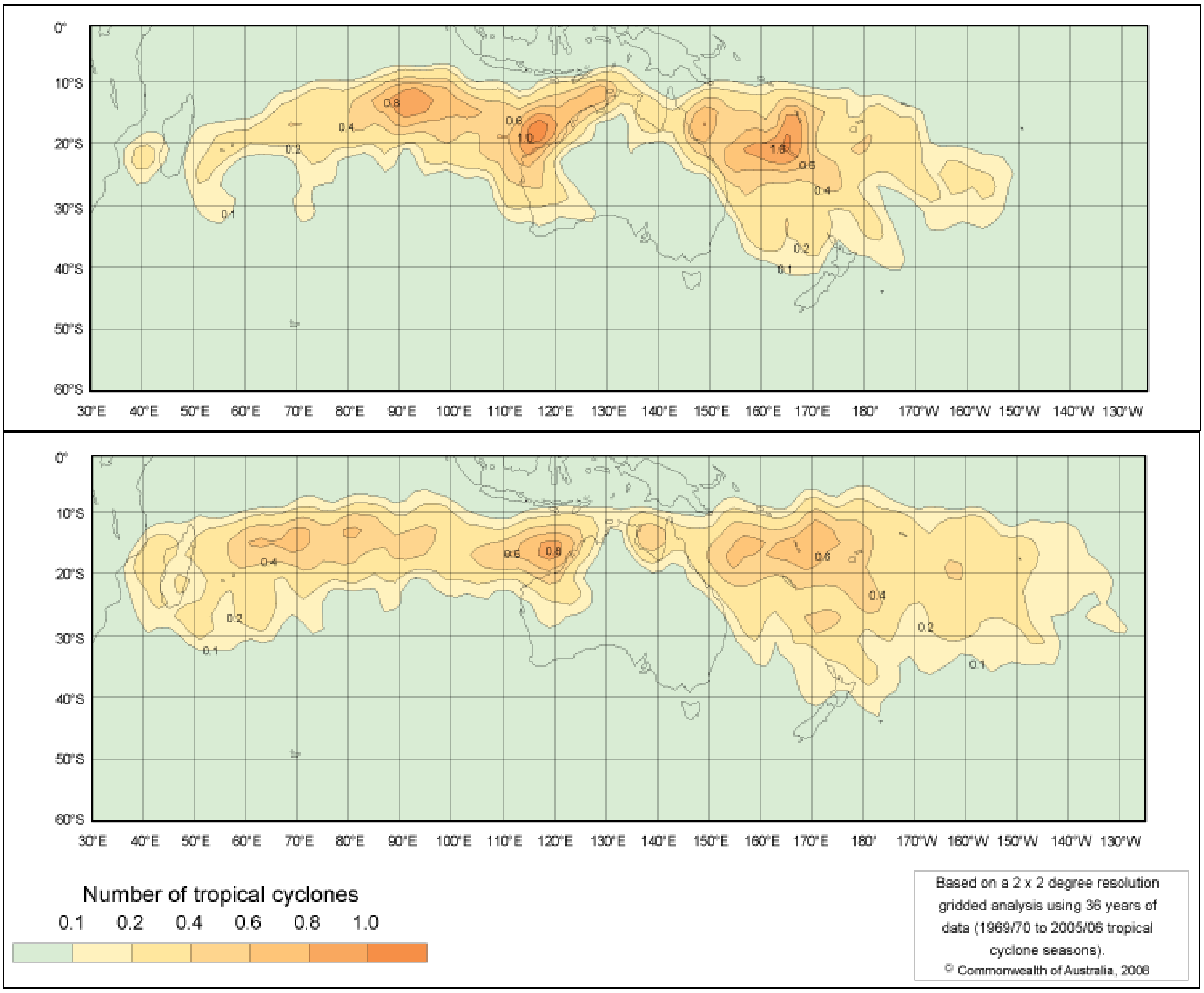
Large tropical storms on high islands are responsible for major floods in downstream areas. These have resulted in loss of life, destruction of houses and infrastructure, and damage to agricultural land.

For the five year period 1997-2002, flooding affected approximately half a million people in PNG and was the second worst natural disaster in terms of people affected after droughts (World Bank, 2009).

3.2.4 Tropical cyclones

Tropical cyclones (also called typhoons and hurricanes) are also a significant feature of the current climate of all of the countries within the study region except Kiribati and Nauru (which are in the equatorial zone not affected by cyclones).

The patterns of tropical cyclones differ between El Niño, La Niña and normal periods. Figure 16 shows maps of the average number of cyclones occurring in the Pacific and Indian Oceans in La Niña and El Niño years, using 36 years of data (1969-70 to 2005-06).



Based on a 2 x 2 degree resolution gridded analysis using 36 years of data (1969/70 to 2005/06 tropical cyclone seasons).
© Commonwealth of Australia, 2008

Figure 16 **Average number of tropical cyclones in La Niña years (top) and El Niño years (bottom) in Pacific and Indian Oceans (from ABoM, 2011)**

For La Niña periods, the western part of the Pacific, particularly near the Solomon Islands and Vanuatu, experience a higher risk of cyclone activity than in El Niño periods and compared with countries further east. During El Niño periods, countries in the central Pacific both north and south of the equatorial zone (including Cook Islands, Niue, RMI, Samoa and Tonga) have a significantly higher risk of cyclone activity when the sea surface temperatures in this area become much warmer (Terry, 2007; Spennemann and Marschner, 2000; USAID, 2009). For example, Spennemann and Marschner (2000) showed that over 70% of cyclones (typhoons) occur in the RMI in El Niño years.

Cyclones are a major problem for island communities, often causing severe wind damage, floods and hillside erosion with consequent downstream damage and sedimentation. The highest rainfall intensities and maximum daily rainfalls on small islands are normally associated with tropical cyclones and tropical depressions. Cyclones often cause major damage to infrastructure (including water supply infrastructure), agriculture and some cause loss of life. For instance, Cyclone Ofa (1990) and Cyclone Val (1991) caused major flooding and damage to water storage and reticulation networks near Apia, Samoa and consequent disruptions to the water supply system (Samoa Ministry of Finance, 2011). Forested areas within water supply catchments, which act to reduce floods, were also damaged and hydrological measurement infrastructure was destroyed.

Terry (2007) presents a detailed account of the occurrence and impacts of tropical cyclones in the South Pacific region. Major flooding from cyclones has occurred in a number of countries. Terry et al. (2004) and Terry (2007) describe the impacts of major flooding resulting from Cyclone Ami in 2003 on Vanua Levu, Fiji. Flooding was made worse by the simultaneous occurrence of peak discharges and a strong storm surge. It is noted that flooding is not just caused by tropical cyclones but also due to large tropical storms. Yeo et al. (2007) provide an account of 100 years of flooding on the Ba River in north-western Viti Levu, Fiji. They also show that major floods have occurred at times when the SOI was both negative and positive, suggesting that the SOI is not a good indicator of flood potential for that area.

Major landslides have been caused by torrential rainfall during tropical cyclones. In 2002, heavy rainfall associated with Typhoon Chata'an caused 250 landslides on several islands in Chuuk State, FSM with loss of life and destruction or damage to many buildings and infrastructure including water supply systems (Harp et al., 2004). Terry (2007) provides details of landslides triggered by intense rainfall due to cyclones in Fiji, Samoa and Solomon Islands which also have caused loss of life, destruction and damage.

Freshwater lenses on small low-lying islands can suffer due to partial inundation with seawater as a result of overtopping by waves generated by cyclonic storms. This has occurred on a number of atolls (e.g. in the northern Cook Islands, RMI and Tuvalu). Many months may be required to naturally "flush" the saltwater from freshwater lenses and restore wells to a potable condition. Saline intrusion into freshwater lenses resulted from waves and storm surge generated by Cyclone Percy in 2005. Based on measurements from groundwater monitoring boreholes, recovery occurred over 12 months as the more dense saline water moved downward through the freshwater lens (Terry and Falkland, 2010).

Severe storms generated by cyclones can also cause wind damage to houses and other buildings and severely impact on rainwater collection systems and even storage tanks. On Majuro atoll, the airport rainwater collection systems can be contaminated by sea spray (USAID, 2009) and by partial overtopping by waves. Coastal erosion processes caused by severe storms can modify and even reduce the land area overlying freshwater lenses.

3.2.5 Seasonal rainfall

Table 6 shows mean annual rainfalls and percentage rainfalls during dry and wet seasons for the capitals of each of the selected countries.

The mean dry and wet season percentage rainfalls were calculated using the lowest and highest six-month rainfalls, respectively. In most cases, the dry and wet seasons for locations south of the equator were from November to April and May to October, respectively, with the opposite applying to locations north of the equator. In some cases, the seasons were displaced one or two months other side of these periods.

Additional data is included in Table 6 for sub-regions of Cook Islands, FSM, Kiribati and RMI for which rainfall projections have been made, as explained in section 4.2.2.

Data is also shown for an additional location in Fiji and for approximate spatial average rainfalls over PNG and East Timor, as explained below.

For Fiji, results are shown for the capital, Suva, on the eastern and wetter side of the main island, Viti Levu, and for Nadi on the drier western side. Mean annual rainfalls at these locations are approximately 3,000 mm and 1,900 mm, respectively. The differences in rainfall across the island, as on many other high islands, are caused by the dominant south-east trade winds and the orographic influence of the interior highlands (Terry, 2002).

For PNG, results are shown for the capital, Port Moresby, on the dry south-eastern coast of the main island and for Kavieng at the western end of the island of New Ireland in the northern part of the country. Mean annual rainfalls at these locations are approximately 1,100 mm and 3,100 mm, respectively. The rainfall for Kavieng is close to the spatially averaged rainfall for the whole country from inspection of a mean annual rainfall map for the whole country (Stewart, 1993, Figure 3).

For East Timor, results are shown for the capital, Dili, on the dry northern coast, where the rainfall is about 900 mm, and for a spatially averaged rainfall over the country of about 1,800 mm, from inspection of a mean annual rainfall map for the whole country (Kirono, 2010, Figure 3).

Table 6 Mean annual and percentage seasonal rainfalls

Country	Location	Mean annual rainfall (mm)	Mean percentage rainfalls in dry / wet seasons
Cook Is	**Northern Islands** (Penrhyn)	2,200	40% / 60%
	Southern Islands (*Rarotonga*)	2,000	35% / 65%
FSM	**West** (Yap)	3,000	36% / 64%
	East (*Pohnpei*)	4,700	45% / 55%
Fiji	*Suva* (east side of Viti Levu)	3,000	37% / 63%
	Nadi (west side of Viti Levu)	1,900	23% / 77%
Kiribati	**Gilbert (western) Group** (*Tarawa*)	2,000	39% / 61%
	Phoenix (central) Group (Kanton)	1,000	43% / 57%
	Line (eastern) Group (Kiritimati)	1,000	34% / 66%
Nauru	*Yaren*	2,100	40% / 60%
Niue	*Alofi*	2,100	34% / 66%
Palau	*Melekeok*	3,700	41% / 59%
PNG	*Port Moresby*	1,100	20% / 80%
	Kavieng (approx. spatial average)	3,100	43% / 57%
RMI	**Northern Islands** (Kwajalein)	2,600	37% / 63%
	Southern Islands (*Majuro*)	3,300	43% / 57%
Samoa	*Apia*	2,900	30% / 70%
Solomon Is	*Honiara*	2,000	32% / 68%
Tonga	*Nuku'alofa*	1,700	38% / 62%
Tuvalu	*Funafuti*	3,500	42% / 58%
Vanuatu	*Port Vila*	2,100	33% / 67%
East Timor	*Dili*	900	20% / 80%
	Spatial average	1,800	20% / 80%

Notes: Sub-regions (refer section 4) are shown in bold, if applicable, and capitals of each country are shown in italics.

The data in Table 6 shows some countries have marked wet and dry seasons, particularly East Timor and some coastal parts of PNG. At both capitals (Dili, East Timor and Port Moresby, PNG), approximately 20% of the rainfalls falls in the dry season while 80% falls in the wet season. The distinct dry and wet seasons are also a feature of most of East Timor. For PNG, the rainfall away from the coastlines near Port Moresby and some other parts of PNG becomes less seasonal. For Kavieng, the mean dry and wet seasonal rainfalls are 43% and 57%, respectively.

The rainfall pattern has a large impact on the seasonal availability of water resources in East Timor with water stress and water shortages in the dry season, and surplus water resources in the wet season (Yance, 2004; Costin and Powell, 2006; Barnett, 2007; Kirono, 2010). There are many reports of springs drying up seasonally (Costin and Powell, 2006). In El Niño years, the January – March rainfall is lower in all parts of East Timor and the wet season is generally delayed by two to three months (Barnett et al., 2007). In the wet season, high rainfalls cause flooding with consequent damage to property and infrastructure. Flooding is exacerbated by forest clearing within many catchments (Costin and Powell, 2006).

The other countries in the selected region show mean dry and wet season percentage rainfalls varying from moderately seasonal values of 23% and 77% for the relatively dry climate of Nadi, Fiji to mildly seasonal values of 45% and 55% for the very wet climate of Pohnpei, eastern FSM. Most countries or sub-regions show mean dry season rainfall percentages in the range from 30% to

40%. It is noted that rainfall in some countries (e.g. Kiribati and Nauru) is dominated by ENSO activity and seasonal differences are of lesser importance.

The data in Table 6 is used later in section 4.2 to assess changes in dry and wet season rainfalls based on climate change projections.

3.2.6 Further information

Further information about climate and water resources of PICs is available in a number of publications including UNESCO (1991), Terry (1998), White et al. (1999); World Bank (2000), Burns (2002), Terry and Raj (2002); Carpenter et al. (2002), Scott (2002), Hay et al. (2003); Scott et al. (2003) and White et al. (2007a).

For East Timor, further information is contained in Yance (2004), Furness (2004), Costin and Powell (2006), Barnett et al. (2007); Kirono (2010), Wallace et al. (2010a; 2010b).

3.3 Non-climatic factors and their impacts

Non-climatic factors that impact on water security include geological hazards and various human factors. These factors are considered in the next two sub-sections.

3.4 Geological hazards and impacts

Geological hazards include volcanic eruptions and earthquakes with the resulting hazards of tsunamis and landslides.

Many of the 15 countries are subject to seismic activity. Some have active volcanoes including PNG, Tonga and Vanuatu while some other countries have dormant volcanoes. Explosive volcanic activity can produce a range of problems to water supplies including contamination from ash and catastrophic damage from volcanic blast (Scott et al., 2002). The volcanic eruption at Rabaul, the provincial capital of New Britain, PNG in 1994 resulted in thick ash deposits through the town and the destruction of infrastructure, including water supply infrastructure. This event led to the resettlement of the population requiring additional water supply development. Ash from volcanic eruptions has also a beneficial effect by providing good soils for agriculture, as on most volcanic islands. Volcanic ash from one or more past volcanic eruptions has also provided rich soil on many limestone islands in Tonga (Furness and Helu, 1993).

Earthquakes and tremors have been experienced in a number of the selected countries especially those near tectonic plate boundaries including Tonga, Samoa, Solomon Islands and Vanuatu. Damage to water supply systems has occurred due to cracking of pipes and rainwater tanks leading to the need for emergency water supplies in the short-term. For example, the Vanuatu earthquake in November 1999 (Higgins et al., 1999) caused damage to water supplies in a number of islands.

Destructive tsunamis have been generated from submarine earthquakes (e.g. Solomon Islands in 2007, Samoa in 2009) or submarine landslides generated by earthquakes (e.g. PNG in 1998). The 1998 Sissano Lagoon-Aitape tsunami on the north coast of the main island of PNG caused the loss of more than 1,600 lives, the destruction of villages including water supply facilities and the resettlement inland of 10,000 people (Ripper et al, 2001; Davies et al., 2001). The 2007 submarine earthquake and tsunami in the western Solomon Islands caused loss of life, destruction and damage to infrastructure including water supply infrastructure on a number of islands (IFRC, 2007). The tsunami resulting from a major submarine earthquake south of Samoa in 2009 caused destruction and loss of life in Samoa, nearby America Samoa and Tonga. In Samoa, 43 villages and associated water supply infrastructure were damaged or destroyed, leading to the resettlement of some coastal villages to higher areas and associated assessment and planning for the development and use of alternative water resources (UNICEF, 2009a; 2009b). Apart from damage to infrastructure, coastal inundation from tsunamis (and cyclone generated waves) can cause temporary salinisation and pollution of groundwater resources and the wells used to extract groundwater for many coastal villages.

Submarine landslides can also cause catastrophic changes to atolls with the loss of whole or parts of islands as have occurred in the past, for example, on the atolls in the northern Cook Islands (Hein et al., 1997).

3.5 Human factors and impacts

There are a wide range of human factors which can negatively impact on the security of water resources, water supplies and water infrastructure.

3.5.1 Increasing water demands due to high population growth

The largest water supply problems are found in relation to urban and peri-urban settlements on the fringes of the main centres, where population densities, growth rates and the increasing demands for water are highest. As shown in section 2.4, population densities exceed 10,000 people per km^2 in parts of South Tarawa and urban growth rates between 4.8% and 3.4% are found (in descending order) for East Timor (Dili), Solomon Islands (Honiara), Vanuatu (Port Vila) and Kiribati (South Tarawa).

Crowded urban and adjoining peri-urban areas with high population densities are placing large, increasing and, in some cases, non-sustainable demands on both limited land and water resources. This is particularly noticeable in the crowded urban and peri-urban areas of some atoll islands (e.g. South Tarawa on Tarawa atoll, Kiribati; and the densely populated Djarrit-Uliga-Delap (DUD) area of Majuro atoll and Ebeye island on Kwajalein atoll, RMI). In these and other urban centres, increasing populations are degrading water quality and putting increasing pressure on remaining areas designated for freshwater supply.

The problems of expanding urban and peri-urban settlements in PICs have been described in a number of reports including Carpenter and Jones (2004). Squatter settlements are increasing and causing housing and population densities to rise. Urban planning is generally well behind the expansion of peri-urban and squatter settlements within urban areas. Water supply infrastructure is often sparse, inadequate or non-existent in peri-urban areas and less than adequate in very high density urban areas.

In East Timor, peri-urban areas (or “informal” urban settlements) make up more than 75% of the households in Dili (Costin and Powell, 2006).

In crowded South Tarawa, where population densities exceed 10,000 people per km^2 (refer section 2.4), the situation regarding provision of water supply is dire. The current water supply based on existing groundwater development and household rainwater harvesting systems (typically using a 5,000 L tank) cannot match even existing demand at reasonable per capita demands let alone the needs of an ever-increasing future population (White, 2011a, 2011b). Even possible future groundwater development in currently rural parts of the atoll would not meet demands by 2030. Alternative water supply measures such as increased rainwater harvesting could be introduced. However, due to extensive droughts, this option is expensive as a primary source of water. The most likely long-term option is desalination.

Majuro atoll is another example of a serious water supply situation where the existing natural freshwater resources (surface water collected from the airport, groundwater from a small freshwater lens and rainwater catchments and storages) are not adequate to cope with demand during droughts (USAID, 2009). For this reason, desalination units have been installed in the past and are likely to be required as supplementary sources in the future.

Another example is Nauru where demand is often much greater than the very limited capacity of fresh groundwater resources and the limited rainwater harvesting capacity. Desalination is used as one of the primary sources of water, and the major source during droughts. The estimated island demand for potable water is also far greater than the current production capacity of the desalination (RO) plants (SOPAC, 2010; White, 2011c).

The water supply situation in many other urban and peri-urban areas is also under significant stress, especially during droughts. The public water supply system for Dili, East Timor is unable to meet demand and about half the population use shallow, often contaminated wells as a sole or supplementary source (Costin and Powell, 2006; GHD, 2007).

3.5.2 Pollution of water resources

Biological and chemical pollution and water quality degradation of surface water and groundwater resources has occurred through inadequate sanitation and waste disposal practices, especially in crowded urban and peri-urban areas.

Pollution of water resources and water quality degradation is one of the largest threats to water security in the selected countries. The relatively small size and steep slopes of surface water catchments on many high islands enable water and pollutants to move quickly to downstream areas and the coastal zone (including aquatic life, fish resources, inner reef lagoons, mangrove areas and coral reefs). Also, the highly permeable soils and shallow water tables on many small coral islands enable pollutants to easily migrate to fresh groundwater.

There are many examples of surface water and groundwater resources, and the water supplies based on these resources, which are suffering from contamination due to human and animal excreta (e.g. Vanuatu: Nath et al., 2006; Kiribati: White et al., 2007; Majuro, RMI: USAID, 2009, Nauru: SOPAC, 2010). Often inappropriate sanitation systems such as pit toilets and flush-toilets with septic tanks are installed in urban and rural communities on small low-lying coral islands where the soils are highly permeable and where groundwater is extracted from nearby wells. Limestone islands also offer little protection from groundwater contamination unless they are overlain by thick soil sequences. Pit toilets, which are normally dug to the water table, allow direct contamination of the underlying groundwater. Septic tanks are most often not well constructed and maintained allowing raw sewage to leak through poor joints, or overflows to occur due to blockages caused by lack of periodic de-sludging. The problem of poor sanitation is endemic in many of the countries in the study region.

Extensive deforestation on slopes on high islands leads to erosion and loss of soil, increases water turbidity, and exacerbates flooding problems which damages infrastructure and causes sedimentation of streams and the coastal environment. Examples of extensive land clearing with impacts on springflows, streamflows and water supply infrastructure are reported, respectively, for East Timor (Costin and Powell, 2006), Solomon Islands (Powell et al., 2006) and Upolu, Samoa (Samoa Ministry of Finance, 2011). The high turbidity in streams after heavy rain makes untreated water from these streams unusable for several days and leads to clogging of pipes and sedimentation in storage tanks.

Other inappropriate land use practices include raising of pigs and chickens, mining of gravel for sale, continued use of graveyards and growing crops on areas reserved for groundwater pumping on small coral islands (e.g. Tarawa: White, 2010 and Majuro: USAID, 2009) . Such actions make the already vulnerable groundwater resources at greater risk from increased pollution.

Further examples of the extent of pollution problems within the study region are contained in many reports including Falkland (2002a, 2002b), Scott et al. (2003), Costin and Powell (2006), White et al. (2007a) and White (2010).

Other pollution problems are:

- Pollution of groundwater from chemical sources including hydrocarbon contamination from power stations (e.g. Betio, Tarawa, Kiribati) and fuel and oil drums and containers, many of which are not properly bunded except at major fuel installations.
- Pollution of streams and rivers by industrial discharges and accidental spillages of toxic chemicals from mining sites (e.g. from some of the gold mining sites in PNG).
- Chemical contamination of surface water and groundwater resources, caused by inappropriate and uncontrolled use of agricultural chemicals (fertilisers, and toxic insecticides and pesticides).

The major issue of water pollution, particularly faecal pollution, in the Pacific region and the linkages with waterborne diseases and impacts on human health has been recognised for many years (e.g. Detay et al., 1989; Miller et al., 1991; Crennan and Berry, 2002; WHO & SOPAC, 2008; White, 2010, 2011a; SOPAC, 2010). Baisyet, (1994) stated that “the pollution of drinking water and the resulting health hazard may be one of the biggest watershed issues in island countries of the South Pacific.”

The incidence rate of diarrhoeal diseases in PICs is about four to five times higher than in developed countries such as Australia and New Zealand (WHO & SOPAC, 2008). The high incidence of diarrhoeal diseases (including dysentery, typhoid and cholera) is mainly caused by contaminated drinking water which is linked to poor sanitation and hygiene conditions. Outbreaks of cholera in PICs have been linked to contaminated water (e.g. Tarawa, Kiribati in 1977, and in FSM: Chuuk in 1982-83 and Pohnpei in 2000).

Diarrhoeal diseases are a significant cause of infant (under-five) mortality in PICs (approximately 10%: WHO & SOPAC, 2008) and East Timor (22%: WHO, 2006).

The incidence of diarrhoeal diseases in PICs has been found to vary with water availability and climate, with high incidences associated with low water availability and higher temperatures (Singh et al., 2001).

3.5.3 Over-pumping and salinisation of groundwater resources

Over-pumping of groundwater has led to seawater intrusion and increasing salinity (salinisation) of water supplies. The most vulnerable groundwater systems to over-pumping are freshwater lenses on small coral islands.

Examples of over-pumping include now disused groundwater boreholes near the coastline in parts of Weno Island, Chuuk State, FSM (Falkland, 2007). The Laura freshwater lens on Majuro atoll, RMI has shown signs of over-pumping from infiltration galleries (USAID, 2009). Major freshwater lenses on Tarawa atoll, Kiribati used for urban water supply are at risk of longer-term reduction or depletion due to pumping at higher than long-term sustainable rates (White, 2011a).

Problems have arisen due to the use of inappropriate technology and methods of groundwater extraction. For instance, in small coral islands the use of conventional boreholes for groundwater pumping can lead to greater seawater intrusion than the use of more appropriate infiltration galleries (refer Figure 11 and section 6.5.4).

3.5.4 Inadequate water supply infrastructure and high loss rates

Many water supply systems are old and dilapidated and suffer from poor maintenance over many years. Others have been partially upgraded and extended to cover new areas but leave parts of networks in urgent need of replacement. This problem is particularly prevalent in many urban water supply systems.

Symptoms of these problems include low pressure, intermittent supply, high leakage and poor water quality. As an example, over 50% of the Dili water supply system experiences high leakage, low or variable pressures and intermittent supply with water available between three and 16 hours per day (GHD, 2007). Complaints of no water and low pressure make up a significant proportion of consumer complaints. This often forces many households to obtain water from other sources including polluted wells and streams. There are other examples of these problems throughout the study region.

Rural villages in general have relatively stable populations with generally lesser problems with water supplies than in urban areas. However, many villages have very basic water supply systems which are prone to pollution due to unprotected sources (streams, springs and wells). Rural water supply and sanitation programmes in some of the more populated countries (e.g. PNG, Solomon Islands and Vanuatu), are gradually improving these systems.

Leakage from water supply pipelines and other losses including illegal connections and uncontrolled overflows at community or household tanks ("non revenue water") in urban centres and larger rural villages are a major issue (e.g. SOPAC, 1999). Losses equal to or greater than 50% have been measured or estimated in a number of urban water supply systems including Nuku'alofa, Tonga (TWB, 2010), Koror-Airai, Palau (Gerber, 2010), Majuro, RMI (SOPAC, 2007a), South Tarawa, Kiribati (White, 2011b) and Honiara, Solomon Islands (PRIF, 2010). In Dili, East Timor, the losses have been estimated at over 85% (GHD, 2007).

Increased groundwater pumping or surface water diversions are required to cater for such losses adding to total operating costs. In many cases, water shortages during both normal climate periods and droughts could be significantly reduced if regular and systematic leakage control and other demand management measures (e.g. education and awareness) were implemented. In addition, infrastructure costs to develop new sources to supply future demands could be delayed.

Leakages in pipe networks are normally due to a combination of poor joints (e.g. PVC pipes that have been heated to form sockets, a common practice in some islands), or where joints are not properly prepared before solvent cement is used. Other problems occur with deteriorated joints (e.g. perished rubber rings) or broken, cracked or split pipes (due to earth movements or washaways after floods, or piercing due to poor backfill and insufficient cover above pipes). Corrosion of steel pipes is an additional problem. The use of pipes and other materials with different specifications is an additional source of leakages.

By-passing of water meters by consumers and non-collection of revenue by water supply authorities occurs in some water supply systems where meters are installed, for example South Tarawa, Kiribati (White, 2011b) and Dili, East Timor (GHD, 2008).

Major causes of the problems above are inadequate capital investment in water supply systems and inadequate operation and maintenance budgets within water supply authorities or rural communities to properly manage water supply systems.

3.5.5 Damage to water infrastructure

Vandalism causing destruction of water supply facilities occurs in some countries due to land disputes on customary or privately owned land. This includes vandalism of water intakes and pipelines (e.g. Solomon Islands: Powell et al., 2006) and groundwater pumping stations and monitoring boreholes (e.g. Tarawa, Kiribati: White et al., 1999; Chuuk State, FSM: Falkland, 2007). Theft of water supply items, for example, brass water meters and stainless steel cabinets (valuable and saleable metals) is a problem in some countries.

Failure to properly maintain infrastructure and implement remedial measures can lead to the loss of water supply due to vandalism. An example of this occurred in Tarawa when a road bridge between two islands failed in June 2008 causing breakage of a water supply pipeline and loss of water supply from a number of groundwater supply pumping stations (approximately a quarter of the total groundwater supply). Subsequent delays led to vandalism of water supply infrastructure and the need for expensive rehabilitation works. This problem led to less water being available than normal in the public water supply system during the recent La Niña drought in Tarawa.

3.5.6 Water governance and management factors

There are many factors associated with poor water governance and management that impact negatively on, and increase risks to, water security. Many are related to “human inactivity” (Scott et al., 2003). Prime examples of these factors are:

- Constraints on effective water management due to inadequate water governance. Problems include lack of water policy and plans, water legislation and ineffective coordination and administration of water sector agencies. Water governance is considered further in section 6.5.1.
- Insufficient knowledge of national water resources due to inadequate effort and resources being applied to water resources assessment, monitoring, analysis and reporting to government and dissemination to the wider community. Many of the countries in the study region have benefitted from short-term, project-based water resources assessment projects over many years. On a broad scale, water resources including surface and groundwater are reasonably well described in some countries. Few, however, have a comprehensive and detailed knowledge of their water resources and, in particular, how they respond to current climate variability. Knowledge of water resources tends to be best in areas close to large settlements, agriculture production areas and other activities but there are many rural areas and outer islands where the knowledge of water resources is limited.
- Roles and responsibilities of agencies involved in water matters are sometimes unclear, fragmented and un-coordinated. For example, in some of the smaller island countries, there is, or has been until recently, a lack of a clear distinction between the agency or agencies involved in the provision of water supply and the regulation and protection of water resources.

- Ineffective or no water source protection measures implemented to ensure that important and vulnerable water resources are not contaminated from human settlements and activities.
- Inequitable distribution of available water between urban, peri-urban and nearby rural communities. This is a common problem in many PICs. In East Timor, upstream users of water for agriculture have access to a disproportionate share of water resources with detrimental impacts on downstream uses including agriculture, industry and households (Costin and Powell, 2006).
- Human and financial resource capacity limitations preventing even essential water resources assessment and monitoring from being conducted. Monitoring is often left to the vagaries of intermittent external funding for development projects. In many countries, such activities are not seen as a priority and water agencies are often very under-resourced.
- Insufficient professional and technical water resources and water supply personnel to conduct routine operations. Water improvement projects are generally beyond the financial and human resource capacity of local agencies to plan and implement and external development aid is required. Externally organised and funded projects place large additional burdens on local staff, especially where multiple projects are running concurrently. For local staff, there is often limited time available for routine tasks owing to the large amount of time and effort required to supply consultants with information as well as attendance at a large number of project-related meetings and workshops.
- Insufficient training, education and ongoing development of water sector personnel. This is a major constraint to effective water management and risk to water security. In some cases, personnel with limited knowledge and experience are required to make major decisions about water planning and management leading to less than optimal solutions. Errors and other deficiencies with the collection and presentation of monitoring data have occurred leading to incorrect management decisions.
- Loss of trained staff from water and sanitation agencies. There are a number of factors which cause this. Often personnel are encouraged by externally funded projects to be seconded from regular positions. Flow-on effects include personnel leaving the country to take up more lucrative positions elsewhere. Also, a disproportionate amount of external project funding is often channelled into the environmental agencies, when compared with water and sanitation agencies. This has led to the internal migration of staff away from under-funded and under-resourced water agencies.

3.5.7 Insufficient community involvement

In many countries there is a lack of, or only limited, community participation in freshwater management, conservation and protection. A case study of problems arising from limited community participation in relation to protection of groundwater reserves is provided in White et al. (1999; 2008). There are many other examples of water catchment management problems arising from lack of community participation in PICs (e.g. Falkland, 2002a) and East Timor (Costin and Powell, 2006; Powell et al., 2006).

Damage to infrastructure and monitoring equipment can occur due to lack of participation of land owners in decisions about the siting of water supply infrastructure.

While there are project-related efforts at community education and awareness programmes about the need for responsible water use, conservation and protection of water sources and water supply infrastructure, there is a lack of ongoing commitment. Storey and Hunter (2010) mention that to effectively achieve community awareness, longer-term programmes are required to allow sufficient time to build trust and achieve behavioural change.

3.6 Summary

It is fair to conclude that the problems currently experienced in some of the countries within the study region, particularly in urban and peri-urban areas, with regard to high and increasing populations and population densities, increasing demands for water, inadequate water supply, sanitation and solid waste disposal are of greater concern than the likely impacts of climate change in the foreseeable future. This has been stated previously (e.g. Wyrtki, 1990) and more recently in a water master plan for Tarawa, Kiribati, where White (2011a, 2011b) states that “the main threat to providing adequate supplies of safe freshwater in South Tarawa…is the growing population there, not climate change” and that “the greatest and most immediate threat to the availability and safety of water supplies in South Tarawa is its growing population.” The problems of rising population, inadequate natural water resources, and water quality degradation due to crowded settlements on South Tarawa are some of the most severe in the study region. At the same time, it is recognised that the current problems will be exacerbated by any adverse climate change impacts. Storey and Hunter (2010) stress the need for approaches which concurrently strengthen the resilience of communities to future climate change impacts and the current impacts from urbanisation and pollution.

Risks posed to water security from both non-climate and climate related factors are further considered in section 5.8.

4. Climate Change Projections

4.1 Outline

This section has been added to the list of requirements in the Scope of Services (Annex A) to identify the likely magnitude of changes to climate parameters of importance to water resources using available climate change projections.

Where possible, climate change projections have been based on information recently supplied to PASAP under the Pacific Climate Change Science Program (PCCSP). PCCSP is presently being conducted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Bureau of Meteorology (ABoM) and funded by the Australian Government. These projections are considered in section 4.2.

Climate change projections made in other reports are also briefly reviewed for selected countries (refer section 4.3), especially for climate change parameters not currently available from PCCSP documents supplied to PASAP.

It is noted that all climate change projections in this report are based on global climate models (GCMs) which have relatively large spatial scales or grid-cell resolutions (typically 100 km to 500 km and approximately 280 km for the PCCSP climate projections). These GCMs lack definition at the scale of the small countries and individual islands in the study region. Even proposed regional scale climate models, with typical grid-cell resolutions of 60 km, lack sufficient detail to account for local climate processes at the scale of most islands.

The term “GCM” is used in this report for simplicity rather than the often-used term “AOGCM” (for atmosphere-ocean coupled general circulation model).

4.2 PCCSP climate change projections

4.2.1 Summary

The PCCSP has recently provided **interim projections** to PASAP based on selected output from 18 global climate models (GCM’s) for a number of climatic and ocean parameters for the 15 countries (PCCSP; 2011a, 2011b). These interim projections, which are subject to change, are consistent with the “First Order Draft” of PCCSP (2011c). This draft report was not made available for the current study.

The PCCSP interim projections (refer section 4.2) are for the 20-year period centred on the year 2030 (i.e. the period 2020-2039) for each of the 15 countries. Changes are relative to a baseline 20-year period centred on 1990 (i.e. 1980-1999). The spatial scale (grid-cell resolution) for the PCCSP projections is 2.5° of latitude x 2.5° of longitude (approximately 280 km x 280 km at the equator) to standardise the results from various GCMs at different spatial scales.

It is noted that the interim projections supplied by PCCSP to PASAP do not include those for two later periods centred on the years 2055 (i.e. 2045-2064) and 2090 (i.e. 2080-2099). Only the period to 2030 was selected by DCCEE for PASAP so as to focus on a planning horizon within the next 20 years (Martin Sharp, pers. comm., June 2011).

For reasons of simplicity, this report will use “2030” to refer to the longer terms “the period 2020-2039” or “the 20-year period centred on the year 2030”. Similarly, “2055” and “2090” are used rather than the equivalent longer terms.

Interim projections to 2030 and associated comments made in PCCSP (2011a; 2011b) for a number of climatic and ocean parameters are summarised below. PCCSP (2011a) stresses the need for care in using the interim projections due to a number of uncertainties and mentions the need to consider the spread of projections from the various models and not just the average of the projections.

- **Mean monthly rainfall and air temperature**: Mean monthly rainfall and air temperature projections were made in PCCSP (2011b) for each country (including three sub-regions for

Kiribati and two sub-regions for each of Cook Islands, FSM and RMI). These projections are based on the A2 emission scenario of the Special Report on Emission Scenarios, SRES (IPCC, 2000) for 2030. For each country and sub-region, the outputs from two climate models were selected from 18 GCM's. The two climate model outputs were selected to represent, respectively, the "most likely" and "largest change" future climate conditions. The most relevant models were different for the two future climate conditions and, in most cases, different between countries. The results show that the future climate would be wetter in most countries and warmer in all countries.

- **Rainfall intensity**: PCCSP (2011b) provides monthly projections of changes in rainfall intensity or "heavy rain" (in mm and %) for each country and sub-region. The change in "heavy rain" is defined as the mean monthly change in the 99th percentile of daily rainfall intensity. As for mean monthly rainfall, the "most likely" and "largest change" future climate conditions are considered, with the proviso that model selection was based on availability of daily rainfall data.

- **ENSO**: PCCSP (2011a) recommends the assumption of no change in climate variability associated with ENSO. This is due to the lack of consensus in projections from the different GCMs.

- **Tropical cyclones**: Interim projections were not available from PCCSP (2011a) at the time of preparing this report. It was stated that it is "difficult to use GCMs to make robust regional projections for tropical cyclone activity under climate change (WMO, 2006; Knutson et al., 2010). The available model projections suggest that the PCCSP [study] region may experience a decrease in cyclone numbers by the end of the 21st century ranging from 10 to 50%, with the possibility that the proportion of cyclones with higher intensities will increase. However, some of the CMIP3 [Coupled Model Intercomparison Project models] show the opposite result."

- **Mean sea level (MSL)**: Projected global MSL rises to 2100 relative to 1990 for four emission scenarios (A1F1, A2, A1B and B1) are provided in PCCSP (2011a) from CSIRO (2011). It is noted in PCCSP (2011a) that projected regional variations in MSL rise are not spatially uniform. Spatial standard deviations relative to the global average are provided from the average of 13 CMIP3 models assuming the A1B (medium) emission scenario for the 20-year periods centred on 2030, 2055 and 2090. Three maps are provided showing the projected regional sea level changes relative to the global mean values.

- **Ocean acidification**: PCCSP (2011a) estimates minimum and maximum periods from the present for the aragonite saturation state (Ωar) to fall below a value of 3.5 which is considered to be marginal for maintaining healthy reef ecosystems. Ωar values were projected using A1B and A2 emission scenarios and 11 GCMs. It is noted that the aragonite saturation state is one of a number of potential stressors on reef ecosystems under climate change, another being ocean temperature. Within the study region, the projections indicate the central Pacific area will experience marginal growing conditions in the period 2010-2025. The islands in the southern Pacific near Samoa are projected to be the last area to be affected. The whole study region is projected to be exposed to seawater with Ωar values below 3.5 within 50 years.

- **Sea surface temperature (SST)**: Coloured maps in PCCSP (2011a) show the mean SST change by 2030 and 2090 relative to 1990 from a (non-stated) number of GCMs using the A2 emission scenario. The results indicate maximum warming (0.8ºC by 2030) will occur in the central equatorial Pacific and the least warming (0.3ºC by 2030) will occur in the south-eastern Pacific Ocean. Within the study region, the range of SST changes are approximately 0.6ºC to 0.8ºC by 2030.

Regarding current availability of PCCSP projections for use in this report, the following comments are made:

- The latest PCCSP projections (in the "Second Order Draft") are not currently available to PASAP.

- Potential evaporation projections for each country have been made but were not available to PASAP at the time of preparing this report.
- The latest MSL projections are also not available and the information that has been supplied in PCCSP (2011a) does not readily enable country by country MSL changes to be deduced.
- Where considered appropriate, other sources of information have therefore been used in this report.

Parameters of most relevance for this report are the magnitude and variability of rainfall as these are the main influences on the availability and sustainability of water resources.

From the parameters listed above, mean monthly rainfall is of most importance and is considered in more detail in section 4.2.2 (using the PCCSP projections).

In the study region, the main cause of variability is ENSO activity. Inconsistent projections from the GCMs regarding ENSO activity result in no guidance on future rainfall variability associated with ENSO activity beyond current variability.

Other parameters listed above which have some direct influence on water resources or water demand are rainfall intensity, mean air temperature and mean sea level rise. These are considered in sections 4.2.4, 4.2.5 and 4.2.7, respectively.

Evaporation is also an important component of the water balance and of significance to water resources availability. Evaporation is dependent on many factors including solar radiation (or cloudiness), temperature, humidity, wind speed and carbon dioxide levels. The primary climatic influence is solar radiation which is not included in the listed of parameters supplied to PASAP in PCCSP (2011a; 2011b).

While evaporation projections at country scale from PCCSP are not yet available to PASAP, preliminary estimates for the whole study region were provided (refer section 4.2.6). In addition, other sources of information regarding evaporation projections are considered (refer section 4.3.3).

The other parameters listed above are tropical cyclones, sea surface temperature and ocean acidification. These three parameters are not considered further regarding potential impacts on water resources, except for the following brief comments.

- While tropical cyclones have a large impact on short-term rainfall and devastating effects on infrastructure, agriculture and people's lives and livelihoods, no interim projections are available from PCCSP and other available information is not sufficiently detailed to be useful for assessment of impacts on water resources by 2030. Also, it is noted that the impacts of tropical cyclones on heavy rainfall has already been accounted for within the projections regarding rainfall intensity.
- Inter-annual changes in SST already impact on current climate and its variability within the study region, particularly through impacts on ENSO activity (refer section 3.2.2). Projected increases in SSTs will impact on rainfall (especially through possible changes to ENSO events), temperature and other climate parameters, and thermal expansion of the ocean causing sea level rise. In terms of water resources, the impacts from SST are accounted for in the projections provided for rainfall, temperature and mean sea level rise.
- Ocean acidification has no direct impact on water resources but may have an impact on coral reefs and, in turn, on the integrity of coral sand islands and coastlines in larger islands. These impacts in turn may affect water resources in the longer term, but are unlikely to be of significance by 2030.

4.2.2 Projected mean rainfall changes

(a) Mean rainfall conditions and annual changes

PCCSP (2011a; 2011b) presents "most likely" and "largest change" projected mean rainfall conditions for 2030 for each of the selected countries and sub-regions. The projected mean rainfall conditions and changes in mean annual rainfall (in depth units, mm) are summarised in Table 7.

Table 7 Summary of projected mean rainfall conditions and changes for 2030

Country	**Region (if applicable)**	**Rainfall projections**		**Change in mean annual rainfall (mm) for 2020-2039**	
		Most likely	**Largest change**	**Most likely**	**Largest change**
Cook Is	Northern Islands	Little change	Much wetter	72	169
	Southern Islands	Little change	Wetter	25	43
FSM	West	Little change	Much wetter	80	160
	East	Little change	Wetter	190	72
Fiji		Little change	Drier	8	-106
Kiribati	Gilbert Group (west)	Much wetter	Much wetter	205	467
	Phoenix Group (centre)	Much wetter	Much wetter	181	370
	Line Group (east)	Much wetter	Much wetter	177	195
Nauru		Much wetter	Much wetter	216	494
Niue		Little change	Drier	30	-81
Palau		Little change	Wetter	36	252
PNG		Wetter	Much wetter	162	137
RMI	Northern Islands	Little change	Much wetter	36	110
	Southern Islands	Little change	Much wetter	85	321
Samoa		Little change	Wetter	69	116
Solomon Is		Little change	Wetter	67	71
Tonga		Little change	Drier	-22	-101
Tuvalu		Little change	Wetter	100	118
Vanuatu		Little change	Drier	-15	-84
East Timor		Little change	Drier	-22	-172

The following observations are made from the summary in Table 7.

- For the “most likely” future condition, 12 countries show little change in rainfall. Three of these countries (Tonga, Vanuatu and East Timor) show a slight reduction while all others show an increase. Three countries show either much wetter conditions (Kiribati and Nauru) or wetter conditions (PNG).
- For the “largest change” future condition, ten countries show either a wetter or much wetter climate while the other five countries (Fiji, Niue, Tonga, Vanuatu and East Timor) show a drier climate. These latter five countries all show little change in rainfall for the ““most likely” future condition.
- For Kiribati and Nauru, a much wetter climate is shown for both the “most likely” and “largest change” conditions. Other countries show changes in future rainfall between the two conditions.
- It is noted that some of the classifications made in PCCSP (2011a) may need alteration for consistency in the numerical results. For instance, FSM East and possibly PNG could be classified as “much wetter” for the “most likely” condition given that the projected annual rainfall increases are 190 mm and 162 mm, respectively. Also, Palau for the “largest change” condition with a projected rainfall increase of 252 mm should be classified as “much wetter”.

Using the numerical values for projected rainfall changes in Table 7, the present mean annual rainfall (from Table 6) is compared with the projected mean annual rainfalls for both “most likely” and “largest change” conditions in Figure 17. The present and projected rainfalls are based on the mean annual rainfall for the capitals of each country and additional locations in sub-regions of some countries as shown in Table 6.

For those countries shown in Table 7 with sub-regions away from the capital, mean annual rainfall from representative rainfall stations in the sub-regions were used. These rainfall stations were Penrhyn for the northern Cook Islands, Yap for eastern FSM, Kanton for central Kiribati, Kiritimati for eastern Kiribati and Kwajalein for northern RMI. Additional rainfall data is shown for Fiji (capital Suva and Nadi), PNG (capital Port Moresby and Kavieng, as an approximate spatial average for the country) and East Timor (capital Dili and a spatial average for the country), as described in section 3.2.5.

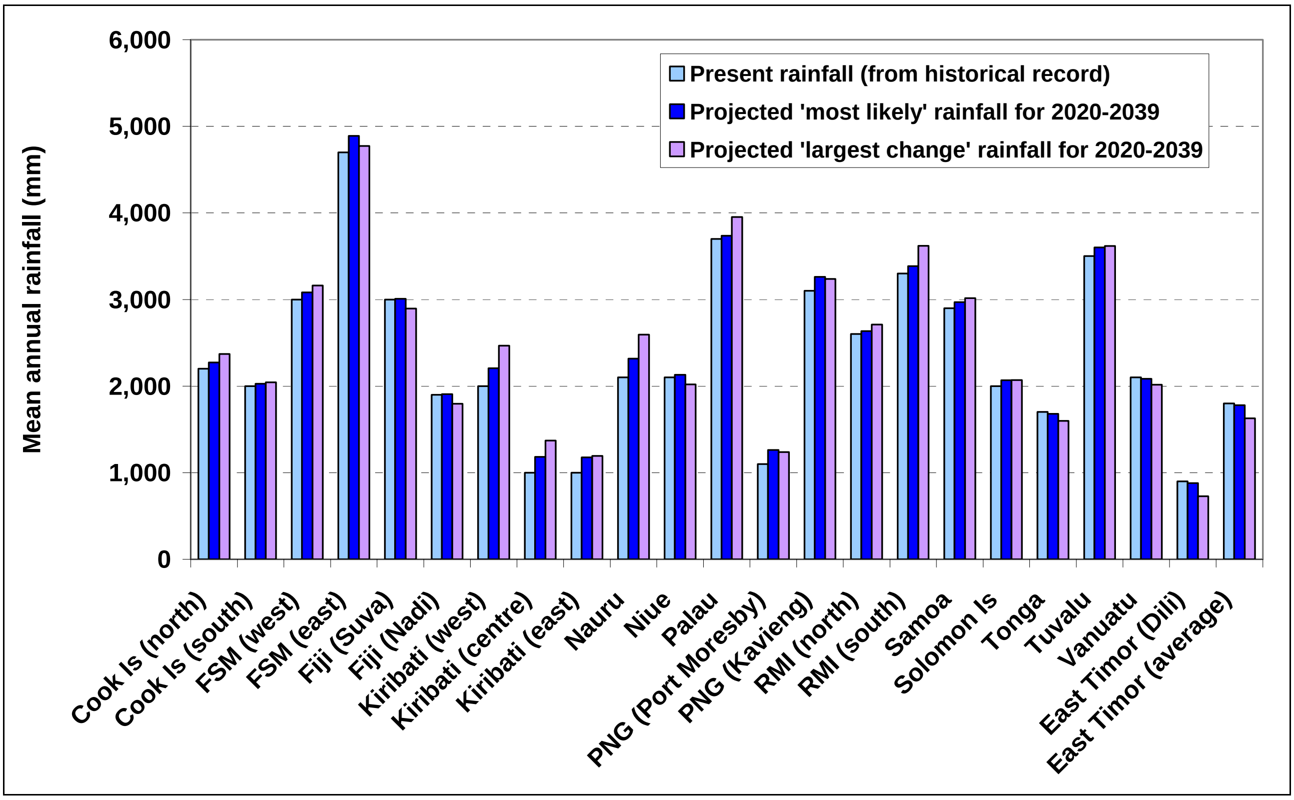


Figure 17 **Mean annual rainfall for present and projected conditions for the selected countries, sub-regions and other locations**

Figure 17 shows that the mean annual rainfall changes between present and projected conditions are relatively small.

If only the "most likely" projected rainfall conditions are considered, the climate by 2030 is anticipated to be similar or wetter to present conditions in the 15 countries. This is encouraging in terms of water resources. However, if the "largest change" projected rainfall conditions are also considered, then the countries of most interest from a water resources perspective are the five which are projected to have drier conditions (i.e. Fiji, Niue, Tonga, Vanuatu and East Timor).

Table 8 shows the projected changes in mean annual rainfall expressed as percentages of present mean rainfall at capitals and other locations shown in Table 6. This approach is not strictly correct as the projected rainfall changes apply to the spatially-averaged rainfall across all grid cells within the maritime boundaries of each country. These spatially-averaged rainfall values were not readily accessible from PCCSP. However, the values give a reasonable estimate of relative changes between the five countries.

The following observations are made about the results in Table 8:

(a) Annual changes

- The three countries with projected rainfall reductions under the "most likely" condition show very small percentage rainfall reductions. The greatest reduction was 2% for Dili, East Timor.

- Four of the five countries with projected rainfall reductions under the “largest change” condition show moderate reductions (4% to 6%). Dili, East Timor shows the largest reduction of 19%. Using the spatially averaged rainfall over East Timor, the percentage rainfall reduction is approximately 10%.
- The largest percentage increases in rainfall were for Kiribati and Nauru under both the “most likely” and “largest change” conditions.

Table 8 Projected percentage changes in mean annual rainfall for 2030

Country	**Location**	**Change in mean annual rainfall (%)**	
		Most likely	**Largest change**
Cook Is	**Northern Islands** (Penrhyn)	3%	8%
	Southern Islands (*Rarotonga*)	1%	2%
FSM	**West** (Yap)	3%	5%
	East (*Pohnpei*)	4%	2%
Fiji	*Suva* (east side of Viti Levu)	<1%	-4%
	Nadi (west side of Viti Levu)	<1%	-6%
Kiribati	**Gilbert (western) Group** (*Tarawa*)	10%	23%
	Phoenix (central) Group (Kanton)	18%	37%
	Line (eastern) Group (Kiritimati)	18%	19%
Nauru	*Yaren*	10%	23%
Niue	*Alofi*	1%	-4%
Palau	*Melekeok*	1%	7%
PNG	*Port Moresby*	15%	12%
	Kavieng (approx. spatial average)	5%	4%
RMI	**Northern Islands** (Kwajalein)	1%	4%
	Southern Islands (*Majuro*)	3%	10%
Samoa	*Apia*	2%	4%
Solomon Is	*Honiara*	3%	4%
Tonga	*Nuku'alofa*	-1%	-6%
Tuvalu	*Funafuti*	3%	3%
Vanuatu	*Port Vila*	-<1%	-4%
East Timor	*Dili*	-2%	-19%
	Spatial average	-1%	-10%

Notes: Sub-regions (refer section 4) are shown in bold, if applicable, and capitals of each country are shown in italics. Results are shown to the nearest percentage or as <1% when the value was less than 1%. Reductions in percentage rainfall are shaded in yellow and orange for “most likely” condition and “largest change” condition, respectively.

(b) Monthly changes

Projected mean monthly rainfall changes are summarised from PCCSP (2011b) for all countries and sub-regions and the “most likely” and “largest change” conditions in Table B1, Annex B. Following is a summary of the projected monthly rainfall changes:

- For the “most likely” projected rainfall condition, all countries show at least one month with a reduction in rainfall except for FSM (eastern sub-region), Kiribati (all three sub-regions) and Nauru. Countries or sub-regions showing three or less months with small monthly reductions (arbitrarily taken as 5 mm) were northern Cook Island (northern sub-region), Palau, PNG, RMI (both sub-regions), Solomon Islands and Tuvalu. Tonga and East Timor show the most number of months (six each) with rainfall reductions. The largest monthly reduction was found for Samoa (21 mm in June).

- For the "largest change" projected rainfall condition, ten countries show at least one month with a reduction in rainfall. Countries or sub-regions showing no reductions were Kiribati (all three sub-regions), Nauru, Palau, PNG, RMI (Southern Islands) and Tuvalu. Countries showing three months or less with small monthly reductions (arbitrarily taken as 5 mm) were Cook Islands (southern sub-region), FSM (both sub-regions), Samoa and Solomon Islands. Fiji and Tonga show the most number of months (ten and nine, respectively) with monthly rainfall reductions. The largest monthly rainfall reductions were found for East Timor (between 26 mm and 50 mm for May, June and July) and Vanuatu (30 mm in April).

(c) Seasonal changes

It is also useful to examine the projected seasonal rainfall changes according to wet and dry seasons (selected as November to April and May to October, respectively, for the Southern Hemisphere countries and the opposite in the Northern Hemisphere countries). This data (in depth units, mm) is summarised in Table B2, Annex B for both "most likely" and "largest change" conditions.

Table 9 shows the projected changes in mean dry and wet season rainfall expressed as percentages of present mean seasonal rainfalls (refer Table 6) at capitals and other locations.

Table 9 Projected percentage changes in mean seasonal rainfalls for 2030

Country	Location	Change in mean dry season rainfall (%)		Change in mean wet season rainfall (%)	
		Most likely	Largest change	Most likely	Largest change
Cook Is	**Northern Islands** (Penrhyn)	<1%	4%	5%	10%
	Southern Islands (*Rarotonga*)	3%	3%	<1%	2%
FSM	**West** (Yap)	7%	12%	<1%	7%
	East (*Pohnpei*)	2%	2%	6%	1%
Fiji	*Suva* (east side of Viti Levu)	-2%	-6%	2%	-2%
	Nadi (west side of Viti Levu)	-6%	-14%	2%	-2%
Kiribati	**Gilbert (western) Group** (*Tarawa*)	17%	34%	6%	17%
	Phoenix (central) Group (Kanton)	25%	48%	13%	29%
	Line (eastern) Group (Kiritimati)	25%	33%	14%	13%
Nauru	*Yaren*	13%	35%	8%	16%
Niue	*Alofi*	<1%	-8%	3%	-2%
Palau	*Melekeok*	- <1%	9%	2%	7%
PNG	*Port Moresby*	26%	26%	12%	9%
	Kavieng (approx. spatial average)	4%	4%	6%	5%
RMI	**Northern Islands** (Kwajalein)	<1%	6%	2%	3%
	Southern Islands (*Majuro*)	3%	11%	2%	9%
Samoa	*Apia*	2%	4 %	3%	4%
Solomon Is	*Honiara*	- <1%	7%	5%	2%
Tonga	*Nuku'alofa*	-6%	-8%	2%	-5%
Tuvalu	*Funafuti*	3%	5%	3%	2%
Vanuatu	*Port Vila*	-3%	-6%	<1%	-3%
East Timor	*Dili*	-12%	-96%	- <1%	<1%
	Spatial average	-6%	-48%	- <1%	<1%

Notes: Sub-regions (refer section 4) are shown in bold, if applicable, and capitals of each country are shown in italics. Results are shown to the nearest percentage or as <1% when the value was less than 1%. Reductions in percentage rainfall are shaded in yellow and orange for "most likely" condition and "largest change" condition, respectively.

The following observations are made from the summary in Table 9 and Table B2, Annex B.

(i) Dry season

- Relatively small to moderate rainfall reductions are shown for the "most likely" condition in six countries with the largest reduction in depth terms being for Tonga (40 mm) and the least for Solomon Islands (1 mm). In percentage terms, the largest dry season rainfall reduction is approximately 12% for Dili, East Timor based on a 21 mm reduction and a long-term dry season rainfall for Dili of approximately 170 mm. However, using the spatially averaged dry season rainfall over East Timor of 360 mm (i.e. 20% of 1,800 mm), the 21 mm reduction represents a percentage reduction of 6%. Tonga also shows a 6% reduction. For Fiji, the rainfall reduction for the drier western side (Nadi) on the main island was 6% compared with only 2% for the wetter eastern side (Suva).
- East Timor shows the largest projected reduction (173 mm) in dry season rainfall using the "largest change" condition. This represents 96% of the dry season rainfall at the capital, Dili, which appears unrealistically high. If the spatially averaged dry season rainfall over East Timor of 360 mm is used, the reduction of 173 mm represents a percentage reduction of nearly 50%, which is still very significant. Niue and Tonga show an 8% reduction. For Fiji, the rainfall reduction for Nadi on the main island was 14% compared with 6% for Suva.
- Significant percentage increases in dry season rainfall for both "most likely" and "largest change" conditions are shown for Kiribati, Nauru and the lower rainfall parts of PNG (e.g. Port Moresby).

(ii) Wet season

- All countries show an increase in wet season rainfall for the "most likely" condition except for East Timor which shows effectively no change.
- Relatively small wet season rainfall reductions of between 26 mm and 49 mm were noted using the "largest change" condition for the four countries Fiji, Niue, Tonga and Vanuatu with East Timor showing very little change. Tonga shows the largest reduction of 49 mm which represents a percentage reduction of about 5% of wet season rainfall.
- Significant percentage increases in wet season rainfall are shown for Kiribati and Nauru using both conditions.

The results in this sub-section are summarised in section 4.4 and the impacts on water resources are presented in section 5.4.

4.2.3 Analysis of historical and projected rainfall for Tonga

A more detailed analysis was made of the historical and projected rainfall data for Tonga, one of the five countries with possible drier conditions. Tonga shows the most reduction in projected annual rainfall for the "largest change" condition after East Timor and the same reduction as East Timor for the "most likely" condition.

Figure 18 shows the mean monthly rainfalls for Nuku'alofa, Tonga for six different periods: the full period of historical record (1945-2010), the baseline period used for climate projections (1981-2000), the two ("most likely" and "largest change") future projections for 2030, a 12 month period during a significant El Niño event (June 1982 – May 1983) and a 12 month period during a significant La Niña event (September 1973 – August 1974).

From Figure 18, the following observations are made:

- The baseline 20-year period shows lower or similar mean monthly rainfalls compared with those for the full period of record in all months except December. The mean annual rainfall for the baseline period (1,523 mm) was 12% less than for the full period (1,728 mm). In addition, the variability of the baseline period (Cv = 0.31) is significantly higher than for the full period (Cv = 0.24).
- The projected mean monthly rainfalls in 2030 using the "most likely" condition were less than the baseline mean monthly rainfall in the dry season (May to October) but higher in the

wet season (November to April). The mean annual rainfall for the “most likely” condition (1,500 mm) was only 1% less than for the baseline period. The Cv of annual rainfall were also very similar for both periods (0.32 and 0.33, respectively).

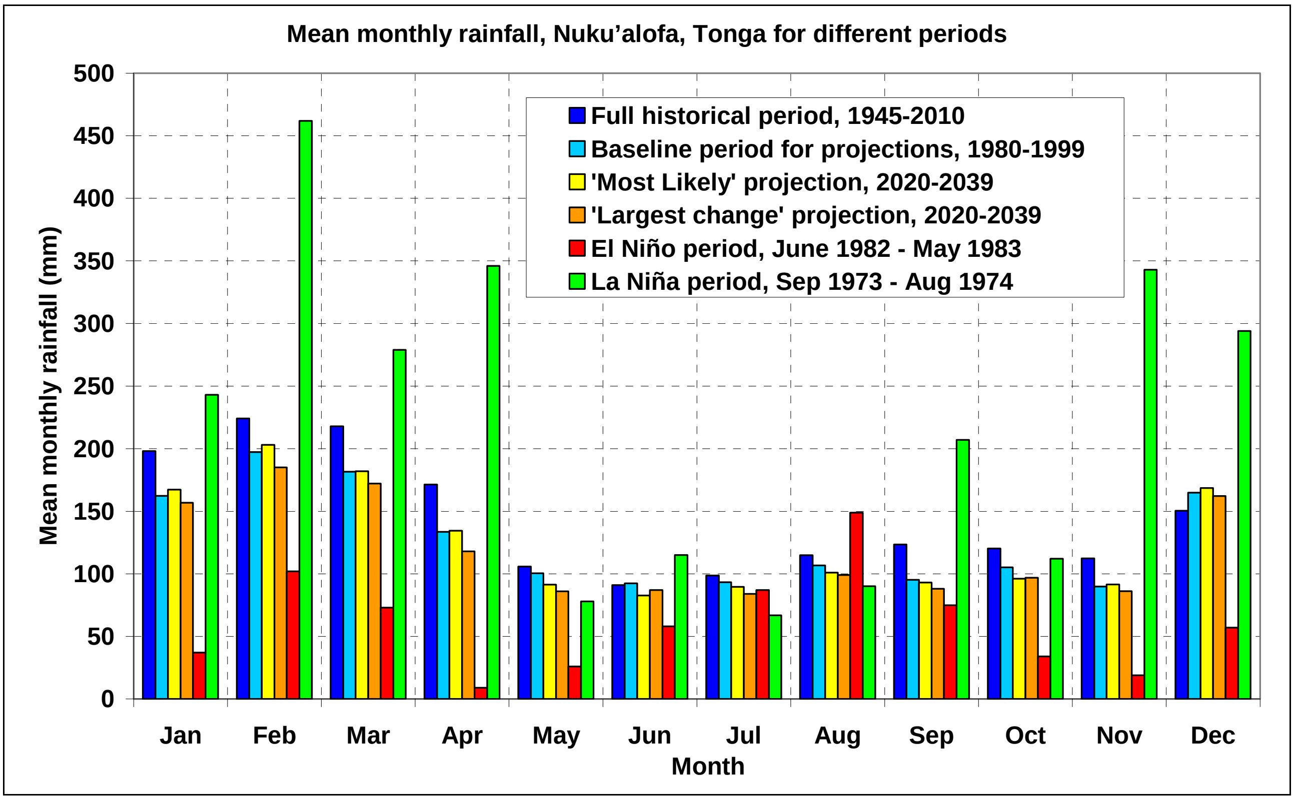


Figure 18 Mean monthly rainfall for Nuku'alofa, Tonga

- From a recent groundwater assessment for Tongatapu including an analysis of rainfall (White et al., 2009), the rainfall from 1945 to 2007 shows an average annual decrease of 2.3 mm/year. For the wet and dry seasons, respectively, an average decrease by 3.2 mm/year and an average increase by 0.7 mm/year were observed. These trends are opposite to those projected by the PCCSP model used for the “most likely” condition in 2030.
- The projected mean monthly rainfalls in 2030 using the “largest change” condition were less than the baseline mean monthly rainfall for all months of the year. The mean annual rainfall for the “largest change” condition (1,421 mm) was 7% less than for the baseline period. The Cv of annual rainfall for the “largest change” condition (0.33) was slightly greater than for the baseline period.
- The projected mean monthly rainfalls are, therefore, not much different from the baseline period in terms of both magnitude and variability.
- A much greater difference in rainfall magnitude and variability can be seen in current climate conditions during El Niño and La Niña episodes. For instance, the El Niño episode in 1982-1983 resulted in the lowest 12 month rainfall (726 mm) on record which is far less than the mean annual rainfall for all other periods considered, including the “largest change” condition. Conversely, the La Niña episode in 1973-1974 resulted in one of the highest 12 month rainfalls (2,636 mm) which is far greater than the mean annual rainfall for all the other periods considered.
- Regarding monthly rainfall, the 1982-83 El Niño episode showed lower rainfall in all months than the two projected rainfall conditions except for July and August. The 1973-74 La Niña episode showed higher rainfall in all months except May, July and August. Monthly variations similar to these are likely for all El Niño and La Niña episodes but mean monthly

variations would be more extreme for both El Niño and La Niña episodes than for the two projected rainfall conditions.

The main conclusion from the above analysis is that current rainfall variability associated with ENSO activity in Tonga is far greater than the projected mean rainfall decrease even under the “largest change” condition.

It is beyond the scope of this report to make similar analyses of other countries in the study region particularly those showing potentially drier future conditions. However, similar results would apply in the other countries.

4.2.4 Projected changes in rainfall intensity

Projected changes in mean monthly rainfall intensity (or “heavy rainfall”) for 2030, as defined in PCCSP (2011b) and section 4.2.1 of this report, are summarised in Tables C1 and C2, Annex C and Figure 19 for “most likely” and “largest change” conditions. Numerical values are shown in depth units (mm) rather than percentages, as advised in PCCSP (2011b).

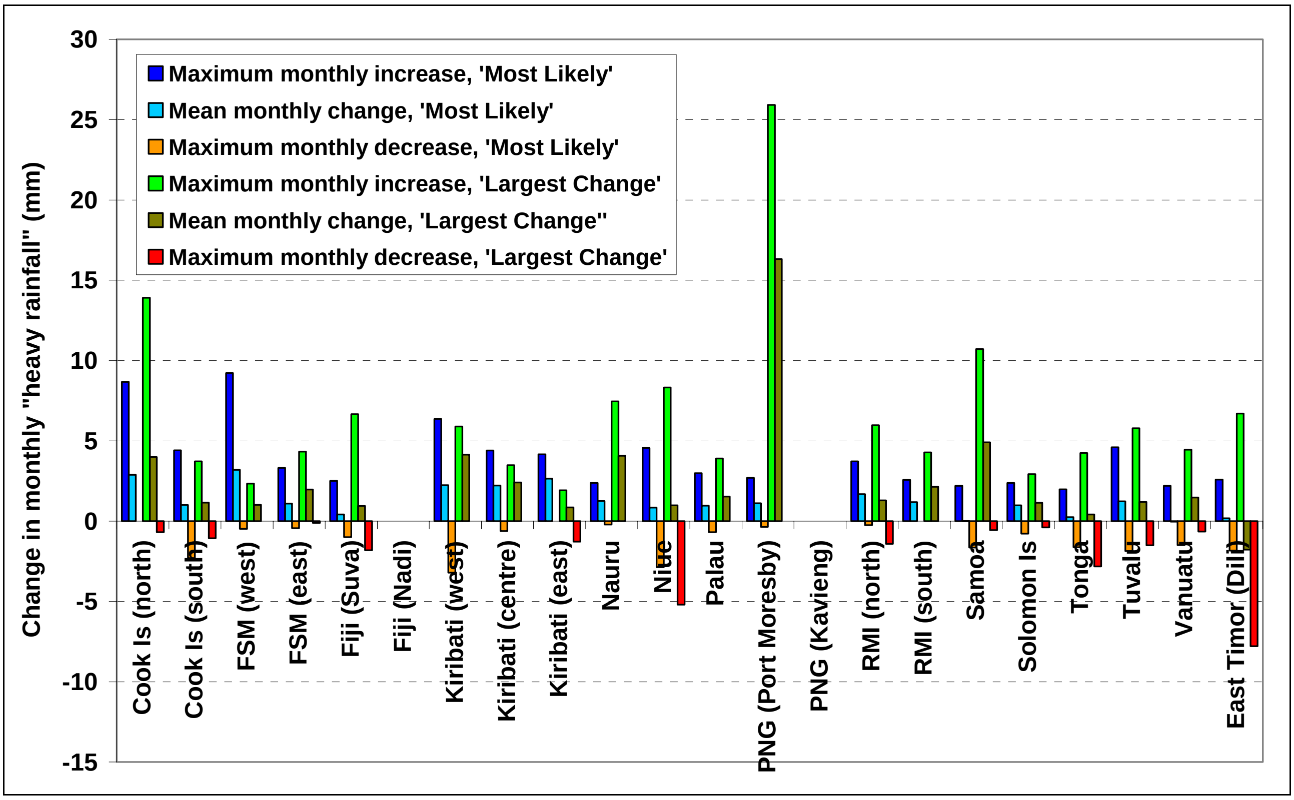


Figure 19 Projected changes in monthly “heavy rainfall” for 2030

For projected mean monthly rainfall intensity changes under the “most likely” condition, the results are summarised as follows:

- Changes were either small to moderate increases or small decreases. Western FSM shows the largest monthly increase (9 mm) followed by the northern Cook Islands and western Kiribati (Gilbert Group). Western Kiribati and Niue show the largest monthly decrease (both 3 mm).
- The northern Cook Islands, eastern Kiribati (Line Group) and southern RMI show only increases and no decreases for all months.
- Vanuatu shows the most number of months (eight) with decreases followed by Samoa and East Timor (seven months each).
- During the wet season, all countries and sub-regions show increases with the highest in the northern Cook Islands (4 mm). In the dry season, 11 countries show increases while four countries (Fiji, Samoa, Tonga and Vanuatu) show relatively minor decreases.

For projected mean monthly rainfall intensity changes under the “largest change” condition:

- Changes varied from small to large increases and small to moderate decreases. PNG shows the largest monthly increase (26 mm) followed by the northern Cook Islands (14 mm). East Timor shows the largest monthly decrease (8 mm) which is consistent with the findings for the decreases in mean rainfalls.
- Six countries (western FSM, western and central Kiribati, Nauru, Palau, PNG and the southern RMI) show only increases or no change for all months.
- East Timor shows the most number of months (nine) with decreases followed by Tonga (seven).
- During the wet season, all countries and sub-regions show increases with the highest in PNG (14 mm). In the dry season, 11 countries show increases with PNG again showing the highest (19 mm). Three countries show relatively small decreases (Fiji, Niue and Tonga) and one (East Timor) shows a moderate decrease (5 mm).

The above results are summarised in section 4.4.

4.2.5 Projected mean monthly air temperature changes

Projected increases in mean monthly air temperatures for 2030 (PASAP, 2011b) are summarised in Tables D1 and D2, Annex D for “most likely” and “largest change” conditions. All results show an increase in temperature, as expected.

For the “most likely” condition, the results are summarised as follows:

- Mean monthly temperature increases vary from 0.6ºC for East Timor and Tuvalu to 1.1ºC for western and central Kiribati.
- The minimum and maximum increases in projected monthly temperatures are 0.6ºC (Tuvalu in December) and 1.2ºC (western Kiribati in July).

For the “largest change” condition:

- Mean monthly temperature increases vary from 0.6ºC for Niue and Tonga to 1.2ºC for western Kiribati and Nauru.
- The minimum and maximum increases in projected monthly temperatures are 0.4ºC (Niue in August) to 1.3ºC (western and central Kiribati and Nauru in May-June).

In summary, the monthly temperature increases across the study region by 2030 are projected to be between about 0.4ºC and 1.3ºC.

4.2.6 Projected evaporation changes

As mentioned in section 4.2.1, PCCSP has prepared potential evaporation projections for each of the selected countries but these were not available at the time of preparing this report. It would have been very useful to have projections at country scale, as evaporation is an important component of the hydrological cycle and has significant impacts on the availability of water resources.

From preliminary information provided for the whole study region by PCCSP, the projected increase in potential evaporation in 2090 is likely to be between 0.2 and 0.4 mm/day (approximately 75 to 150 mm/year). Assuming a linear increase from present to 2090, the increase in potential evaporation to the year 2030 is likely to be about one third of this range (i.e. about 25 to 50 mm/year).

Given that the current range of potential evaporation within the region is in the order of 1,500 to 1,800 mm/year on average (refer section 2.3), the preliminary projected increase to 2030 is a very small increase in percentage terms (between about 1% and 3%).

Other projected evaporation changes are considered in section 4.3.3.

4.2.7 Projected mean sea level changes

Projected global mean sea level rises at decadal intervals to 2100 relative to 1990 for four emission scenarios (A1F1, A2, A1B and B1) are provided in PCCSP (2011a) from CSIRO (2011). These are shown as ranges of values for each emission scenario and year in Table 10. It is noted in PCCSP (2011a) that the "range represents the 5th to 95th percentile, derived by adjusting projections from the IPCC Third Assessment Report to correspond to the IPCC (2007) projections at 2095, including the potential dynamic response of the Greenland and Antarctic Ice Sheets (Hunter, 2010)".

Table 10 Summary of projected global mean sea level (mm) from CSIRO (2011)

Year	A1FI	A2	A1B	B1
1990	0	0	0	0
2000	9-28	9-27	10-27	12-25
2010	19-60	20-60	21-59	26-56
2020	32-99	32-97	35-96	44-92
2030	**48-146**	**47-139**	**55-143**	**64-132**
2040	69-204	67-190	77-200	84-178
2050	96-278	89-251	102-266	105-227
2060	130-368	115-320	126-337	127-279
2070	165-471	142-401	150-413	145-333
2080	200-584	173-490	173-493	161-388
2090	234-701	203-588	192-571	175-444
2100	266-819	237-692	208-649	185-496

The projected global MSL rises of most interest in Table 10 are for 2030, the nominated time horizon for this report. The range of MSL rises for each of the four emission scenarios are reasonably similar in 2030 and range from the lowest value of 47 mm (0.048 m) for the A2 scenario to 146 mm (0.146 mm) for the A1F1 scenario.

For projected regional sea level changes, PCCSP (2011a) provides maps of the Pacific Ocean showing deviations from the projected global MSL rise for the A1B emission scenario and for 2030, 2055 and 2090. These regional changes, due to ocean density and circulation changes, are based on 13 CMIP3 models and are relative to a baseline 20-year period centred on 1990. Values for other SRES emission scenarios are not provided in PCCSP (2011a). The map for 2030 is shown in Figure 20.

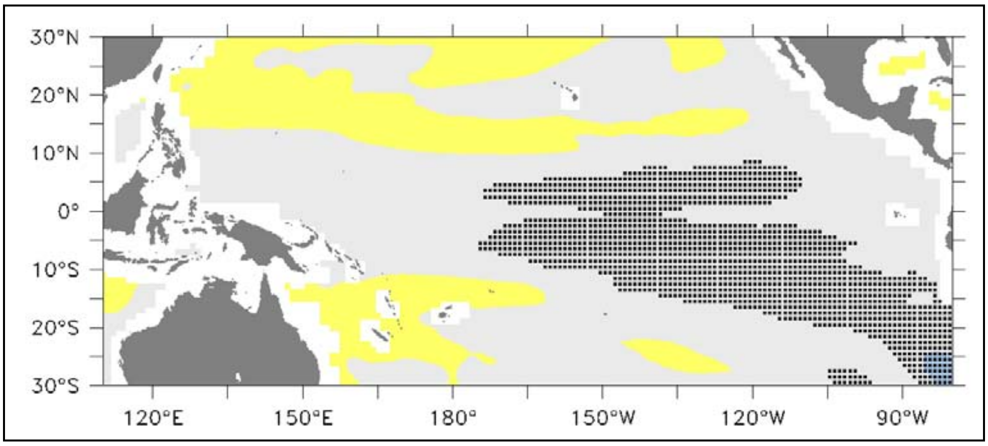


Figure 20 Map showing regional sea level changes relative to global average for 2030 and SRES emission scenario A1B (from PCCSP, 2010a)

In Figure 20, yellow shaded areas indicate increases of between 0 and 20 mm and light grey shaded areas indicate decreases of between 0 and 20 mm relative to global MSL changes. The stippled area is where the models tend to agree.

From Figure 20, the projected sea level changes relative to global MSL changes in the study region are in the range from +20 mm to -20 mm, indicating no significant difference from the projected global MSL. Using the range of global MSL values from Table 10, the projected maximum and minimum MSL changes in the study region are 27 mm to 166 mm (approximately 0.03 m to 0.17 m) for 2030. Over the 40-year period from 1990 to 2030, this represents a projected mean sea level rise in the range 0.7 to 4.1 mm/year.

4.3 Other climate change projections

4.3.1 Outline

Some other studies with climate change projections were reviewed in addition to the PCCSP projections.

Only the parameters of most significance to water resources, namely rainfall, evaporation and mean sea level are considered. Other projections for air temperature were not considered.

For rainfall and evaporation projections, studies for Kiribati, Tonga and East Timor were reviewed. For mean sea level, historical information reported by the National Climate Centre (NTC) of ABoM was reviewed as well as studies of projected levels for Kiribati and East Timor.

4.3.2 Projected mean rainfall and intensity changes

(i) Kiribati

NIWA (2008a) used 12 GCMs in a study of climate change in Tarawa atoll, Kiribati under the Kiribati Adaptation Programme (KAP). The main findings regarding rainfall projections were:

- Mean rainfall and extreme rainfall events will increase.
- There were inconsistent results between GCMs for future intensity and frequency of ENSO events. Accordingly, impacts on droughts are not known.

The above findings are consistent with those in PCCSP (2011a; 2011b).

NIWA (2008a) concluded that drought characteristics will remain similar to the present over the next 100 years.

Due to the uncertainties regarding rainfall in NIWA (2008a), the Tarawa Water Master Plan (White, 2011a) assumed that rainfall variability over the next 20 years in Tarawa (i.e. to 2030) will be similar to that experienced in the historic rainfall record (since 1949). This assumption implies that future droughts will occur with similar frequency, duration and severity.

White (2011a) notes that the failure of GCMs to simulate ENSO events means that their projections are of little relevance in predicting future rainfall or droughts in Tarawa, as these are strongly coupled to ENSO events.

(ii) Tonga

White et al. (2009) presents the results of 23 GCMs used by CSIRO to project changes in monthly rainfalls for the main island of Tongatapu in Tonga. Projections were made to the years 2020, 2050 and 2095 relative to a baseline period of 1975-2004. Four emission scenarios were considered (highest and lowest values for the SRES scenarios, A1F1 and B1).

The main findings regarding monthly rainfall projections were:

- The models gave widely divergent future monthly rainfalls. For a given emission scenario, some models show increases in rainfall and others show decreases. The mean of all model projections was used as a “consensus” value for each emission scenario and projection year. The results show very large coefficients of variation, and hence limited confidence can be placed in them.

- For the period 1990 to 2095, mean annual rainfall was projected to increase by between 0.2 and 1.3 mm/year. Mean wet season rainfall was projected to increase by between 0.4 and 2.1 mm/year, and mean dry season rainfall was projected to decrease by between 0.1 and 0.8 mm/year.
- These projected trends are opposite to the very weak trends found in historic rainfall records from 1945 to 2007. In this period, annual rainfall decreased by 2.3 mm/year, wet season rainfall decreased by 3.2 mm/year and dry season rainfall increased by 0.7 mm/year.

Using the range of increases in mean annual rainfall above, the projected mean annual increase by 2030 would be between 8 mm and 52 mm compared with projected mean annual decreases of 22 mm for the "most likely" condition and 101 mm for the "largest change" condition using the PCCSP projections (refer Table 8). Reasons for the differences in rainfall projections have not been examined in detail but could be due to a combination of factors including differences between the selected GCM's, the baseline period, the selected emission scenarios and the averaging of results in White et al. (2009) compared with the selection of "most likely" and "largest change" conditions by PCCSP.

(iii) East Timor

Rainfall projections for East Timor are made in Barnett et al. (2007), Seeds of Life (2010), Cardno Acil (2010) and Kirono (2010).

Barnett et al. (2007) used the results of nine GCMs to project rainfall and temperature changes for 2030 and 2070. The results show a range of changes from increases to larger decreases, particularly for 2070. The dry season projections show more variable results than the wet season and a greater likelihood of drier conditions. Extreme rainfall events are projected to become more intense.

Seeds of Life (2010) used the outputs from four GCMs to project rainfall and temperature in 2020, 2050 and 2080. This report predicted annual rainfall would increase by an average of 10% (with a range of 7% to 13%) by 2050 across all districts in East Timor. It also predicted that most of the increased rainfall would fall in the three month January, February and May and that the dry season would remain largely unchanged. One of the four models predicted a drier climate by 2050. The report also noted that unfortunately climate change models cannot predict with any accuracy whether variability will increase or decrease in the future, which is of primary importance for agriculture in East Timor.

Cardno Acil (2010) and Kirono (2010) projected mean annual rainfall to increase by 2%, 4% and 6% for 2020, 2050 and 2080 relative to a 30-year baseline period 1961-1990. It is noted that the three estimates are mean values in large ranges of, respectively, -12% to +15%, -25% to +15% and -21% to +32% (Cardno Acil, 2010). Seasonally, small increases in rainfall are projected by 2080 for the wet season December-May, a small decrease for June-August, and no change for September-November. Extreme rainfall events are projected to become fewer but more intense.

Furness (2011) points out that the projected increases in Kirono (2010) may be considered almost insignificant, especially considering the uncertainty in current modelling and the current rainfall variability due to ENSO cycles.

It is noted that the mean rainfall and rainfall intensity projections in the above studies are different from those in PCCSP (2011a; 2011b). As for Kiribati and Tonga, reasons for the differences in rainfall projections have not been examined in detail but could be due to a combination of the same factors listed for Tonga above.

Similar to other previous comments, Kirono (2010) notes that current GCMs do not allow for any conclusions to be made about whether ENSO activity will be enhanced or dampened, or if its frequency will change. Hence, projections regarding rainfall variability due to ENSO activity are not possible.

Furthermore, two of Kirono's recommendations are pertinent here: (a) "There is a real need to develop and analyse results from fine-resolution models over Timor-Leste" and (b) "In model evaluations for Timor-Leste, it is important to focus on the mean climate, year-to-year variability, the processes driving this variability (e.g. ENSO and the monsoon), and extreme weather events. This research is underway in the PCCSP."

4.3.3 Projected evaporation changes

(i) Kiribati

NIWA (2008a) did not consider potential changes to evaporation under climate change scenarios.

(ii) Tonga

White et al. (2009) presents the results of 14 GCMs used by CSIRO to project changes to monthly potential evaporation for the main island of Tongatapu in Tonga. The number of GCMs available for potential evaporation was less than the 23 available for rainfall projections. The main findings regarding monthly potential evaporation projections were:

- All model projections for each emission scenario and projection year show increasing potential evaporation. The results show much lower coefficients of variation than for rainfall.
- For 2020, the mean annual potential evaporation increase varied with emission scenarios from 0.2% to 0.9%. For 2050, the range was from 2.2% to 10%.

Using the range of increases above, the potential evaporation increases for 2030 would be approximately 1% to 4%. For the annual potential evaporation estimate of 1,460 mm (Thompson, 1986a), this would represent potential evaporation increases to 2030 of approximately 15 to 60 mm/year. These results are very similar to the range of 25 to 50 mm/year in the PCCSP preliminary estimates for the study region (refer section 4.2.6).

(iii) East Timor

Projections in Kirono (2010) based on work in Indonesia (Katzfey et al., 2010) indicate that potential evaporation decreases by up to 0.5 mm/day for the months December to February in 2090 relative to a baseline period of 1970-2000. For other seasons, increases of up to 1 mm/day are projected. No projections for annual potential evaporation changes are presented in Kirono (2010).

4.3.4 Actual and projected mean sea level rise

(i) Regional

The National Tidal Centre (NTC), Australian Bureau of Meteorology, under the auspices of the South Pacific Sea Level and Climate Monitoring Project (SPSLCMP) has been operating high resolution SEAFRAME sea level recorders in many PICs since the early 1990s and at the most recent site in FSM since December 2001. Details are provided in various NTC reports including (SPSLCMP; 2009; 2010; 2011). A summary of these recording stations and sea level rises since installation is provided in Table 11. No SEAFRAME recorders are located at Niue, Palau or East Timor.

In Table 11, the relative sea level rises are shown for two periods: from start of record to December 2009 (SPSLCMP, 2010) and to April 2011 (SPSLCMP, 2011). The "relative sea level" is the sea level as measured by the tide gauge and nearby land. "Net relative sea level rises" are those which remove the effects of any land movement at the recorder, measured with a continuous global-positioning system (CGPS) relative to the International Terrestrial Reference Frame (Geoscience Australia, 2008) and barometric pressure effects. Net relative sea level changes are important when assessing the effects of global climate change. Table 11 and Figure 21 show the net sea level changes (all rises) for the period from start to December 2009 for comparison with the relative sea level rises for the same end month.

The SEAFRAME sea level records are still considered relatively short (all less than 19 years). SPSLCMP (2011) notes that sea level records of less than 25 years are too short for obtaining reliable sea level trend estimates. SPSLCMP (2011) advises caution in interpreting the available data and notes that observed sea level trends include natural variability due to ENSO activity and many other atmospheric, oceanographic and geological processes. Longer-term data sets are needed to separate the effects from these processes.

From CGPS measurements, subsidence has been noted at a number of recorders with the highest being 0.9 mm/year at Apia, Samoa and 0.7 mm/year at Rarotonga, Cook Islands (SPSLCMP, 2010). Subsidence rates of 0.4, 0.5, 0.3 and 0.1 mm/year were noted for the recorders in, respectively, FSM, RMI, Solomon Islands, Tonga and Tuvalu. The tide gauges at Fiji and Nauru are rising by 0.6 and 0.2 mm/year, respectively. The Kiribati and PNG recorders showed no appreciable vertical movement.

Table 11 Summary of SEAFRAME sea level recorders and sea level trends

Country	Location	Installation date	Relative sea level rise (mm/year)		Net relative sea level rise to Dec 2009 (mm/year)
			To Dec 2009	To April 2011	
Cook Is	Avarua, Rarotonga	Feb 1993	5.3	4.8	4.6
FSM	Pohnpei	Dec 2001	16.7	16.5	16.8
Fiji	Lautoka, Viti Levu	Oct 1992	5.7	4.7	5.5
Kiribati	Betio, Tarawa	Dec 1992	4.3	3.0	3.9
Nauru	Nauru	Jul 1993	5.2	3.8	4.9
Niue	-	-	-	-	-
Palau	-	-	-	-	-
PNG	Lombrum, Manus Is	Sep 1994	7.4	7.6	5.9
RMI	Majuro	May 1993	3.8	4.6	3.2
Samoa	Apia, Upolu	Feb 1993	5.7	6.1	4.6
Solomon Is	Honiara, Guadalcanal	Jul 1994	7.8	6.9	7.7
Tonga	Nuku'alofa, Tongatapu	Jan 1993	9.5	8.4	8.6
Tuvalu	Fongafale, Funafuti	Mar 1993	5.1	4.0	4.7
Vanuatu	Port Vila, Efate	Jan 1993	6.5	4.9	5.6
East Timor	-	-	-	-	-

Note: The sea level trend at FSM is derived from a comparatively short data record.

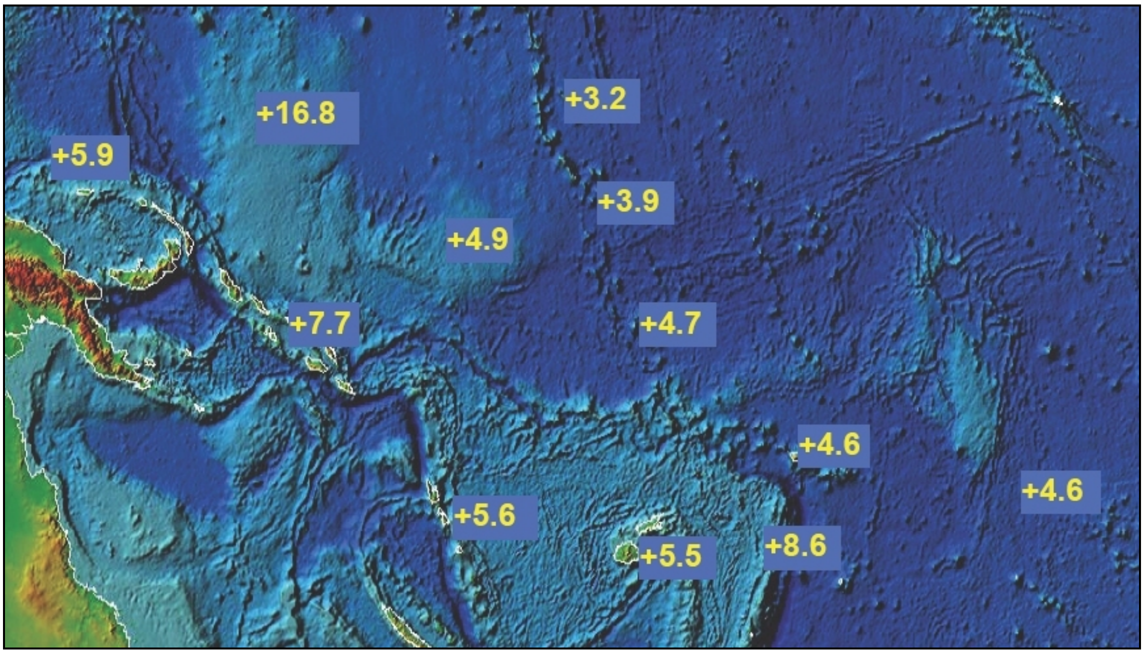


Figure 21 Net relative sea level rises for SEAFRAME sea level recorders to December 2009 (SPSLCMP, 2010)

The following observations are made from the results in Table 11 and Figure 21:

- The sea level trend in FSM is much larger than for the other stations. This is due to a shorter record than for the other PICs and the trend has not stabilised as for the other stations (SPSLCMP, 2009).
- Apart from the FSM sea level rise, all net relative sea level rises to December 2009 are between 3.2 mm/year (RMI) and 8.6 mm/year (Tonga). It is noted in SPSLCMP (2009) that Tongatapu is situated in the vicinity of a tectonic subduction zone with vertical motion of the whole island. The records from the CGPS station are relatively short (from February 2002) and estimates of the vertical land movements are "still too noisy to be reliable" (SPSLCMP, 2009).
- Excluding the results for both FSM and Tonga, the mean relative sea level rises to December 2009 and April 2011 are 5.7 mm and 5.0 mm, respectively. The mean net relative sea level rise to December 2009 was 5.1 mm/year.
- For the five countries away from tectonic plate boundaries but excluding FSM (i.e. Kiribati, Nauru, Tuvalu, RMI, Cook Islands), the mean net relative sea level rise to December 2009 was 4.3 mm/year.

Sea level data from other sources is summarised below from SPSLCMP (2010):

- Sea level data for other stations in the Pacific islands with longer records than the SEAFRAME stations are available from the Joint Archive for Sea Level (JASL). The JASL was established in 1987 to supplement the University of Hawaii Sea Level Centre data (available from website http://uhslc.soest.hawaii.edu/uhslc/jasl.html). The mean sea level rise from stations with more than 25 years of data is 1.3 mm/year. It is noted that this mean is based on datasets with different lengths that span different time periods.
- Global mean sea level rise since 1992 derived from satellite altimeters (available from the University of Colorado website http://sealevel.colorado.edu/) is 3.1 +/- 0.4 mm/year. Regional differences are evident e.g. the southwest Pacific shows higher rates of rise than the global mean.

It is noted that the SEAFRAME stations which have a similar record length to the satellite altimetry data, show higher rates of rise than the global mean rate of rise but are consistent with the higher rates of rise in the southwest Pacific measured by satellite altimeters.

(ii) Kiribati

NIWA (2008b) considered two MSL rise scenarios based on the A1B and A1F1 emission scenarios, a 20-year baseline period centred on 1990 and a time horizon of 100 years (i.e. for a 20 year period centred on 2090). The first scenario assumed no additional allowance for increased ice sheet discharge and projected a sea level rise of 0.48 m by 2090. The second scenario assumed a 0.2 m additional allowance for increased ice sheet discharge and projected a sea level rise of 0.79 m by 2090.

It is noted that the projected MSL rise for the A1B emission scenario from NIWA (2008b) for 2090 is within the range of values from CSIRO (2011) and PCCSP (2011a), as shown in Table 10. However, the projected MSL rise for the A1F1 emission scenario from NIWA (2008b) for 2090 is above the highest value in the range of values from PCCSP (2011a).

(iii) East Timor

Projections of MSL rise in Kirono (2010) use the same global data as in Table 10. Kirono (2010) adds that a mean of 17 GCM projections show that the MSL rise near East Timor will be zero to 10 mm less than the global mean MSL rise. These projections are similar to those from PCCSP (2011a) shown in section 4.2.7 and Figure 20.

Thus, by 2030 the projected range of MSL rises in East Timor would be between 47 mm – 146 mm and 37 mm - 136 mm.

Kirono (2011) estimates the East Timor land mass to be uplifting by 10 mm/year based on evidence from the Quaternary period. If this is so, the land uplift in the 40 year period from the baseline year of 1990 to 2030 would be 400 mm. This would mean that MSL relative to the land mass of East Timor would actually fall (Furness, 2011) by between approximately 250 and 350 mm. Furness (2011) provides further information from other sources about tectonic uplifting in parts of East Timor and concludes that the current rate of uplift is lower than in the past and that this uplift rate may partially offset the predicted MSL rise.

4.4 Summary of climate change projections

Following is a brief summary of the projections to 2030 for climate and ocean parameters of most relevance to water resources. These parameters are:

- Rainfall changes, especially mean monthly values but also intensity
- Evaporation changes, especially mean monthly values
- Mean sea level changes.

In addition, air temperature changes are of interest through their impacts on evaporation and potential influences on water demand.

Regarding **projected rainfall changes** to 2030:

- PCCSP projections show that 12 of the 15 countries will experience little change in mean annual rainfall for the “most likely” condition with only three of these (Tonga, Vanuatu and East Timor) showing a slight decrease. Three countries show a much wetter climate (Kiribati and Nauru) or wetter climate (PNG) for the “most likely” condition. For the “largest change” condition, ten countries show either a wetter or much wetter climate while the other five countries (Fiji, Niue, Tonga, Vanuatu and East Timor) show a drier climate.
- In the dry season, six countries show relatively small to moderate reductions in rainfall for the “most likely” condition. Four countries show relatively small reductions in dry season rainfall for the “largest change” condition while East Timor shows a large reduction.
- In the wet season, all countries show an increase or no change in wet season rainfall for the “most likely” condition. Four countries show relatively small reductions for the “largest change” condition. Kiribati and Nauru show significant increases in wet season rainfall for both the “most likely” and “largest change” conditions.
- Due to inconsistent projections from GCMs regarding ENSO activity, future climate variability, including rainfall variability, has been assumed by PCCSP to be the same as at present.
- Rainfall variability is of greater importance regarding impacts on water resources than gradual changes in mean annual rainfall. To assess this in more detail, variability in the historical rainfall record for Nuku'alofa, Tonga was compared with projected annual rainfall decreases. Tonga shows the second highest reduction in mean annual rainfall for the “largest change” condition (after East Timor) and equal highest reduction (with East Timor) for the “most likely” condition. The analysis shows that current rainfall variability associated with ENSO activity in Tonga is far greater than the projected rainfall decrease even under the “largest change” condition. Similar results would apply to other countries in the study region.
- PCCSP projections show that most countries will experience increases rather than decreases in rainfall intensity. Under the “most likely” condition, the monthly changes were either small increases and decreases or moderate increases. Under the “largest change” condition, most countries show similar results except for PNG which shows moderate to high increases in all months and East Timor which shows small to moderate decreases in most months.
- For Tarawa, Kiribati, projections made by NIWA in 2008 indicate that mean rainfall and extreme rainfall events will increase. These results are consistent with those in PCCSP. As found by PCCSP, inconsistent results were found between GCMs for future intensity and frequency of ENSO events. Accordingly, impacts on droughts are not known but it was

concluded that drought characteristics will remain similar to the present over the next 100 years.

- For Tonga, projections in White et al. (2009) using an average of results, mean annual rainfall would slightly increase. This is different to the findings by PCCSP of a slight to moderate decrease in mean annual rainfall for the "most likely" and "largest change" conditions.
- For East Timor, projections made in three studies in 2010 show increases in mean annual rainfall and rainfall intensity. These are different from the findings of PCCSP which show decreases in mean rainfall for both the "most likely" and "largest change" conditions and decreases in rainfall intensity for the "largest change" condition.

Regarding **projected air temperature changes** to 2030:

- PCCSP projections show mean monthly temperature increases across the study region to be small to moderate (between 0.6ºC and 1.2ºC) using the "largest change" condition. Minimum and maximum changes in mean monthly temperature are projected to be 0.4ºC (Niue) and 1.3ºC (Nauru) using the same condition. Slightly lower ranges of temperatures are shown for the "most likely" condition.
- Other sources of information were not considered.

Regarding **projected evaporation changes** to 2030:

- PCCSP projections are not available. Preliminary estimates indicate an increase of between 25 and 50 mm/year over the study region. This is only a very small increase in percentage terms (between about 1% and 3%).
- Projections for Tonga in 2009 show an increase of approximately 15 and 60 mm/year (about 1% to 4%), similar to the PCCSP preliminary estimates.

Regarding **projected mean sea level changes** to 2030:

- PCCSP projections show mean sea level increases to be in the range from 0.03 m to 0.17 m within the study region (about 0.7 to 4.1 mm/year since the baseline year of 1990).
- Data from SEAFRAME stations for five PICs away from tectonic plate boundaries indicates a mean sea level rise of 4.3 mm/year between 1993 and 2009. This mean rise is after deducting the effects of vertical land movement and barometric effects.
- Other projections were reviewed for Tarawa and East Timor. These were both in broad agreement with the projections by PCCSP where similar assumptions were made.

Regarding the **accuracy of projections** it is noted that:

- There are considerable differences in the projections for rainfall and other parameters given by individual GCMs.
- Due to their coarse grid-cell resolution of GCMs (e.g. about 280 km x 280 km for the PCCSP projections and larger for some other GCMs) cannot account for local climate effects which are important at island scale. For instance, the island of Pohnpei in FSM with a width of only 25 km has a large difference in rainfall between the coastal margin and the highest parts of the island. The annual rainfall gradient on that island is from about 3,000 m at sea level to about 7,500 mm near the highest peak at an elevation of about 800 m (Landers and Khosrowpanah, 2004). Even regional scale models with grid-cell resolutions of about 60 km cannot account for such local climate variations. Kirono (2010) noted that even for the relatively large land mass of East Timor, "Many important climate processes, such as convection and cloud formation, occur on a finer spatial scale (~10 km) than simulated within GCMs, so there is a need to downscale GCM information before it can be applied for local use."

5. Climate Change Impacts on Water Resources & Demand

5.1 Outline

The main climate change impacts to the year 2030 on surface water and groundwater resources within the 15 countries are likely to be caused by changes to rainfall patterns. Changed rainfall patterns will impact on streamflows, availability of water in natural lakes and dammed water storages, recharge to groundwater and groundwater in storage.

From section 4, the rainfall is likely to increase in many of the selected countries with positive impacts on water resources through increases in streamflows and groundwater recharge. In a smaller number of countries, rainfall is likely to decrease with corresponding negative impacts on streamflows and groundwater recharge.

Lesser impacts on water resources are likely to be caused within the period to 2030 from increased evaporation and mean sea level rise. Increased evaporation would act to reduce streamflows and groundwater recharge. Mean sea level rise beyond 2030 has the potential to impact on groundwater resources in low-lying parts of “high islands” (coastal aquifers) and low-lying islands (freshwater lenses). If tropical cyclone severity was to increase, this could also impact on storm surge and potential erosion and inundation of at least parts of low-lying islands and coastal areas of high islands.

There are also likely to be some relatively minor impacts on water demand due to increasing temperature.

Assessment of changes to surface water resources, coastal aquifers and freshwater lenses requires an understanding of the hydrological cycle. This is particularly relevant to small island water resources, where the hydrological cycle occurs within a limited areal domain and processes occur over relatively short time frames.

In section 5.2, water balance principles are briefly introduced. These principles are used to demonstrate the effects of changed rainfall and other parameters on the key water resource components of streamflow and groundwater recharge, which impact on surface and groundwater availability. Following, an analysis is presented of the likely magnitude of impacts on water resources and water demand in the selected countries based on the climate change projections in section 4.

5.2 Water balance

Simple water balance equations are often used to describe the main elements of the hydrological cycle and their inter-relationships. They can also be used to assess changes in water resources due to changes in climate, starting with very simple approaches to gain a general understanding to more complex equations where further information is required. The latter requires adequate definition of the various parameters for these to be of any real benefit. In this report, simple approaches only are considered due to the uncertainty in the likely changes of key parameters due to climate change.

A water balance (or water budget) for a single catchment or an island equates water inputs to outputs, storage terms and a possible error term (UNESCO, 1991).

The following two sub-sections outline the main features of the water balance for (a) the land surface, which affect both surface water and groundwater depending on the type of island, and (b) under the land surface, which affects groundwater systems.

5.2.1 At the land surface

At the surface of a catchment or island, rainfall is the input (of the water balance). Evaporation (or evapotranspiration), surface runoff (if it occurs) and recharge to groundwater are outputs. Surface retention (interception by vegetation and surface depressions) and water held in the soil and the unsaturated zone (between the soil and the groundwater table) are the storage terms.

A general water balance equation at the surface is:

$$P = Et_a + SR + R \pm \Delta V \qquad (1)$$

where P is precipitation (most commonly rainfall), Et_a is actual evapotranspiration (evaporation from soil and other open surfaces and transpiration from vegetation), SR is surface runoff (most commonly in the form of streamflow), R is recharge to groundwater, and ΔV is the change in moisture within the soil and the unsaturated zone.

If the water balance at the surface is considered over a sufficiently long time-scale (e.g. several months), the change in soil moisture component becomes insignificant to the water balance, and equation (1) can be simplified to:

$$P = Et_a + SR + R \qquad (2)$$

Equation (2) can also be expressed in terms of the available water remaining after subtracting evaporation from rainfall (i.e. surface runoff and groundwater recharge) as follows:

$$SR + R = P - Et_a \qquad (3)$$

Equations (1) to (3) relate to "high islands" where surface runoff occurs and where the relative magnitude of actual evapotranspiration, surface runoff and recharge is largely dependent on the vegetation cover, the permeability of soils and the near-surface geology, and the topography, particularly the gradient of stream channels.

On relatively flat coral sand and limestone islands with highly permeable soils and subsurface geology, infiltration occurs rapidly and surface runoff is negligible (except on paved surfaces). By deleting surface runoff, water balance equations (2) and (3) can be simplified to:

$$P = Et_a + R \qquad (4)$$

or, expressed in terms of groundwater recharge, as:

$$R = P - Et_a \qquad (5)$$

Figure 22 shows a water balance model used for estimating recharge on a typical low coral island with a shallow water table. In this model, Et_a has three terms, namely, interception (E_I), evaporation and transpiration from the soil zone (E_S), and transpiration of deep rooted vegetation directly from groundwater (T_L).

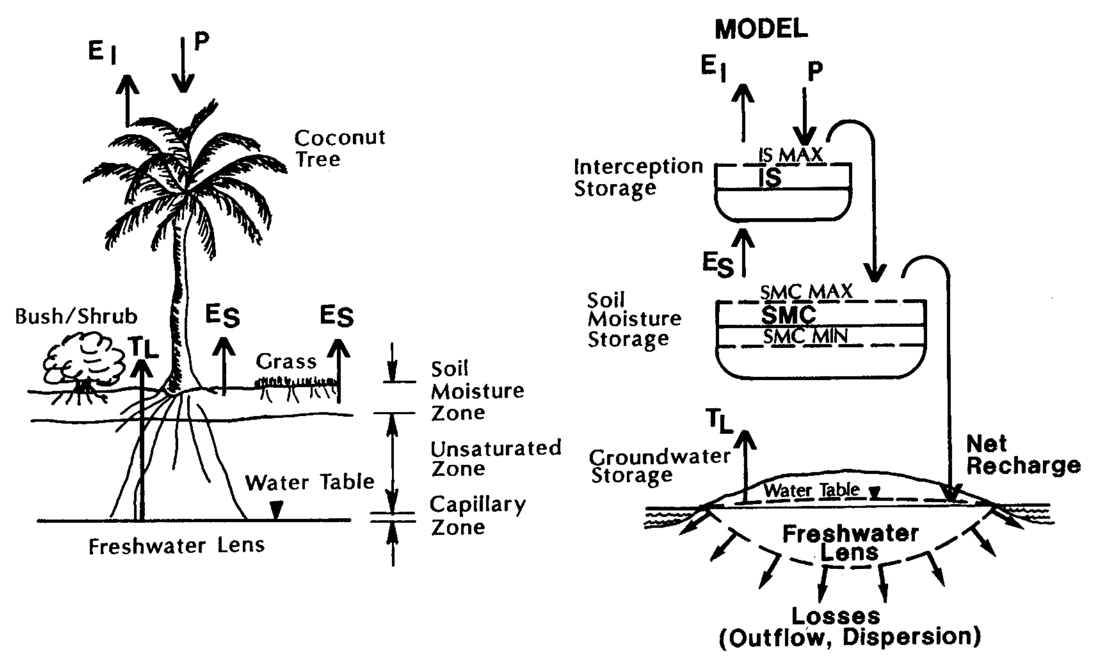


Figure 22 Water balance model to estimate recharge for a coral island (from Falkland & Woodroffe, 1997)

Actual evapotranspiration is a very important component of the water balance and can range from about 50% to more than 70% of rainfall in some small islands. White et al. (2002; 2007a) provide a detailed analysis of the water balance for Bonriki island, Tarawa atoll, Kiribati. There the actual evaporation and recharge components were estimated to be approximately 50% of rainfall based on detailed rainfall, climate, tree sap flow (in coconut trees), soil moisture and groundwater measurements over several months and longer-term calculations taking account of the variability of rainfall and estimated tree density.

The water balance is more complex for islands with raised topography including limestone islands, volcanic and bedrock islands, and islands with mixed geology. Further information and case examples can be found in UNESCO (1991) as well as many country-specific reports.

5.2.2 Under the land surface

For the water balance under the land surface and within the groundwater system, recharge (from the surface zone) is the input with the outputs being discharges from the groundwater. For a perched aquifer on a "high" island, the natural discharges are outflows at springs and possible leakage to deeper aquifers. For a basal aquifer (either coastal aquifer or freshwater lens), the natural discharges are outflows at the edge to surrounding seawater and mixing (dispersion) of fresh groundwater with underling seawater. Groundwater extraction (pumping) is a possible additional discharge for both types of aquifers.

The water balance within a basal island groundwater system can be expressed in terms of groundwater recharge as:

$$R \quad = \quad GF + D + Q \pm \Delta S \qquad (6)$$

where R is groundwater recharge, GF is groundwater flow to the sea, D is dispersion at the base of the groundwater, Q is groundwater extraction and ΔS is change in fresh groundwater storage.

If the groundwater balance is considered over a sufficiently long time-scale (e.g. several years), the change in fresh groundwater storage becomes insignificant to the water balance, and equation (6) can be simplified to:

$$R \quad = \quad GF + D + Q \qquad (7)$$

Figure 23 shows a typical groundwater balance for a freshwater lens on a small coral island.

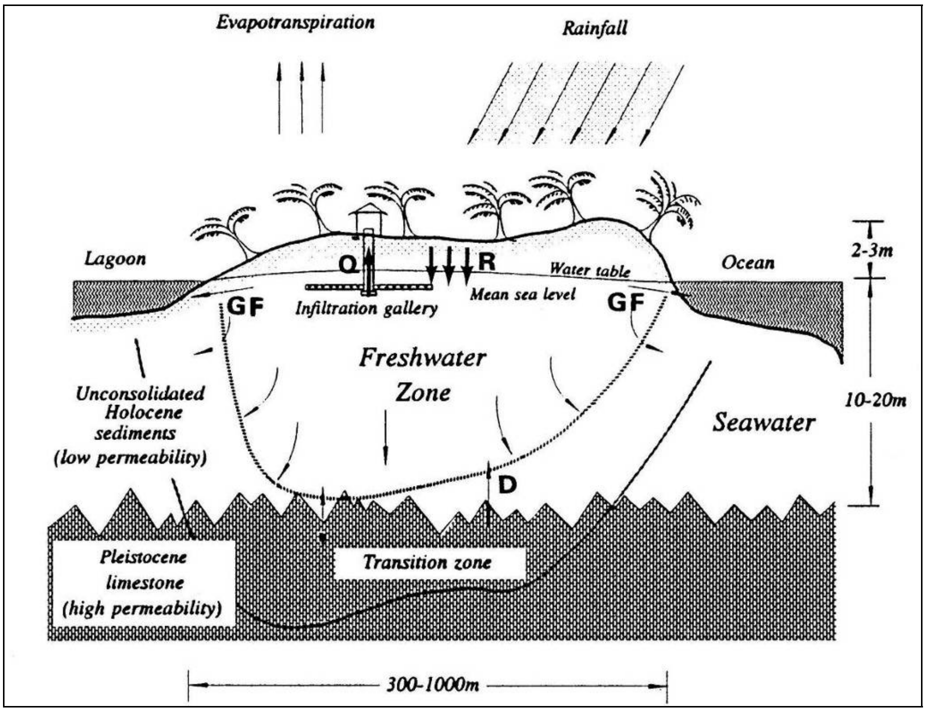


Figure 23 Groundwater balance for a typical coral island freshwater lens

5.3 Runoff coefficients

For countries with surface water resources, a measure of the amount of streamflow generated by rainfall is the runoff coefficient. The runoff coefficient for a catchment is the ratio of the volume of streamflow (or average depth of runoff) at the catchment outlet to the volume of rainfall (or average depth of rainfall) over the catchment.

Runoff coefficients vary considerably between islands and may vary between catchments on islands depending on catchment slope, soil infiltration capacity, vegetation type and cover and the permeability of underlying geology. Higher runoff coefficients are enhanced by one or more of the following factors: steep catchment slopes, low infiltration capacity soils and lower permeability of underlying geology (meaning less groundwater recharge) and sparse or cleared vegetation (meaning lower evapotranspiration). Inter-annual variations in runoff coefficient occur due to variations in annual rainfall, with lower runoff coefficients tending to occur in low rainfall years and vice versa (demonstrating the non-linear response of streamflow to rainfall for a given catchment).

In many of the smaller "high" islands of the Pacific, rainfall intensity is high and catchments are steep and small, causing streamflows to be "flashy". High flows occur rapidly after rainfall and the flows can reduce to very small or no flows after several hours.

Some examples of runoff coefficients for streams and rivers on islands within the selected study region are listed below. It is noted that in most cases, these are based on relatively short-term records.

- **Cook Islands**: coefficients of 0.37 to 0.90 for three small catchments on the volcanic island of Rarotonga based on rainfall and runoff data in Kley (2007a; 2007b).
- **FSM** (volcanic islands):
  - (a) Pohnpei (Ponape): average coefficients of 0.66 and 0.69 for two catchments (van der Brug, 1984a; Spengler et al. (1992) during the period 1978 and 1987, indicating the low permeability of the volcanic rocks.
  - (b) Kosrae: average coefficients of 0.80 to 0.84 for four small catchments during the period 1972 to 1981 (van der Brug, 1984b). Annual coefficients varied from 0.61 to 0.98 across the four catchments. The last value seems unrealistically high and could be due to data errors.
  - (c) Weno (Moen) island, Chuuk (formerly Truk) State: average coefficients of 0.44 to 0.50 for three small catchments during the period 1969 to 1978 (van der Brug, 1983a). Annual coefficients varied from 0.24 to 0.66 across the three catchments.
  - (d) Other islands in Truk lagoon, Chuuk State: average coefficients for Dublon and Tol islands of 0.40 and 0.45, respectively (Takasaki, 1989).
  - (e) Yap islands, Yap State: average coefficients of 0.51 to 0.67 for six small catchments during the period 1970 to 1981 (van der Brug, 1983b). Annual coefficients varied from 0.41 to 0.74 across the six catchments.
- **Fiji**: average coefficients of 0.44 from 33 catchments on the large volcanic island of Viti Levu (Wright, 1989).
- **Palau**: average coefficients of 0.68 to 0.73 for four catchments on the volcanic island of Babelthuap for the period 1969 to 1981 (van der Brug, 1984c). Annual coefficients varied from 0.58 to 0.91 across the four catchments.
- **PNG**: coefficients varying between 0.25 and 0.75 (Stewart, 1993).
- **Samoa**: average coefficient of about 0.6 for the Salani River at Afulilo, the site of a dam used for hydropower generation, for the period 1971 to 1985 (HECEC, 1997).

From the above examples, there is a large range of runoff coefficients from a low of about 0.25 to a high over 0.84. Many are above 0.4 indicating that most of the available water (after subtracting evaporation from rainfall) is in the form of runoff (streamflow) rather than groundwater recharge.

It is noted that for atoll islands (e.g. in the northern Cook Islands, FSM, Kiribati, RMI and Tuvalu) and limestone islands (e.g. Nauru and Niue), the runoff coefficients are essentially zero as surface runoff to the sea is zero or negligible, except where there are paved surfaces. In these cases, all available water is in the form of groundwater recharge.

Further examples of runoff coefficients for streams and rivers on Pacific Islands outside the selected study region are:

- **French Polynesia**. Coefficients varying between 0.48 and 0.88 for streams on the volcanic islands of Tahiti and Moorea (data from Atlas of French Polynesia).
- **Hawaiian Islands**: Coefficients vary between 0.2 and 0.6 for seven volcanic islands (Wright, 1989).
- **New Caledonia**: Coefficients on La Grande Terre Island (a geologically complex island) vary between 0.27 and 0.81 (Terry and Wotling, in press). These coefficients were obtained from 22 catchments with data extending over periods from 15 to 52 years. Coefficients for catchments on the wetter, windward side of the island were about 40% higher than on the drier, leeward side.
- **Norfolk Island**: Coefficients varying between 0.05 and 0.23 (Abell & Falkland, 1991), due to differences in catchment conditions (cleared versus forested) on this volcanic island.

Other examples of runoff coefficients for various islands outside the study region are reported in UNESCO (1991). One example is Malta, a limestone island with a low runoff coefficient of 0.06 due to the high permeability of the rock.

5.4 Impacts from mean rainfall and evaporation changes

5.4.1 Overview

The main potential impacts from mean rainfall and evaporation changes will be on streamflows and groundwater recharge, and hence surface and groundwater availability particularly in the drier parts of the year.

Impacts of projected changes on potential evaporation cannot be quantified at present as the PCCSP projections are not yet available (refer section 4.2.1). However, given the preliminary estimates of a relatively minor increase in potential evaporation in the study region (refer section 4.2.6), the impacts on streamflow and recharge compared with projected changes in rainfall are likely to be relatively small.

It is noted that larger impacts on water resources are likely from changes to the variability of rainfall, due mainly to changes in ENSO activity, than from changes in mean rainfall. Hence, future rainfall variability is potentially of much greater importance regarding impacts on water resources. As outlined in section 4.2.1, the lack of consensus in projections from GCMs has led to the assumption that future climate variability including rainfall variability will be the same as at present (PCCSP, 2011a).

For this report, relatively simple methods based on water balance principles are used to assess impacts on streamflow and groundwater recharge. Given the extent and accuracy of the interim projections, any more complex hydrological modelling is not warranted.

5.4.2 Streamflow

Changes in rainfall lead to a proportionally larger change in streamflow (or surface runoff). This amplifying effect has been found in many international studies. The amplifying effect in changes to streamflow due to changes in rainfall is sometimes referred to as the “climate elasticity of streamflow” or “rainfall elasticity of streamflow” (e.g. Chiew, 2006) and is equal to the proportional change in mean annual streamflow divided by proportional change in annual rainfall. For simplicity, this amplifying effect has been termed the “streamflow multiplier” in this report.

Detailed studies of streamflow response to potential climate change in PICs and East Timor are few. This is due largely to the lack of streamflow data that is both long-term (over 20 years) and of good quality. Fewer streamflow stations are operating than before in some countries (e.g. PNG, Solomon Islands, Vanuatu and East Timor). Valuable data records have been lost due to fire (e.g. Vanuatu), destruction (East Timor) and in some cases have not been processed (e.g. PNG: World Bank, 2009).

A study of climate change impacts on two streams in Fiji was conducted over a decade ago by the International Global Change Institute (Feresi et al., 1999) for the Pacific Islands Climate Change Assistance Programme (PICCAP). They used the streamflow records from two streams (Nakauvadra and Teidamu creeks) in the western, drier side of Viti Levu. Records were available since the late 1970s (Terry, 2002). Feresi et al. (1999) used two GCMs (DKRZ and CSIRO9M2) and two emission scenarios (B2 (mid) and A2 (high) to project changes in 1 in 10 year minimum and maximum streamflows for 2025, 2050 and 2100. Flows were generated using rainfall projections and the FIJICLIM model (Kenny et al., 2000). The results from the two models showed different results ranging from increases to decreases of about 10% by 2050 and 20% by 2100 for both low and high flows.

For East Timor, there is also a lack of good quality, long-term streamflow records. As a result, Yance (2004) used limited data from a stream in West Timor to model streamflows in catchments in East Timor for a study of national water resources. Recently, streamflow gauging stations have been installed for studies of hydropower potential in seven catchments (Lindsay Furness, pers. comm., 2011) but the records are too short to be of use for climate change modelling.

Owing to the paucity of available, good quality, long-term streamflow records in PICs and East Timor, other studies were reviewed. Studies of long-term streamflow records in Australia have shown that a changes in rainfall lead to greater percentage changes in mean annual runoff (e.g. Jones et al., 2005; Chiew, 2006; WA DoW, 2010; Bari et al., 2010).

Using two rainfall-runoff models, Chiew (2006) found that 70% of 219 Australian catchments with data records varying from 25 to 93 years show a 2% to 3.5% change in mean annual streamflow from a 1% change in mean annual rainfall. This “streamflow multiplier” was found to be very strongly correlated to runoff coefficient (with streamflow changes being more sensitive to rainfall changes in catchments with low runoff coefficients) and strongly correlated to mean annual rainfall (with streamflow changes being more sensitive to rainfall changes in drier catchments).

For a catchment in south-west Western Australia with a spatial rainfall variation of about 700 mm to 1,150 mm (similar to the low rainfall parts of East Timor), Bari et al. (2010) found that a 14-24% reduction in rainfall under the SRES A2 emission scenario would lead to a 49-69% reduction in streamflow. This indicates a “streamflow multiplier” of between 2.8 and 3.5.

Chiew (2006, Figure 8) provides a number of graphs linking the “streamflow multiplier” to various catchment characteristics including runoff coefficient and mean annual rainfall. The results were approximately similar for both models, with both showing less scatter for the graph with runoff coefficient than the one for mean annual rainfall. From these graphs, approximate ranges of the “streamflow multiplier” were estimated for a range of runoff coefficients and mean annual rainfalls relevant to the countries in the study region and within the range of the Australian data. “Outliers” have not been used in the estimation of these ranges. The results are summarised in Table 12.

Using the streamflow multipliers in Table 12, approximate estimates of streamflow changes can be made for the relevant countries in the study region using projected rainfall changes. Of most interest here are those countries with surface water resources which show projected mean rainfall reductions, and hence will experience reduced streamflows.

Countries showing projected mean annual rainfall increases will experience a beneficial effect on streamflows and surface water resources. Those countries which show projected increases in rainfall intensity may experience worse flooding conditions.

From Table 8 and Table 9, the countries showing projected annual and seasonal rainfall decreases and with at least some surface water are Fiji, Tonga, Vanuatu and East Timor. For Tonga, the predominant water resource is groundwater but the island of ‘Eua, with a rainfall of approximately 1,700 mm (similar to Nuku'alofa), uses surface water (small streams discharging from caves) for water supply. In the other three countries, surface water sources are used extensively for water supply and, to varying degrees, for hydroelectricity (refer section 2.6.1). Other countries showing rainfall reductions which were not considered further are Palau and Solomon Islands (only 0.1% reductions) and Niue (no surface water resources).

Table 12 Summary of approximate streamflow multiplier ranges related to runoff coefficient and mean annual rainfall (from Chiew, 2006)

Runoff coefficient	Range of "streamflow multiplier"	Mean annual rainfall (mm)	Range of "streamflow multiplier"
0.1	3 - 4.5	600	2.5 - 5
0.2	2 - 3	800	2 - 4
0.3	2 - 2.5	1,000	2 -3.5
0.4	2	1,500	1.8 - 3
0.5	1.8	2,000	1.5 -2
0.6	1.7	2,500	1.5
0.7	1.6	3,000	1.2 - 1.5
0.8	1.5	> 3,000	Beyond range (assume 1.2)
0.9	0.8 - 1.4		

The estimated range of streamflow multipliers for each of the four countries are shown in Table 13 based on the current mean annual rainfall ranges in Table 2 and the relationships in Table 12. It is noted that there is only limited information on runoff coefficients for these countries and hence emphasis is placed on the range of mean annual rainfalls. For Fiji, the average runoff coefficient of 0.44 (section 5.3) would indicate a streamflow multiplier of 2 which is approximately midway in the range of values shown in Table 13.

Table 13 Estimated range of streamflow multipliers for selected countries

Country	Current mean annual rainfall range (mm)	Estimated range of streamflow multipliers
Fiji	1,500 - 6,000	1.2 - 3
Tonga ('Eua only)	1,700	1.5 - 2.5
Vanuatu	2,000 - 4,000	1.2 - 2
East Timor	700 - 3,000	1.2 - 4

The range of streamflow multipliers shown in Table 13 is considered a worst case scenario. For instance, while the minimum rainfall for East Timor is about 700 mm, the mean rainfall over individual catchments is likely to be higher than shown, given that catchments extend from elevated ranges, where mean rainfall is higher, to the coastline, where mean rainfall is lower. Hence, the minimum rainfall of 700 mm shown in Table 13 is unlikely to apply at catchment scale. For present purposes, it is used as a lower bound.

Table 14 and Table 15 show the estimated range of percentage changes in mean annual and seasonal streamflows, respectively, for 2030 based on the range of streamflow multipliers in Table 13 and the rainfall reductions shown in Table 8 and Table 9. Results are shown for both "most likely" and "largest change" conditions. It is noted that the same streamflow multipliers have been applied for mean seasonal streamflows as for mean annual streamflows.

Table 14 Estimated percentage changes in mean annual streamflows for 2030

Country	Estimated range of changes in mean annual streamflow (%)	
	Most likely	Largest change
Fiji	Less than +1%	-4% to -10%
Tonga ('Eua only)	-2% to -3%	-9% to -15%
Vanuatu	-1% to -1.5%	-5% to -8%
East Timor	-1.5% to -5%	-11% to -38%

Note: Reductions are shaded in orange and increases are shown in green.

Table 15 Estimated percentage changes in mean seasonal streamflows for 2030

Country	Estimated range of changes in mean dry season streamflow (%)		Estimated range of changes in mean wet season streamflow (%)	
	Most likely	Largest change	Most likely	Largest change
Fiji	-3% to -7%	-7% to -17%	+2% to +5%	-2% to -7%
Tonga ('Eua only)	-9% to -15%	-12% to -20%	-3% to -4%	-7% to -12%
Vanuatu	-4% to -7%	-7% to -11%	+1%	-4% to -6%
East Timor	-7% to -24%	-58% to -100%	Negligible	Negligible

Note: Reductions are shaded in orange and increases are shown in green.

For East Timor, the spatially averaged percentage rainfall changes from Table 8 and Table 9 have been used rather than higher percentage rainfall values at Dili.

The following observations are made about the estimated percentage changes in streamflow in Table 14 and Table 15:

- The mean annual streamflow reductions for the "most likely" condition are all equal to or less than 5% (Fiji shows a slight increase). These are reasonably insignificant reductions given the uncertainties associated with these estimates. For the "largest change" condition, the reductions for Fiji, Tonga and Vanuatu (all between 8% and 15%) are moderately significant while the reductions for East Timor (from 11% to nearly 40%) are very significant.
- The mean dry season streamflow reductions are greater in all cases than the mean annual reductions. For the "most likely" condition, the reductions for all four countries (all between 3% and 24%) are mildly to moderately significant. For the "largest change" condition, the reductions for Fiji, Tonga and Vanuatu (all between 7% and 20%) are moderately significant while the reductions for East Timor (from 58% to 100%) are highly significant. The percentage streamflow reduction using the "largest change" condition for East Timor appears unrealistically high and both the rainfall projections for this condition and the adopted range of streamflow multipliers warrant further examination.
- The mean wet season streamflow changes under the "most likely" condition vary from small increases (5% for Fiji) to small decreases (3% for Tonga). For the "largest change" condition, the changes vary from an insignificant increase for East Timor to a moderately significant decrease of 12% for Tonga.

Results are summarised in section 5.4.4.

5.4.3 Groundwater recharge

Fresh groundwater is found in all 15 countries (refer section 2.5). The countries showing projected mean annual rainfall increases will experience a beneficial effect on groundwater recharge and hence on groundwater resources. The projected increase in mean annual rainfall for Kiribati and Nauru of 10% to 18% under "most likely" conditions (and 3% to 23% under "largest change" conditions) would be particularly beneficial.

Of most interest here are those countries which show projected mean rainfall reductions, and hence will experience reduced groundwater recharge. From Table 8 and Table 9, the countries showing projected annual and seasonal rainfall reductions of at least 1% are Fiji, Tonga, Niue, Vanuatu and East Timor. Niue is the only additional country to those considered in the previous sub-section regarding streamflow.

To assess recharge for an island including the impact of reduced rainfall on recharge, a number of methods can be used. One approach is to use water balance models based on equation (3) for high islands with surface runoff (streamflow) and equation (5) for coral sand or limestone islands with no surface runoff.

For some coral sand and limestone islands, detailed water balance studies to estimate recharge have been made for some Pacific islands including Tongatapu, Tonga (White et al., 2009) and some atolls in Kiribati and Cook Islands (e.g. Falkland, 2006). These studies have used the historical daily rainfall record, estimates of monthly potential evaporation and parameters related to soil types and depths and vegetation types and densities.

Other simpler approaches can be used for preliminary estimates of recharge for coral and limestone islands. These include empirical relationships between rainfall and recharge (refer Figure 24) and areal maps showing estimated mean annual recharge (refer Figure 25). Figure 25 is based on water balance studies for atoll islands in and beyond the study region assuming a rooting depth for coconut trees of 1 m (from UNESCO, 1991; modified from Nullet, 1987). Other relatively simple methods and a more detailed method using measures of the main water balance components (refer section 5.2.1) are described in White and Falkland (2010).

Figure 24 shows the relationship between rainfall and groundwater recharge is non-linear. As rainfall increases, the percentage of the rainfall that recharges groundwater can increase. It also shows the large impact of vegetation on recharge. As vegetation densities increase, particularly for deep-rooted trees, evapotranspiration tends to increase, thus reducing groundwater recharge.

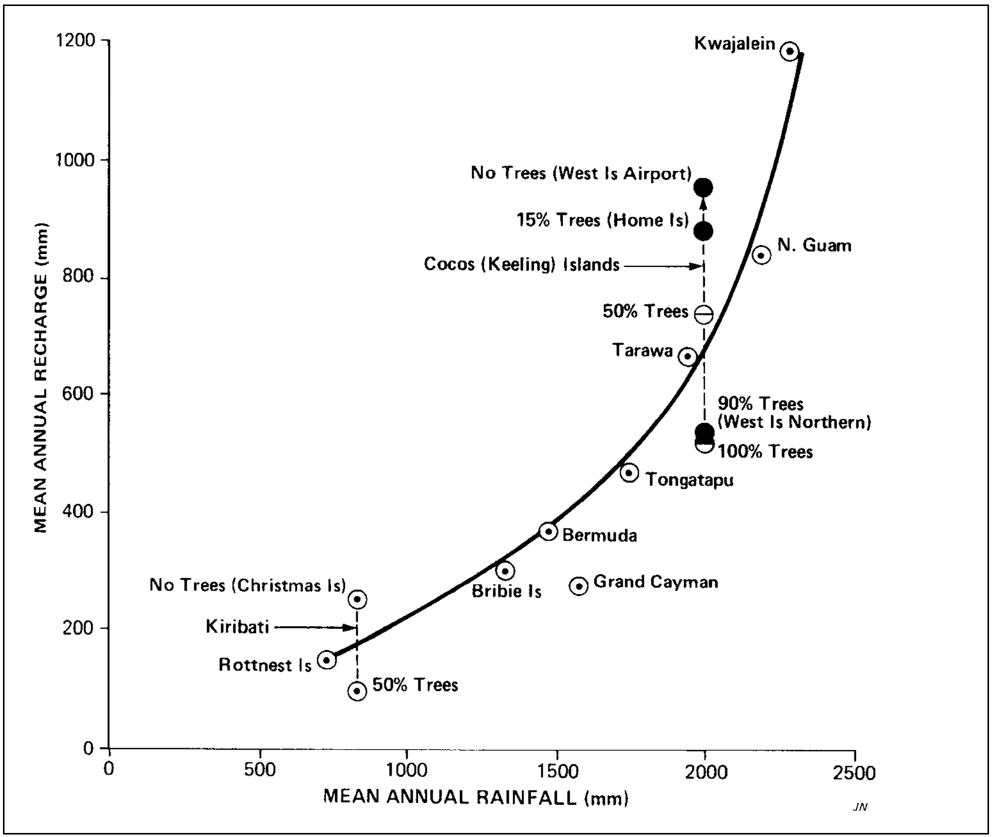


Figure 24 Relationship between mean annual rainfall and mean annual recharge for a number of low-lying islands (from Falkland and Brunel, 1993)

Estimation of groundwater recharge on volcanic and mixed geology islands is more complex and cannot be generalised as it is dependent on many local factors including the permeability and thickness of soils, the type, extent and density of vegetation, and the topography including gradient of stream channels. The groundwater balance is further complicated if there are significant perched or volcanic dyke-confined aquifers present on the island. In mixed geology islands, especially in areas with karstic limestone (e.g. in parts of East Timor: Furness, 2004; Wallace, 2010b), the groundwater flow pattern may include subterranean streams. These streams may emanate as springs either above or below sea level, or become more diffuse flows near the edge of the island. These factors have a large impact on the balance between surface runoff and groundwater recharge. The best method of estimating recharge is through long-term measurement of rainfall, evaporation and streamflow and use of equation (3). However, in general, long-term, good quality streamflow data is not available (refer section 5.4.2) and hence detailed water balance calculations are not possible. A simpler and approximate estimation of the balance between surface runoff and recharge can be made using runoff coefficients. In most cases, runoff coefficients are relatively high (refer section 5.3). This means that on many high volcanic islands, the available water occurs mainly as surface runoff rather than recharge.

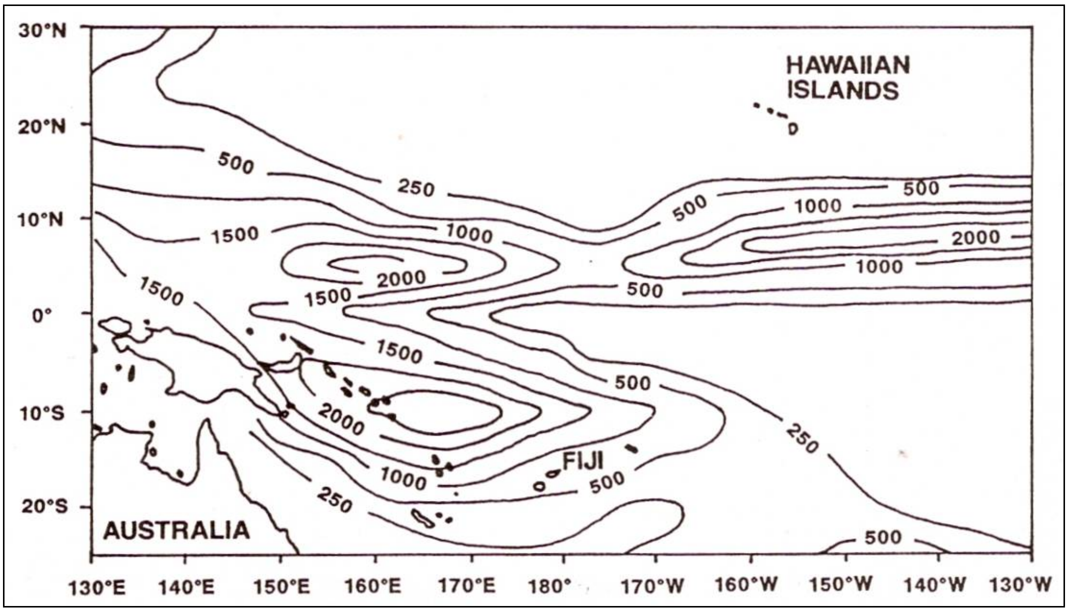


Figure 25 **Mean annual recharge (mm) for atoll islands using a rooting depth for coconut trees of 1 m (from UNESCO, 1991; modified from Nullet, 1987)**

Of the five countries of interest, Niue is a single limestone island, Tonga has mainly limestone islands with some coral areas and a few volcanic islands, Fiji has a range of islands (volcanic, limestone and coral), Vanuatu has mainly volcanic islands and the main part of East Timor is of mixed and more complex geology.

For the coral sand and limestone islands (some of Fiji, Niue and most of Tonga), the results of a recharge analysis using the water balance approach for Tonga under possible climate change scenarios (White et al., 2009) are relevant. Using the projected changes to rainfall (mean annual increase but mean dry season decrease) and potential evaporation (mean annual increase) as outlined in section 4.3.3 and a base year of 1990, it was estimated that recharge will decrease between 5% and 25% by 2095. The projected increase in annual rainfall was offset by the projected increase in evaporation and decrease in dry season rainfall. On a pro-rata basis, the decrease in recharge by 2030 would be between 2 and 10%. However, it is noted that both annual and dry season rainfall for Tonga will decrease using the PCCSP projections (refer Table 8 and Table 9).

To estimate the changes in annual recharge for the coral sand and limestone islands, the non-linear curve in Figure 24 was used in conjunction with the projected mean annual rainfall changes in Table 8. Seasonal changes are not considered as the hydraulic residence times of significant groundwater systems are generally measured in years and not months. Further detailed water balance studies could be done but are considered unwarranted at present given the lack of projected evaporated changes. The results are summarised in Table 16. The percentage changes in recharge are approximately double the percentage changes in rainfall in Table 8.

For East Timor, estimates of groundwater recharge for different hydrologic units (corresponding to river catchments) are available in Furness (2004) and Yance (2004). The estimated “recharge factors” are in the range 0.2 to 0.3 (i.e. mean recharge is estimated to be between 20% and 30% of mean rainfall). These reports also estimate the mean annual rainfall for the catchments groundwater and this range is shown in Table 16. Projected mean rainfall reductions for East Timor, as per Table 8, will cause reductions in recharge. However, the magnitude of the reductions is not easily estimated, owing to insufficient knowledge of the balance between streamflows and recharge. As a first approximation, it is assumed that the percentage recharge reductions will be approximately double the percentage rainfall reductions. As for the streamflow assessments (refer section 5.4.2), the spatially averaged percentage rainfall changes from Table 8 and Table 9 have been used rather than the higher percentage rainfall values at Dili. The results are summarised in Table 16.

For groundwater aquifers on volcanic islands in Fiji and Vanuatu, a number of assumptions were made. Firstly, the range of mean annual rainfall was reduced below that shown in Table 2 to account for the fact that highest rainfalls are reduced when spatially averaged over catchments. The highest catchment rainfalls in both cases were reduced to 3,000 mm and the minimum values were retained. Secondly, the recharge factors were assumed to be between 0.1 and 0.3, allowing for the fact that some volcanic catchments have very high runoff coefficients. Thirdly, the percentage recharge reductions were assumed to be approximately double the percentage rainfall reductions, as for East Timor. The results are again summarised in Table 16.

Table 16 Estimated percentage changes in mean annual recharge for 2030

Country (and island type where applicable)	Estimated current mean annual rainfall range (mm)	Estimated current mean annual recharge range (mm)	Estimated changes in mean annual recharge (%)	
			Most likely	Largest change
Fiji (coral & limestone)	1,500 - 3,000	400 – 1,600	Less than +1%	-7% to -12%
Fiji (volcanic)	1,500 – 3,000	150 - 900	Less than +1%	-8% to -12%
Niue (limestone)	2,100	770	+2%	-8%
Tonga (limestone & coral sand)	1,700	500	-2%	-11%
Vanuatu (volcanic)	2,000 - 3,000	200 - 900	Less than -1%	-8%
East Timor (mixed geology)	750 – 2,000	150 - 600	-2%	-20%

Note: Reductions are shaded in orange and increases are shown in green.

The following observations are made about the estimated percentage changes in mean annual groundwater recharge in Table 16:

- For the "most likely" condition, the reductions for Tonga, Vanuatu and East Timor are all equal to or less than 2%. These are reasonably insignificant changes given the uncertainties associated with these estimates. Fiji and Niue show small increases.
- For the "largest change" condition, Fiji, Niue, Tonga and Vanuatu show reductions varying between 7% and 12% which are moderately significant. East Timor shows a larger reduction of 20% which is significant.

Results for both groundwater recharge and streamflow are summarised below.

5.4.4 Summary

In summary, estimated changes in streamflow and groundwater recharge due to projected mean rainfall changes are:

- Small mean annual streamflow reductions for Tonga and Vanuatu and East Timor under the "most likely" condition (up to 5%) and a small increase for Fiji. Higher reductions under the "largest change" condition of up to 15% for the three PICs and nearly 40% for East Timor.
- Significant reductions in mean dry season streamflow for East Timor under the "most likely" condition (up to 24%) and much higher under the "largest change" condition (60% to 100%, with the latter value appear unreasonably high).
- Lesser reductions in mean dry season streamflow for Fiji, Tonga and Vanuatu of up to 15% and 20% for the "most likely" and "largest change" conditions, respectively.

- Small reductions in mean annual groundwater recharge for Tonga, Vanuatu and East Timor (up to 2%) under the "most likely" condition.
- Moderately significant reductions in mean annual groundwater recharge for Fiji, Niue, Tonga and Vanuatu (up to 12%) and significant reductions for East Timor (20%) under the "largest change" condition.

Impacts of reduced streamflow and recharge are outlined in section 3.2 and any further reductions would obviously exacerbate existing impacts on the sustainable yields from surface water and groundwater resources.

It is recognised that the above estimates of streamflow and recharge changes due to projected mean rainfall changes are rather coarse. However, such estimates are considered reasonable given the uncertainties inherent in the interim projections of rainfall and the scale at which they are available, the lack of projections regarding evaporation and the assumption that climate variability due to ENSO activity will be the same as at present.

It is not possible in this report to estimate impacts on streamflow and recharge conditions at catchment scale given the resolution of the projected rainfall conditions. As mentioned in section 4.2.1, the spatial scale (grid-cell resolution) for the PCCSP climate projections is 2.5° of latitude x 2.5° of longitude (approximately 280 km x 280 km at the equator). This scale is larger, and in most cases much larger, than the size of the islands within the study region except for the main island of PNG (the eastern part of New Guinea island). As an example, the main island of Fiji, Viti Levu has approximate east-west and north-south dimensions of 150 km and 100 km.

Even proposed regional scale climate models, with typical grid-cell resolutions of 60 km, lack sufficient detail to account for variations in streamflow at catchment scale, which have typical areas on many islands of only several square kilometres.

As mentioned above, the estimated changes in streamflows and recharge do not take account of potential changes to evaporation as these projections are not yet available from PCCSP. However, given the preliminary estimates of a relatively minor increase in potential evaporation in the study region (refer section 4.2.6), the impacts on streamflow and recharge compared with projected changes in rainfall are relatively small. This aspect can be further considered when the evaporation projections from PCCSP are available.

5.5 Impacts from rainfall intensity changes

Projected increases in rainfall intensity by 2030 are provided in section 4.2.4. These show that most countries will experience increases rather than decreases in rainfall intensity. Under the "most likely" condition, the monthly changes were either small increases and decreases or moderate increases. Under the "largest change" condition, most countries show similar results except for PNG which shows relatively high increases in most months and East Timor which shows small to moderate decreases in most months.

It is not possible to provide quantitative assessments of impacts from heavy rainfall increases, given the information available. However, in qualitative terms the following impacts would be expected:

- Increased flooding and consequent problems including damage to infrastructure, increased land erosion, especially in cleared, steep catchments, and sedimentation of downstream reaches of streams and rivers and the coastal environment.
- Beneficial impacts due to enhanced groundwater recharge to freshwater lenses on coral sand and limestone islands and to coastal aquifers in high islands. Groundwater recharge is enhanced during periods of heavy rainfall as rainfall percolates quickly through the highly permeable soils and thus evaporative losses are minimised.
- Some beneficial effects are also likely on high islands due to lakes and larger water storages being replenished from higher streamflows.

5.6 Impacts from mean sea level changes

The prospect of sea level rise is one of the main concerns to small island and coastal communities (e.g. Burns, 2002. Mimura et al., 2007). Low-lying atoll islands are perceived to be vulnerable to sea level rise with potential impacts on shoreline erosion, inundation and saline intrusion into freshwater lenses (Woodroffe, 2008).

Increases in mean sea level (MSL) by 2030, using PCCSP projections, are presented in section 4.2.7. These projections show sea level increases to be in the range from 0.03 m to 0.17 m within the study region (about 0.7 to 4.1 mm/year since the baseline year of 1990). Other projections and sea level recordings in recent years (refer section 4.3.4) were in broad agreement with the projections by PCCSP.

The central question is whether a MSL rise of 0.17 m will have a significant effect on the freshwater lenses of small, low-lying coral islands and coastal aquifers in low-lying areas of high islands.

A number of impact studies have been done for freshwater lenses on atoll islands using groundwater models for a range of projected mean sea level rises and rainfall changes. These include Enjebi Island, Enewetak atoll, RMI (Oberdorfer and Buddemeier, 1988) and Bonriki island, Tarawa atoll, Kiribati (Alam and Falkland 1997 and World Bank 2000). Both studies used the variable density, two-dimensional model SUTRA (Voss 1984; Voss et al. 1997).

The analysis in World Bank (2000) for Bonriki island, which is the main source of freshwater for South Tarawa, included a study of impacts from eight climate change scenarios involving MSL rise, rainfall changes and potential loss of island width relative to a baseline scenario using average freshwater lens thickness and pumping conditions in the late 1990s. The average changes in Bonriki freshwater thickness relative to the baseline scenario, in absolute and percentage terms are summarised in Table 17.

Table 17 Changes to Bonriki island freshwater lens thickness due to changes to MSL, rainfall and island width (World Bank, 2000)

Scenario	Average change in freshwater thickness compared with baseline scenario	
	(m)	(%)
Baseline scenario (current MSL & rainfall): average freshwater thickness = 12.1 m	-	-
1. Current MSL, 7% increased rainfall	+0.7	+6
2. Current MSL, 10% reduced rainfall	-1.7	-14
3. 0.2 m MSL rise, current rainfall	-0.1	-1
4. 0.4 m MSL rise, current rainfall	+0.3	+2
5. 0.4 m MSL rise, 10% reduced rainfall	-1.4	-12
6. 0.4 m MSL rise, current rainfall, reduced island width	-3.5	-29
7. 0.4 m MSL rise, 7% increased rainfall, reduced island width	-2.3	-19
8. 0.4 m MSL rise, 10% reduced rainfall, reduced island width	-4.7	-38

The results in Table 17 of significance to the current study are:

- A MSL rise of 0.2 m (similar to the upper range projection from PCCSP of 0.17m) and similar rainfall to the present would cause virtually no change to the freshwater lens.
- A MSL rise of 0.4 m (more than double the upper range projection) and similar rainfall to the present would cause a slight increase in thickness. This is due to the fact that the average level of the freshwater lens, which is influenced by MSL, would rise slightly into less permeable Holocene sediments than the highly permeable underlying Pleistocene

limestone (refer Figure 11). This effect was also noticed in other modelling studies (Oberdorfer and Buddemeier, 1988; Alam and Falkland, 1997).

- If land is lost at the edges of the island due to inundation from rising sea level and/or erosion from storms, this would have a significant effect on the freshwater lens. The analysis assumed a loss of about 20% in width of the island due to inundation, which led to a 29% reduction in freshwater lens thickness (and volume) for a 0.4 m MSL rise and current rainfall.

A number of the scenarios in World Bank (2000) looked at decreasing rainfall in conjunction with MSL rise and possible reduction in mean annual rainfall. These are worse scenarios than those that would now be used, as Kiribati is projected to have significant increases in mean rainfall. This would mean that the changes to the freshwater lens shown in Table 17 are less optimistic than would be the case if similar groundwater modelling was now done.

The conclusion from the above analysis is that a small rise in MSL (within the upper bound of the projected MSL rise to 2030) would have no detrimental impact on the freshwater lens unless land is inundated due to the MSL rise.

The remaining question for the current study, therefore, is whether an MSL rise of 0.17 m would be expected to cause long-term inundation and loss of land, and hence consequent loss of fresh groundwater.

A study of impacts on Bonriki was conducted by NIWA (2008b) for two possible MSL rises of 0.49 m and 0.79 m in a 20 year period centred on 2090 (refer section 4.3.4). From inundation maps for Bonriki which showed some inundation of the island on the lagoon side, White (2010; 2011a) estimated that the sustainable yield of the Bonriki freshwater lens could be reduced by about 20% by 2030. This reduction was applied to all groundwater yields for Tarawa in a recent master plan study (White, 2011a). It was noted, however, that the estimates of inundated land area require high resolution topographic information (contours to 0.1 m) which was not available. Rather, available 1 m contour maps were interpolated. As a result, the area of inundation is only approximate.

Further work is required to assess the vulnerability of shorelines to erosion due to mean sea level rise (White and Falkland, 2010). It is also noted that erosion of shorelines due to extreme events such as major waves from storms or cyclones is more likely to affect low-lying coastal areas and small islands than a gradual change in sea level (Woodroffe 2007). Webb and Kench (2010) show that many reef islands have remained largely stable or increased in size over the past 20-60 years. These results are contrary to the widespread perceptions that all atoll/reef islands are eroding in response to recent sea level rise. Some are likely to erode, as at present, while others are likely to remain stable with the type and magnitude of changes varying (Webb and Kench, 2010). A better understanding of the processes and impacts on small islands, and coastal areas of larger islands, due to sea level rise is required.

5.7 Impact on water demand

Projected air temperature increases are important as they can impact on evaporation and also on water demand.

Increases in air temperature could increase the demand for water. Given that the maximum monthly rise in projected temperature by 2030 is 1.3ºC under the PCCSP “largest change” condition (refer section 4.2.5), the increase in water demand due to temperature rise is not expected to be significant. The highest projected mean monthly temperature rise under the PCCSP “most likely” condition by 2030 is 1.1ºC for western Kiribati.

In a recent study of future water demand to 2030, as part of a water master plan for Tarawa, Kiribati, White (2011a; 2011b) made a small per capita increase in potable water demand of 2 litres per person per day (L/p/day) to cater for a potential temperature increase of 1°C (very similar to the PCCSP projected mean monthly temperature rise by 2030). The allowance for an increase in per capita demand for Tarawa represents only a small increase in total water demand (approximately 3% increase in the design potable water demand of 60 L/p/day and a 2% increase in the design total water demand of 90 L/p/day). For the present Tarawa population of approximately 56,000 (preliminary estimate from national census of 2010), the water requirement to meet the increased demand of 2 L/p/d would be approximately 110 kilolitres per day (kL/day). For the lower bound population of 84,000, the increase in demand of 2 L/p/d would be approximately 170 kL/day, which again is about 2% of the total water demand.

To put this potential increase in water demand for Tarawa due to projected temperature rise in perspective, it should be noted that the following two factors have a much higher impact on water demand:

- Population increase. The population on Tarawa is expected to increase from the 2010 population to between 84,000 and 110,000 by 2030 based on upper and lower bound population growth rate estimates (White, 2011a; 2011b). Using these future population estimates, the future daily water production is estimated to be between 5,700 and 7,400 kL/day, assuming no losses from pipe distribution systems.
- Losses from pipes. Based on current pipe distribution system losses (mainly leakage) of about 50% of production, the total water supply production in 2030 would be between 11,400 and 14,900 kL/day. Even with an ongoing and effective water leakage control program, losses are unlikely to be reduced to and remain below 25% of production. Assuming the best case scenario in 2030 of the lower bound population estimate and a system loss of 25%, the total water required would be approximately 7,600 kL/day (White, 2011a; 2011b).

Overall, the projected air temperature increases to 2030 are unlikely to have a significant impact on water demand.

5.8 Comparison of risks to water security

A number of potential impacts on, or risks to, water security have been outlined under both current climate conditions (section 3) and climate change conditions (section 5). These risks are related to both climatic and non-climatic factors in relation to water resources, water demand and water infrastructure, particularly water supply systems.

A summary of the potential impacts according to four selected factors (water resources, water demand, water infrastructure and water governance) are listed below for current climate conditions and for projected climate change conditions.

(a) Water resources

For current climate conditions

- Pollution of surface water and groundwater
- Salinisation of groundwater due to over-pumping
- Salinisation of groundwater in low-lying areas due to partial overtopping by waves from current storms, cyclones or earthquakes

For projected climate change conditions

- Reduced availability of surface water and groundwater due to reductions in rainfall
- Partial salinisation and reduced availability of groundwater due to sea level rise

(b) Water demand

For current climate conditions

- Increasing demand due to increasing population and development of agriculture and industry
- Increasing demand due to increasing per capita demand, as expectations increase especially in urban areas

For projected climate change conditions

- Increased demand due to air temperature increase

(c) Water infrastructure

For current climate conditions

- Damage and destruction from natural hazards (cyclones, landslides, earthquakes, volcanic eruptions, tsunamis)
- Leakage and other losses in pipe distribution systems
- Damage and destruction from vandalism

For projected climate change conditions

- Damage and destruction from higher flooding due to increased rainfall intensity
- Damage due to rising sea levels
- Higher rate of deterioration due to higher temperature

(d) Water governance and management

For current climate conditions

- Inadequacies in management, protection and conservation of water resources due to lack of legislation, policies and plans, inefficient and/or ineffective water sector administration, lack of human and financial resources, lack of consultation with and participation by affected communities
- Inadequacies with water supply systems due to poor planning, management, operation and maintenance leading to impacts on water infrastructure and ability of systems to cope with present demand

For projected climate change conditions

- No change to above

Table 18 provides a summary of the risks to water security by the factors and their potential impacts listed above. Risks are shown, in qualitative terms, for current climate conditions and for projected climate change conditions. The latter is shown as the increased risk compared with current climate conditions. Because Table 18 relates to all 15 countries, the results are necessarily broad-based. It would be more useful to prepare such a table for each country to identify the relative water security risks in each country. However, such a task is well beyond the scope of this report.

From the risks shown in Table 18, the following comments are made:

- In general, the highest risks to water security are from increasing water demands due to population increase and other activities and pollution of water resources.
- Increasing water demands based on current annual population growth rates in urban areas by between 2.6% and 4.8% (refer section 2.4), have the potential to increase water demands in 2030 by between 70% and a very large 240%. The largest estimated increase is for Dili, East Timor based on the current population growth rate (which may not continue).
- The loss of freshwater resources due to pollution is hard to quantify. Pollution, especially faecal pollution, has the potential to degrade water resources leaving some effectively unsafe and unusable except for limited purposes. In most cases, water treatment systems can be installed to improve the water quality so the impact is one of additional cost rather than total loss of the resource.
- Contamination of fresh groundwater due to seawater intrusion from over-pumping is also hard to quantify. The process is reversible if pump rates are reduced to sustainable levels. The main impact would be the cost of developing additional water sources once the pump rates were reset in order to meet the required water demand.

Table 18 Summary of risks to water security

Factors and potential impacts	Risk to water security	
	Under current climate conditions	Increased risk due to climate change
Water Resources		
Under current climate conditions		
• Pollution from all sources	Very high	None
• Salinisation due to over-pumping	Moderate to high on some islands	None
• Salinisation of groundwater due to waves overtopping	Moderate for some islands	None
Due to projected climate change		
• Reduced availability due to reductions in rainfall	Not applicable	None to high
• Reduced availability of groundwater due to sea level rise	Not applicable	Moderate for low islands and coastal areas on high islands
Water Demand		
Under current climate conditions		
• Increasing demand due to increasing population and associated development of agriculture and other activities	Very high	None
• Increase due to increasing per capita demand	Moderate	None
Due to projected climate change		
• Increased demand due to temperature increase	Not applicable	Low
Water Infrastructure		
Under current climate conditions		
• Damage/destruction from natural hazards	Low to high	None unless cyclone become more frequent and/or severe
• Leakage and other losses in pipe distribution systems	High	None
• Damage/destruction from vandalism	Moderate for some islands	None
Due to projected climate change		
• Damage/destruction from higher flooding	Not applicable	None on low islands, moderate on high islands
• Damage due to rising sea levels	Not applicable	Low on low islands and coastal areas on high islands
• Higher rate of deterioration due to higher temperature	Not applicable	Low
Water Governance and Management		
Under current climate conditions		
• Inadequacies in management, protection and conservation of water resources	Moderate to High	None
• Inadequacies with water supply systems	Moderate to High	None
Due to projected climate change		
• Nil	Not applicable	None to moderate

From a comparison of the climate and non-climate related impacts and risks, the following comments are made:

- For the four countries showing reductions in seasonal surface water availability (Fiji, Tonga, Vanuatu and East Timor), the reductions due to the "most likely" conditions are between 3% and about 25% (refer Table 15). For the lower probability, "largest change" conditions, the reductions in surface water are between 7% and about 60%. The largest reduction is for East Timor.

- For the five countries showing reductions in annual groundwater availability (Fiji, Niue, Tonga, Vanuatu and East Timor), the reductions due to the "most likely" conditions are between zero and 2% (refer Table 16). For the lower probability, "largest change" conditions, the reductions in surface water and groundwater availability are between 7% and 20%. Again, the largest reduction is for East Timor.
- If the "most likely" conditions for both streamflow and groundwater recharge above are used, then the impact of projected climate change on the main drivers of water resources (streamflow and groundwater recharge) show reductions less than 25% for the worst case scenario (streamflow in East Timor). While significant, this is much less than the demand on water resources which could be as high as 200% or more.
- The reduction in water resources availability due to mean sea level rise is hard to quantify. If the assumption made for Tarawa of a 20% reduction in groundwater sustainable yield is applied to other similar small islands, the impact of this projected climate change is again significant but relatively small compared to the large demand on water resources due to population increase.
- Leakage from many urban pipe distribution systems is 50% or higher. This loss of potential usable freshwater is greater than the effect of projected climate change impacts on streamflow, groundwater recharge and the assumed loss of 20% of groundwater resources on low islands.
- The impact of temperature rise on water demand based on the 2% increase used for Tarawa is insignificant compared with the other impacts.
- Impacts of natural hazards such as overtopping waves due to cyclones and tsunamis, while devastating in the short to medium-term, may not lead to a long-term loss in groundwater resources unless major changes in landform are experienced. Also, damaged infrastructure can be repaired or new infrastructure installed if communities have and use the opportunity to resettle to higher ground.
- Impacts from poor water governance and management are considered to be moderate to high on overall water security. While these factors do not directly lead to a loss of water resources, they can lead to poor decisions about water resources development and protection. This can cause further water quality degradation on existing developed water resources due to lack of action regarding encroachment onto water protection areas. Poor governance can also lead to other problems including delays in implementing much needed water augmentation works for existing populations.
- Impacts from vandalism are also considered to be moderate on overall water security. Vandalism can cause damage to infrastructure with temporary loss or reduction in water supply services. Damaged infrastructure can be repaired or replaced but this can be expensive and time consuming.
- Impacts from works that alter existing coastlines making them more vulnerable to erosion, or gravel mining that exposes shallow groundwater to direct evaporation can potentially lead to a loss of groundwater resources due to man-induced erosion of land or increased evaporation.

In summary, non-climate related factors of increasing water demand due to increasing population and leakage from pipe systems pose the greatest risks to water security.

5.9 Water security implications for vulnerable groups

The main vulnerable groups of people in terms of water security from both climate and non-climate related factors are those living in:

- Crowded urban and peri-urban areas, which are at major risk because of lack of adequate water supply and the need to make use of polluted sources. Water security issues associated with these groups are provided in section 3.5.1.

- Remote islands, which are at risk during droughts if the local water resources are depleted (e.g. rainwater tanks) or become saline (groundwater) and require importation of water. Examples are provided in 2.5.7.
- Remote parts of larger islands (e.g. PNG), which are at risk during droughts if water resources are depleted and food crops fail, due to the difficulty of access for emergency assistance and the time taken to regrow crops once rainfall returns to normal.
- Very low level parts of islands, which are at risk of overtopping, erosion and temporary salinisation of groundwater from waves caused by cyclones or tsunamis in addition to potential inundation from projected sea level rise. Examples are provided in sections 3.4 and 5.6.

5.10 Regional variability

The Scope of Services (Annex A) requests a description of any “significant regional variability or common needs or issues with respect to the climate change implications for water security across the region”.

The main sources of variability in impacts on water security across the study region are the differences in projected rainfall changes between countries and the types of human settlements within and between countries. Added to these factors are major differences in island size, geology, topography and in the risks from geological hazards and human activities, all of which have an impact on water resources and water security.

The countries showing a projected reduction in mean rainfall form a subset of all the countries with potentially greater impacts on water resources in future. If only the “most likely” condition is considered, these countries are Tonga, Vanuatu and East Timor. If the “largest change” condition is considered, additional countries in this subset are Fiji and Niue. Within this subset, however, there are significant differences in other factors most notably population pressures on water security. The largest difference is between the low population density and declining population of Niue and the higher population densities and growth rates, particularly in urban areas, of the other countries.

The other main subset are the countries with projected much wetter conditions. These include Kiribati and Nauru under the “most likely” condition and also PNG, RMI and parts of Cook Islands and FSM under the “largest change” condition. Within this subset there are very large differences associated with human settlements and activities. The main distinction in this subset is between the crowded urban areas on the small atoll islands of Tarawa, Kiribati; Majuro, RMI and the largely rural population of PNG.

6. Review of Experiences to Improve Water Security

6.1 Overview

There have been many water (and sanitation) sector programmes and initiatives within the 14 PICs and East Timor with the aim of improving water security.

Many recent programmes and initiatives have been implemented with a recognition of potential climate change impacts but with a primary focus on more immediate needs such as providing improved water supplies to cater for population growth and development. Many projects have focused on water governance, water resources assessment, water supply development and management, capacity building and training, and community education and awareness. These improvements are required regardless of the additional stresses imposed due to climate change. The ultimate aim of these projects is the improvement of water supply for rural and urban communities, agriculture and, in some cases, hydroelectricity generation for the current and future population. Other projects have been or are being implemented to install new water supply systems or reconstruct/rehabilitate existing systems for communities devastated by natural disasters (e.g. in Solomon Islands and Samoa: refer section 3.3).

Water sector projects which aim to improve water security through proper planning, design and implementation and which cater for current climate variability are also building resilience into physical and human systems which can assist in coping with future climate change.

It is also noted that many water infrastructure components have been built with design timeframes of typically 20-30 years which are similar to the timeframe adopted for this report (2030). Within this timeframe, many existing systems will need to be re-evaluated for their ability and capacity to supply the ever-increasing populations, especially in urban centres, of the selected countries. It is possible that alternative water technologies which are not commonly used in the selected countries, or are yet to be developed, will be available and affordable to enable these countries to cope primarily with future water demands and at the same time with impacts from climate change.

6.2 Pacific Islands

6.2.1 Outline

There have been many regional water sector support programmes and initiatives within the PICs, some of which are ongoing. These have been funded by various agencies including the European Union (EU), Asian Development Bank (ADB), World Bank, the Australian Agency for International Development (AusAID) and the New Zealand Aid Programme (NZAP, formerly NZAID). Many of the regional programmes within the PICs have been planned, coordinated and/or implemented through the former SOPAC Water and Sanitation section (now SPC Applied Geoscience & Technology Division, here referred to as “SPC-SOPAC”).

Country based programmes have largely been implemented through biltateral development aid donors including AusAID, NZAP, United States Agency for International Development (USAID), Japan International Cooperation Agency (JICA) and a number of other countries including Canada, Republic of China and Taiwan. Non-governmental organisations (NGOs) have also provided considerable assistance in the selected countries.

Some of the main water sector programmes and initiatives within the past decade are listed below.

6.2.2 Pacific Regional Action Plan

A consultation meeting of water sector personnel from 18 Pacific island countries and territories, and from regional organisations, was held in Fiji in 2002 in preparation for the 3rd World Water Forum. This Regional Consultation on Water in Small Island Countries included delegates from all of the 14 PICs and East Timor represented in this study plus American Samoa, New Caledonia and Maldives.

The main outcomes of the consultation meeting were the papers and proceedings report (Carpenter et al., 2002) and the Pacific Regional Action Plan on Sustainable Water Management (SOPAC, 2003). The "Pacific RAP" built on previous work and laid the foundations for much of the water sector programmes and initiatives that have been undertaken in the past decade.

While nine years have elapsed since this meeting, the Pacific Regional Action Plan on Sustainable Water Management (SOPAC & ADB, 2003) or "Pacific RAP" is still relevant today. It covered six main themes (Water Resources Management, Island Vulnerability, Awareness, Technology, Institutional Arrangements and Finance). The Communiqué from the meeting, signed by relevant Ministers or Heads of water agencies (refer Annex E) contains the key messages from each of the six themes.

These key messages clearly outline the needs of the water (and sanitation) sector to cope with current and future pressures on often limited water resources caused by increasing populations, non-climate hazards, and climate variability and climate change. This has been recognised in later documents including WHO & SOPAC (2008) and Pacific position papers for the 4th and 5th World Water Forums held in 2006 and 2009.

6.2.3 Pacific Dialogue on Water and Climate

In parallel with the 2002 regional consultation meeting, a Pacific Dialogue on Water and Climate was held. The synthesis report from the dialogue (Scott et al., 2003) focused on the first two themes covered in the Pacific RAP (water resources management and island vulnerability).

Within the theme island vulnerability, climate variability and climate change were considered in the context of water resources vulnerability. In addition, non-climate hazards of geological origin and from human activity were considered.

The key messages arising from the Pacific Dialogue on Water and Climate were:

- Strengthen the capacity of small island countries to conduct water resources assessment and monitoring as a key component of sustainable water resources management.
- Develop capacity to enhance the application of climate information to cope with climate variability and change.
- Change the paradigm for dealing with Island Vulnerability from disaster response to hazard assessment and risk management, particularly in Integrated Water Resources Management (IWRM).

Since 2002, these messages have been re-iterated in several documents (e.g. WHO & SOPAC, 2008; Overmars and Gottlieb, 2009). There have been several programmes which address these messages, as outlined in the following sub-sections.

6.2.4 Regional water sector programmes

A brief overview is provided below of Pacific regional water sector programmes and initiatives, some of which are directly concerned with the linkages between climate and water and all of which are concerned with improving the capacity of the water sector including its resilience in the face of increasing impacts from population pressures and climate variability and change.

These include the following programmes and initiatives being implemented or completed within the recent past by SPC-SOPAC or its predecessor, SOPAC. Further information on most of these programmes and initiatives are provided in SOPAC (2011). Earlier programmes and initiatives are outlined in Carpenter and Jones (2004).

- **Support to Disaster Risk Reduction in Eight Pacific ACP States Project.** This multi-country project, funded by the EU, is focused on eight PICs (as well as others in Africa and the Caribbean). Four of these countries (Nauru, RMI, Tonga and Tuvalu) have or have had projects that are focused on improving water security. The projects have included (but not limited to) repairs to large rainwater storage tanks and catchment roofs (Nauru), installation of rainwater tanks and groundwater protection measures (RMI), upgrading of groundwater pumping stations (Tonga), and local fabrication and installation of rainwater tanks and provision of water tanker (Tuvalu). A detailed assessment of options and recommendations for improvements for Nauru's water supply are presented in SOPAC (2010).

- **Pacific Integrated Water Resources Management (IWRM) National Planning Programme**. This programme, funded by the EU, is being implemented in the 14 PICs (the same as those in the PASAP project) and aims to improve water resources management by supporting the development of national frameworks/policies and plans (including water legislation and policy, inter-sectoral water coordination committees, water partnerships and water use efficiency strategies).
- **Pacific IWRM Project (Sustainable Integrated Water Resources and Wastewater Management Project in Pacific Island Countries)**. This project is funded by the Global Environment Facility (GEF) through the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP). It is being implemented in 13 PICs (all except Kiribati). A series of reports were developed to identify key national priorities ("hot spots") and situation analyses ("diagnostic reports"). From these activities, demonstration projects using IWRM principles were developed for these PICs and are currently being implemented. Further information on recent and past activities is available at website http://www.pacific-iwrm.org/.
- **Pacific HYCOS Project**. This project was funded by the EU and implemented in the same 14 PICs by SOPAC (SOPAC, 2007b). It was developed under the World Hydrological Cycle Observing System (WHYCOS) programme of the World Meteorological Organisation (WMO). Other collaborating partners in the project include the United Nations Educational, Scientific and Cultural Organisation (UNESCO) and the Fiji Meteorological Service. The project was designed to assist the water agencies in these PICs to further develop knowledge and understanding of their water resources. This was done through provision of hydrological equipment for both surface and groundwater resources, and strengthening of technical capacity to carry out water resource monitoring. The project finished in late 2010 when funding ceased (SPC-SOPAC, 2011). The project continues in a much-reduced role from the regular SPC-SOPAC budget. One item that will be finalised is a Catalogue of Rivers for PICs with surface water resources.
- **Pacific Drinking Water Safety Plan (DWSP) Project**. The DWSP Project was administered jointly by WHO and SPC-SOPAC with initial funding from AusAID. The need for drinking water supply management was highlighted during the Pacific consultation meeting in 2002 (Carpenter et al., 2002; SOPAC & ADB, 2003) and the Pacific Framework for Action on Drinking Water Quality Monitoring (WHO, 2005). The project was implemented in five PICs (Cook Islands, Fiji, Palau, Tonga and Vanuatu). DWSP is a "comprehensive risk assessment approach that encompasses all aspects of the water supply from catchment to consumer, to consistently ensure the safety of drinking water supplies" (WHO, 2004). While this project has ceased, the activity continues in a reduced manner from the regular SPC-SOPAC budget.
- **Pacific Water Quality Monitoring Project**. This project was administered jointly by WHO, SPC-SOPAC and the Institute of Applied Sciences of the University of the South Pacific. The project aimed to improve and strengthen their water quality monitoring capacity in PICs and is supported by SPC-SOPAC. The project produced a number of training packages for sanitary surveys and water quality monitoring. This project has also ceased but continues in a reduced manner from the regular SPC-SOPAC budget.
- **Pacific Water Demand Management Project.** This project, funded by the former NZAID, was conducted in Cook Islands, FSM, RMI, Niue, Solomon Islands and Vanuatu. The project was focused on management of existing water supplies including leakage control programs, and encouragement of wise water use. This project has ceased. Leakage control activities are now coordinated by the Pacific Water and Wastes Association, PWWA (see below).
- **Rainwater Harvesting Project.** This project was implemented in Tonga with funding from UNEP. The project produced guidelines for rainwater harvesting (SOPAC, 2004a) and a manual for training in rainwater harvesting (2004b). This project has ceased.

- **Pacific Partnership Initiative on Sustainable Water Management**. This initiative maintains a Water Action Matrix Database that aims to monitor the implementation of the Pacific RAP (SOPAC, 2003) by all partner organisations in the Pacific region. It also produces the quarterly Pacific Water Newsletter which provides water and sanitation information to Pacific Island governments, professionals, non-government and community based organisations, researchers, private sector and counterparts in the donor community who are interested in water sector issues and initiatives. The 25th newsletter was emailed to recipients in March 2011.

Other regional programmes related to climate vulnerability and change and which are at least partially related to the water sector in terms of responses or adaptations are:

- **Pacific Climate Change Science Program (PCCSP).** This project is funded by the Australian Government and implemented by CSIRO and ABoM (refer section 4.1). Further information is available through website http://www.climatechange.gov.au.
- **Pacific Islands Climate Prediction Project (PI-CPP).** This project is funded by the Australian Government and implemented by ABoM. This project has developed a PC-based climate prediction software package (Seasonal Climate Outlook for Pacific Island Countries, SCOPIC) and provided training in its use to National Meteorological Services (NMSs) in PICs. It has also facilitated linkages between NMS staff and other agencies in each country that have a need for climate forecasting information, and provided training to other agencies in the effective use of the predictions. The seasonal outlooks based on either SOI or SSTs are useful for planning ahead for droughts and wet periods. Further information is available at website http://www.bom.gov.au/climate/pi-cpp/.
- **Pacific Adaptation to Climate Change (PACC) Project**. This Pacific regional project is funded by the GEF and administered by the Secretariat of the Pacific Regional Environment Programme (SPREP). There are 13 PICs involved in the project with Kiribati being the only country not included. Kiribati did not join as it was already implementing a bilateral adaptation project (Kiribati Adaptation Programme: refer section 6.2.5). The PACC project's objective is to enhance the capacity of the participating countries to implement adaptation measures in key sectors to deal with climate change, including climate variability. The PACC project has planned demonstration water management measures for five PICs (Nauru, Niue, RMI, Tonga and Tuvalu) all of which are dependent on groundwater and/or rainwater (Hay, 2009). Further information is available at website http://www.sprep.org/climate_change/PACC/index.asp.
- **Pacific Islands Climate Update (ICU).** This monthly newsletter provides regular updates on climate and rainfall forecasts for the 14 PICs plus other countries and territories in the Pacific region (including island groups within French Polynesia, New Caledonia, Pitcairn Island, Tokelau, Wallis & Futuna). The project is a collaborative effort between NIWA and other meteorological services (in the Pacific and elsewhere). Funding is provided by NZAID with additional support from the National Oceanic and Atmospheric Administration (NOAA) and SPREP. Further information is available at website http://www.niwa.co.nz/our-science/climate/publications/all/icu.
- **South Pacific Sea Level and Climate Monitoring Project (SPSLCMP)**. Details are provided in section 4.3.4. Further information is available at website http://www.bom.gov.au/pacificsealevel/.

Other ongoing regional initiatives with major focus on the water sector, or a significant component related to the water sector are:

- **Pacific Water and Wastes Association (PWWA)** is a regional association of water and wastewater sector organisations within the Pacific region. Its membership also includes international water authorities, private sector equipment and services supply companies, contractors and consultants. Further information is available at website http://www.pacificwaterassociation.org/.
- **The Pacific Region Infrastructure Facility (PRIF)** is a multi-partner infrastructure coordination and financing mechanism initiated in 2008 by ADB, AusAID, NZAP and World

Bank (PRIF, 2009). Its aim is to support PICs with infrastructure planning, development and management for five sectors: water and sanitation, waste management, transport, telecommunications and energy. The current partner countries for PRIF are 12 PICs from the current study region except Fiji and PNG. Current projects in the water and sanitation sector are the Kiribati Sustainable Towns Programme (NZAP funded), Preparing the Tarawa Sanitation Improvement Project (Kiribati, ADB funded), Urban Water Supply and Sanitation Sector Project (Samoa, ADB funded) and Port Vila Urban Planning and Management Program (Vanuatu, ADB funded). Further information is available at website http://www.theprif.org/home.

At a recent Strategic Planning session as part of the establishment of the new SPC-SOPAC (i.e. SPC Applied Geoscience and Technology Division), it was recognised that the current focus on climate change adaptation provides an opportunity to implement "no-regrets" water management strategies (i.e. strategies that should be implemented in any case as part of good water management). Using the three key messages from the Pacific Dialogue on Water and Climate above, future emphasis in the following areas was encouraged (Marc Overmars, pers. comm., February 2009):

- Support for continued water resources assessment and monitoring, building on programs such as Pacific HYCOS.
- Support for wider use of climate information, building on programmes such as the Pacific Island Climate Update and the Pacific Climate Change Prediction Project.
- Support for "mainstreaming" of risk management into water supply and sanitation and water resources management (i.e. IWRM) through activities such as incorporating climate risk assessments into Drinking Water Safety Planning and inclusion of flood and drought management into IWRM.

SPC-SOPAC intends to coordinate National Water, Sanitation and Climate Outlooks through relevant national agencies for each PIC to assess progress since the Pacific RAP in 2002 and to identify specific needs for the future.

6.2.5 Country water sector programmes

There are many recent and ongoing country-based water sector programmes and projects (both biltateral and multi-lateral) in the 14 PICs and East Timor. It is beyond the scope of this report to report on all of these.

One of the most relevant country-based programmes covering the linkage between climate change adaptation and the water sector (as well as other sectors) is the Kiribati Adaptation Programme (KAP). In 2004, Kiribati was selected with Columbia as the first two countries to benefit from the Strategic Priority on Adaptation funding from the GEF. Funding was provided jointly by a number of agencies including GEF, World Bank, AusAID and NZAID.

The initial phase of KAP (KAPI) included a national consultation to identify priority issues in relation to climate change and its implications. The consultations ranked seven water improvement or adaptation strategies, especially related to the provision of adequate and safe water, in the top 10 of the full list of 50 covering a range of sectors. Following this, a number of water and other sector pilot projects were recommended for implementation as part of the second phase of KAP (KAPII).

Selected project activities and outcomes of the KAPII water component, largely funded by AusAID, have included:

- Development of a National Water Policy and a National 10 Year Implementation Plan (Government of Kiribati, 2008a, 2008b). This policy and plan were approved by the Cabinet of the Kiribati Government in early 2009.
- Establishment of a national water body, the National Water and Sanitation Coordination Committee.
- Development of a Tarawa Water Master Plan outlining water needs, options and recommended strategies to the year 2030 (White, 2011a).

- Leakage reduction study for part of the island of Betio, Tarawa (Pipeline Network Analysis, 2010).
- Groundwater resource and rainwater harvesting assessments in North Tarawa and two outer islands of Kiribati (e.g. GWP Consultants, 2011).
- Groundwater development project for a secondary school in North Tarawa.
- Rainwater harvesting and master plan for the (limestone) outer island of Banaba (GWP Consultants, 2010).
- Capacity building and training at the Water Engineering Unit, Ministry of Public Works and Utilities in key areas including groundwater monitoring, analysis and reporting.

Despite criticisms of lack of progress with the activities of KAP (e.g. Storey and Hunter, 2010), the above-mentioned water sector activities have assisted in improving water security, particularly in relation to policy and planning.

The key point about the above water sector activities is that they are all essential components of good water management irrespective of climate change. They all aim to assist the government, water agencies and the community to be more resilient to a range of stresses including increasing water demand, inadequate water supplies, pollution of water resources as well as the impacts from climate variability and climate change.

6.3 East Timor

In recent years, there have been various projects and initiatives to improve water resources management and thus improve water security in East Timor. These have included the following activities:

- Preliminary assessment of the country's water resources availability and water demands (Yance, 2004; Furness, 2004)
- Preparation of a situation analysis of the water sector (Costin and Powell, 2006).
- Establishment of the Directorate for Water Resources Management in the Ministry of Infrastructure and the position of Water Resources and Climate Adaptation Advisor attached to it. Functions include water resources assessment and monitoring, impact assessment of droughts and floods; preparation of plans for water resources development and management, and preparation of proposals for legislation and regulations.
- Preparation of a draft national water supply policy (Ministry of Infrastructure, 2010) and later a draft national water resources policy (Ministry of Infrastructure, 2011). The goal of the water resources policy is to "ensure all East Timorese people can have access to safe, adequate and affordable sources of water for drinking, sanitation, food security and other human needs, with respect given to traditional and cultural practices, and the natural environment." The water resources policy also:
    - States that priority for allocation of water will be given to domestic and public health uses.
    - Refers to the formation of a national apex body, the ministerial Water Resource Council with support from a Technical Group comprising "representatives from relevant authorities, stakeholders and can also include user groups, community leaders, donors and non-government organizations and will include female representatives".
    - Adopts an IWRM approach as a continuous process of coordinated and participatory development and management of water resources to achieve the efficient and sustainable use of water.
- Rural water supply and sanitation improvement projects (Government of Timor-Leste, 2008; Dwan, 2008; IDSS, 2010). The draft national water supply policy (Ministry of Infrastructure, 2010) noted that sustainability of water supplies is of fundamental importance, especially for rural water supplies, which serve most of the people. A review of rural supplies in four

districts in 2008-2009 showed that about 50% or new water supply schemes lasted less than two years. Under-funding of operation and maintenance and aging infrastructure has led to major problems with urban water supply. The policy also recognised the water sector's shortage of human resources capacity.

- Planning and commencement of infrastructure improvements for urban water supplies for Dili, New Baucau and Pante Macassar, Oecussi (GHD, 2007; 2008; Lindsay Furness, pers. comm., 2011).
- Assessment of hydropower potential including the establishment of seven streamflow recording stations (Lindsay Furness, pers. comm., 2011).
- Community-based integrated water management in selected catchments (e.g. JICA, 2008).

6.4 Linkage between water resources management and adaptation

Integrated Water Resource Management (IWRM) was defined in 2000 by the Global Water Partnership (GWP) as "a process, which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (Global Water Partnership, 2000).

There have been criticisms of this concept, as outlined for instance in AMRC (2007), one being that IWRM is "a catch all phrase and empty motto".

For the PICs, the concept of an "IWRM Island Style" was introduced by Carpenter and Jones (2004) and developed further (e.g. Waterman et al., 2007) to make it more relevant to the islands of the Pacific. A number of principles were developed, most of which are listed below:

- Island countries should manage water resources not only within watersheds (catchments) but also to take account of receiving coastal waters
- Drought and disaster preparedness planning need to be included
- Due to the small size of island countries, a national approach to capacity building, awareness and governance is needed
- The limited human and financial resource bases in island countries need regional support and collaboration
- Use should be made of international support programmes such as HELP, HYCOS and others
- Rainwater harvesting should be incorporated in water management plans to augment domestic water supply.

Further details are provided in Waterman et al. (2007).

Since 2007, there has been much activity in most of the PICs, largely co-ordinated by SPC-SOPAC, to develop practical water and sanitation projects and initiatives under the two IWRM projects, as outlined in section 6.2.4. For East Timor, a number of water projects have also been implemented in recent years with assistance from external funding agencies (refer section 6.3).

The linkage between IWRM and climate change adaptation has been outlined by the Global Water Partnership (2007) with the following key messages:

- If our global energy habits are the focus for mitigation, the way we use and manage our water must become the focus for adaptation.
- Changes in climate will be amplified in the water environment.
- Improving the way we use and manage our water today will make it easier to address the challenges of tomorrow.
- The best approach to manage the impact of climate change on water is that guided by the philosophy and methodology of Integrated Water Resources Management.

- There are no simple technical fixes.
- In addressing water shortages, as much attention should be given to managing demand as to increasing supply, by introducing more efficient technologies as well as simply promoting a culture of conservation.
- The challenge of “climate-proofing” the future requires that adequate funds are allocated today for water resource management.

In general, the above messages are applicable to water resources management in all 15 countries of the study region. The main concern is the capacity of local agencies to implement these messages. One of the main limitations to effective water resources management is outlined in the last message above i.e. that “adequate funds are allocated today for water resource management”.

6.5 Examples of good practice

The Scope of Services (Annex A) asks for “examples of mal-adaption or good practice responses to climate change in the water sector”.

Below are some of the projects that have made a positive impact on the water sector or have the potential to do so. It is noted that these do not necessarily specifically address climate change impacts but rather consider climate change as one of many stresses on water security.

Section 6.6 has some examples of mal-adaptation practices.

6.5.1 Water governance

Key water governance instruments are water policy and plans, water legislation and national water and sanitation coordinating committees (or “peak bodies”) to facilitate dialogue and decision-making between water agencies and other interested stakeholders including NGOs and representatives of civil society.

In many countries, key documents related to water governance (e.g. draft water policies and legislation) have been available for a number of years but have not been formally adopted by governments. In others, recent steps have been taken to develop draft documents and in a few cases these have been approved by governments.

Peak water committees consisting of government water agencies and in some cases wider groups have been established in some countries. In many cases, these committees lie dormant and have not met for some years.

Table 19 provides a summary of progress on key water governance activities in each of the 15 countries. Green cells in the table means that the item has been formally adopted, yellow cells means that a draft or interim version exists and red cells means the item does not yet exist.

While some items are shown in green, this does not mean that the item is fully functioning.

Table 19 Summary of water governance progress for the 15 countries

Country	Water and Sanitation Policy	Water Legislation	National Water and Sanitation Committee or similar	IWRM Plan(s) or similar
Cook Is	🟨	🟨	🟨	🟥
FSM	🟥	🟥	🟥	🟥
Fiji	🟨	🟨	🟩	🟨
Kiribati	🟩	🟥	🟩	🟩
Nauru	🟨	🟥	🟨	🟨
Niue	🟨	🟨	🟨	🟥
Palau	🟥	🟥	🟨	🟥
PNG	🟨	🟨	🟨	🟥
RMI	🟨	🟥	🟥	🟨
Samoa	🟩	🟨	🟨	🟨
Solomon Is	🟨	🟨	🟨	🟥
Tonga	🟥	🟨	🟨	🟥
Tuvalu	🟥	🟥	🟨	🟨
Vanuatu	🟩	🟨	🟨	🟨
East Timor	🟨	🟨	🟨	🟨

Notes: Information for PICs was obtained from SOPAC (2011), Rhonda Bower, SPC-SOPAC and Ian White, ANU. Information for East Timor was obtained from Lindsay Furness, National Directorate for Water Resources Management, Ministry of Infrastructure. Legend: green: the item has been formally adopted, yellow: draft or interim version exists, red: item does not yet exist.

From Table 19, it is evident that there are many further steps to be taken to improve the water governance in most countries. As stated in White et al. (2007), “there has been a general reluctance to announce national water policies, enact national water legislation, define rights and responsibilities, adopt whole-of-government approaches, and involve communities in planning and managing water and related land resources”.

In recent years, however, considerable steps have been made in this area and a number of countries have water policies, plans and legislation under review and heading towards government acceptance. Once formally accepted, the challenge remains for these measures to be implemented for the benefit of all.

6.5.2 Rainwater harvesting projects

Some of the most successful projects implemented in a number of PICs are rainwater harvesting schemes for households and community buildings. Rainwater collection at household level provides a source of good quality water, except in severe droughts, which is suitable for potable purposes with the added convenience of being close at hand. Rainwater can be best used in many countries as a supplementary source to other sources used for non-potable purposes. There are many examples of this type of project, funded by bilateral aid projects and NGOs.

In Tuvalu, about 300 polythene 10,000 litre tanks were installed under the Support to Disaster Risk Reduction in Eight Pacific ACP States Project (refer section 6.2.4). These tanks were locally fabricated using a moulding machine which was temporarily sent from Fiji to undertake the work. Some countries have their own private sector polythene tank moulding machines (e.g. Fiji and PNG).

In Kiribati, a rainwater harvesting project for households in the early to mid 2000s on Tarawa atoll was based on financing through a revolving fund. Over 700 loans were taken out from this fund to install 6,000 litre polythene tanks and associated gutters and downpipes. The project was a success story not only because of the direct benefits to households, but also as an example of a “self-help” project with householders taking responsibility for improvement to their own water security. This type of project has implications for other urban areas where householders have access to a regular income and are in a position to repay a loan.

6.5.3 Drought and flood planning

As part of climate change adaptation strategies, disaster risk reduction strategies and IWRM, the preparation of drought response plans is an essential component, as all countries are affected to a greater or lesser extent by droughts.

Steps have been taken in recent years in some countries to "change the paradigm for dealing with Island Vulnerability from disaster response to hazard assessment and risk management" (section 6.2.3).

Drought plans can be stand-alone documents or part of wider disaster response plans. A good example of a recent drought response plan is that for South Tarawa, Kiribati where 50% of the national population live. The drought response plan, which was spurred on by the recent La Niña drought in Kiribati, uses a "drought index" based on monthly rainfall to determine different levels of alert and corresponding actions required (Government of Kiribati, 2011).

Similar drought response plans would be worthwhile for other islands of Kiribati and indeed in other countries. Some countries still do not have drought response plans or they require updating (e.g. PNG: World Bank, 2009).

A number of countries have produced flood plans covering flood plain management and response to floods (e.g. Government of Samoa, 2007). This work is largely coordinated by SPC-SOPAC through the Pacific Disaster Risk Reduction and Disaster Management Framework for Action 2005 – 2015 (SOPAC, 2009).

6.5.4 Appropriate technology

Examples of appropriate technology for use in island situations are outlined in previous summary reports including IETC (1998) and Falkland (2002b).

Other reports have identified additional technologies suitable in specific circumstances.

One example of an appropriate technology is the use of horizontal infiltration galleries on low-lying coral islands, or in some coastal areas of smaller volcanic islands, for moderate to relatively high pumping rates rather than conventional vertical boreholes. Where extraction rates are small, dug wells are appropriate and are common in many village areas. However, moderate to high pumping from wells or boreholes can lead to upconing of brackish water, causing the pumped water to become saline. The reason for this is that the impact of the pumping is localised near the point of extraction.

A much more appropriate method of groundwater pumping from freshwater lenses on small coral islands is to pump from infiltration galleries (also called "horizontal wells" or "skimming wells"). Infiltration galleries (refer Figure 11) avoid the problems of saline intrusion because they spread the impact of pumping over a wider area of the freshwater lens. Infiltration galleries generally consist of buried horizontal conduits which are permeable to water, for example PVC slotted pipes (Figure 26) which are laid in trenches dug at or close to mean sea level. Once the pipes are laid and connected to one more sealed pump wells, the area is backfilled.

Infiltration galleries are successfully operating in a number of PICs including Tarawa and Kiritimati, Kiribati (Falkland and Woodroffe, 1997; White and Falkland, 2010), Kwajalein in the Marshall Islands (Hunt, 1996) and Lifuka, Tonga (TWB, 2000). On the island of Lifuka in Tonga, where groundwater pumped to the residents from a combination of wells and later shallow boreholes had traditionally been quite saline, improvements using infiltration galleries in the late 1990s significantly lowered the salinity of the water supply (TWB, 2000). The salinity of the water supply remains low to the present (from recent TWB data).

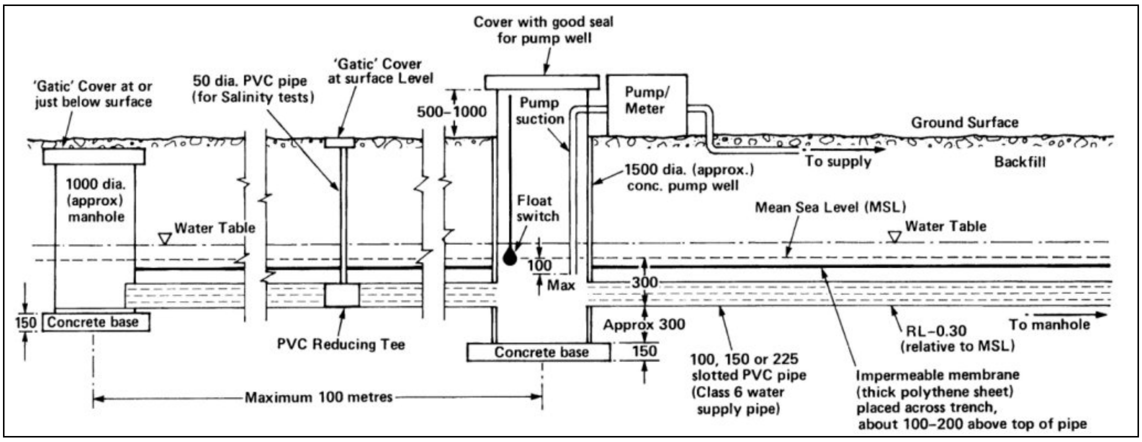


Figure 26 Cross section through a typical infiltration gallery or skimming well [modified from Falkland and Brunel (1993)

6.5.5 Relocation within islands to avoid future problems

In some countries, coastal communities on high islands that have been affected by tsunamis have relocated, or are in the process of relocating, to higher ground to avoid future similar disasters. This has the additional benefit of removing the potential problem of sea level rise into the future. Examples of countries where such relocations have occurred after such events include PNG and Samoa (refer section 3.4). New water supply sources and systems require assessment, planning and development in these situations (e.g. UNICEF, 2009a; 2009b).

Low-lying islands do not have the same option of relocation within the island often due to the small size and limited land availability.

6.6 Examples of poor practice

6.6.1 Poorly implemented projects

There are a sizeable number of projects which have (a) not achieved their original objectives through poor project management or (b) left behind infrastructure, plans or outcomes which are of inferior quality. There is no need to give specific examples here.

6.6.2 Desalination units in inappropriate settings

The performance of desalination (reverse osmosis, RO) units for water supply has generally been unsuccessful in PICs (refer section 2.5.6). Desalination is, in many cases, an inappropriate technology due to high operational costs and maintenance requirements and the need for highly skilled operators. A notable exception in recent years is on Nauru where desalination provides the primary source of freshwater in droughts due to the unavailability of both fresh groundwater and rainwater. It also provides a supplementary source in non-drought periods. On Nauru, the advantages with the installed RO units has been continual operation and regular contact between operators and the company that installed the units.

6.6.3 "Mal-administration"

On a broader scale, there are many examples of "mal-administration" in relation to water security, whether it is adapting to climate change or addressing more immediate and fundamental needs such as provision of adequate and safe water for present populations. Some examples are:

- The timeframes for most water (and sanitation) development projects and other water sector initiatives are too short to make a significant long-term difference to water security and improvements to human health. Most projects have timeframes of one to five years, whereas interventions in the water supply and sanitation sector require much longer timeframes to be of significance. This applies to all activities from water governance; water resources assessment, monitoring and management; water infrastructure improvements, capacity building for water agencies and community participation education and awareness programs. To make a significant difference, timeframes of at least 10 years and more like 15-20 years are required. One example is the Pacific-HYCOS regional project which ran for four years and then funding ceased, bringing to an end important assistance from experienced professional and technical staff at SPC-SOPAC to professional and technical personnel in PICs in the monitoring and assessment of both surface water and groundwater resources. Other examples relate to implementation of water projects where new water supply systems are installed without substantial, long-term assistance to local water utilities to address leakage and other losses from pipe networks, and to water resources agencies to manage and protect valuable water resources in conjunction with local communities. The need for long-term, coordinated and multi-disciplinary programs to deal with the water, sanitation and related health problems has long been recognised (for example, AIDAB, 1993; White et al., 2008).

- There is insufficient attention being given to water resources assessment and monitoring by national government and development aid agencies. Given that there is real concern about the possible impacts of climate change to water resources on top of existing stresses, the lack of commitment to ensuring adequate streamflow and groundwater monitoring networks can only be described as negligent. There is a lot of emphasis being given to discussions and workshops about the possible impacts of climate change on water resources without a commensurate emphasis being given to setting up systems, or at least maintaining existing ones, to measure the long-term trends in flow and groundwater systems.
- There is insufficient attention being given to staffing and resourcing of water agencies including those involved with water resources assessment and monitoring and operation and maintenance of water supply systems.
- A disproportionate amount of external project funding is often channelled into other agencies, including environmental agencies, when compared with the immediate and pressing needs of the water and sanitation agencies. Basic human needs of adequate and safe water supply and appropriate sanitation facilities, which do not pollute the local water resources, seem to be given a lower priority than they should be in the allocation of funding. There is an urgent and ongoing need for a much greater emphasis on improvements in all facets within the water and sanitation sector.

7. Practical Strategies to Improve Water Security

7.1 Overview

This section outlines strategies for managing the implications of climate change in addition to existing stresses on water security for the countries in the study region.

Key principles for these strategies are:

- Ensuring that the water sector in each of the selected countries is resilient to current climate variability, in addition to the major pressures from increasing water demand and stresses from water pollution associated with human settlements. This is the most effective overall strategy to cope with future climate change.
- Strategies to reduce vulnerability of the water sector to climate change and, thus, increase water security are essential components of good water management practice, and are required whether climate changes or not.
- There are "no simple technical fixes" (refer section 6.4) or no single action that will improve water security. Rather a range of strategies are required including improved water governance; effective assessment, development, management, protection and conservation of water resources; effective operation, maintenance and management of water supply systems and other water development schemes; enhanced community participation in the water sector and improved community education and awareness.
- Although there are some regional similarities between countries, each country is different and some have wide variations in water resources and water security between different parts of the country (e.g. high islands and low islands). The mix of potential strategies to improve water security must be adapted to suit local circumstances taking account of population growth and the pattern of settlement and development.
- Introduction of new technologies requires parallel investment in training, education and awareness to gain community and government acceptance.
- In specific circumstances, particularly in countries with limited land and water resources (e.g. crowded low-lying islands and remote islands), there are a number of options to assist in development and management of water resources.

The sub-sections below summarise strategies to improve water security under key headings. The order of these headings does not reflect priorities. Together, these can be viewed as an integrated approach to water resources management.

Further detailed information for PICs, beyond the scope of this report, is available in previous documents including those from the Pacific RAP (Carpenter et al., 2002), Pacific Dialogue on Climate and Water (Scott et al., 2003) and subsequent country-based and regional reports (especially those produced by SOPAC).

7.2 Water governance

In all countries, further work is required in the area of water governance (refer Table 19) to establish a sound institutional basis for effective management of the water and sanitation sector. In most countries, there is a need to develop or finalise draft water policy and plans and water legislation and to establish or reconvene national water and sanitation coordinating committees (or peak bodies). Coordinating committees should include representatives from the government agencies involved in the water and sanitation sector and other interested stakeholders including NGOs and representatives of civil society. In some of the larger countries, regional coordinating committees may also be appropriate.

Enhanced and ongoing commitment to the water and sanitation sector at national level is required. Improved coordination between agencies in the water and sanitation sector is essential. This can be at least partially achieved through the use of regular review and decisions about water and sanitation project proposals and other activities within the sector by a national coordinating committee.

Specific items of relevance in most countries are the need for building codes and regulations requiring appropriate rainwater harvesting facilities (gutters, tanks) for all new houses and buildings and controls on the types and locations of sanitation facilities. Other items are regulations concerning activities that are not allowable on areas designated as water resources protection zones for both surface water and groundwater supplies. Enforcement of regulations is also a priority.

7.3 Assessment and monitoring of water resources

There is a real need to improve the assessment and monitoring of water resources. This applies to all countries.

Such improvement can only occur through a commitment at national government level, supported by appropriate training, education and capacity building efforts at national and regional level.

National water resource assessments should aim towards a water resources database supported by a geographical information system (GIS) with relevant information about surface water and groundwater resources in all islands and/or regions of the country. This information should be updated with additional monitoring data. As such activities are beyond the capacity of water agencies, significant input from regional and bilateral organisations is required, along the lines of the former Pacific-HYCOS project.

Monitoring of water resources should be seen as a long-term activity and not a short-term project-related one. This is especially important now that there is an increased awareness of potential climate change impacts on water resources. There is a real need to move beyond the rhetoric and act to support water monitoring activities to better understand water resource behaviour at catchment scale into the future. Monitoring data should be processed, reviewed and reported to government through the national water and sanitation committees on an annual basis. This requires considerable and ongoing capacity building, training and development of existing water resource agencies in terms of both human and financial resources. Again, the assistance of regional and bilateral organisations is essential.

7.4 Management and protection and of water resources

Again, this is a priority issue in all countries. As mentioned earlier in this report, protection of water resources from pollution from human settlements, animals, agriculture and industry is a major requirement.

Strategies for achieving good management and protection include:

- Effective land use management and control practices including regulations concerning activities that are not allowed on water protection areas.
- Community education and awareness of the problems associated with poor land management and negative impacts on water resources through pollution.
- Community participation in catchment management and protection.

7.5 Appropriate water supply systems

The following strategies are suggested:

- Water resources development should utilise naturally occurring freshwater resources before other options such as desalination and importation are considered.
- Selection of water supply and sanitation technology should take account of all factors - technical, economic, social, cultural and environmental. Materials and equipment should be robust and protected from corrosion in the largely warm, oceanic environments of the region and technologies should be simple.

- Operation and maintenance requirements are most important factors that must be matched to the capacity of water agencies (for urban systems) and the capacity of local government and/or communities (for rural and community based systems).
- The conjunctive use of water from different sources (rainwater, surface water, and groundwater) is a most appropriate approach to water resources management in islands with scarce water resources, or where water quality has degraded. Where available, rainwater is generally the most appropriate source of water for potable purposes with other sources being used for non-potable purposes.
- Rainwater harvesting at households and community buildings should be encouraged for existing buildings and regulated for new buildings. Subsidies or, where appropriate, revolving funds to assist households to take out loans for the provision of rainwater tanks and associated materials, should be encouraged.
- Properly constructed cappings are required for water supplies using springs to rural and some urban areas so as to minimise local pollution from animal and human activity. It is also important that catchments above springs are properly managed to prevent pollution.
- Appropriate methods of pumping for groundwater supply schemes should be used. Boreholes and wells are appropriate in many circumstances but infiltration galleries should be used in low-lying islands with freshwater lenses that are vulnerable to seawater intrusion.
- At present, desalination should be seen as a realistic option for emergency and possible long-term water supply only when all other naturally occurring and available water resources have been fully committed or where the cost of development of alternative sources exceeds that of desalination. In the future, with technological improvements, desalination is likely to be a more appropriate solution for some islands such as the crowded urban areas of some atolls. This is especially so in cases where land ownership issues may present additional access problems to water resources on private or customary land.
- Sanitation methods that are non-polluting should be encouraged wherever possible. Dry composting toilets have this advantage as well as not requiring water. Introduction of this technology in PICs has, in general, not been successful to date owing to cultural perceptions.
- Use of seawater for toilet flushing water and fire fighting may be appropriate in particularly water scarce islands (as in Tarawa and Majuro). However, these systems are expensive to build, operate and maintain.
- Use of recycled wastewater is not a viable option owing to the level and cost of wastewater treatment technology required and the high operation and maintenance requirements.
- Importation of water is only an economic option in special circumstances. Examples are the importation of water by pipeline to smaller, water scarce islands from larger, nearby islands with more abundant resources (e.g. Manono Island in Samoa), and emergency shipment of water by boat or barge to water stressed islands in droughts.

7.6 Demand management

There is an ongoing need for demand management programmes to ensure that water supplied from existing water sources is used wisely, especially before any new sources are considered for development. The focus here is on urban water supply systems, as the largest water supply problems are experienced in these areas and hence the need for demand management is greatest.

Given that many urban and some rural water supply systems have extensive (above 50%) losses due to leakage in both main pipelines and household plumbing, effective leakage control programs are generally the most economical means of augmenting water supplies to meet demands. Reduction of loss rates to 20-25% is achievable in well managed systems. Reductions below these loss rates generally become much more expensive in systems that have been installed for many years.

Water supply flow and leakage monitoring is essential, especially for effective management of urban water supply distribution systems. Leakage control programmes need to become part of mainstream activities rather than short-term, project-oriented activities associated with infrastructure rehabilitation or expansion, or activities to be undertaken solely during droughts. Such programmes require regular monitoring and assessment of pipe network flows and losses using meters at water supply headworks (surface water intakes or groundwater pumping systems), within the distribution systems and at household connections.

While training and capacity building efforts have been made in this area (e.g. through SOPAC and PWWA in the PICs), many countries have not adopted leakage control as a mainstream activity. This is largely due to the lack, again, of adequate financial resources and sufficient trained personnel to conduct these efforts.

Metering of connections and appropriate water tariffs based on water usage are a means of controlling demand in well managed water supply systems. Tariffs should be structured to enable those with limited capacity to pay to obtain an allocation at no or very little cost. Tiered tariffs that charge higher rates as water consumption increases are appropriate as they encourage water conservation. Some water supply systems suffer from tampering or bypassing of meters, non-payment and non-enforcement of tariffs due to ineffective surveillance and administration in water utilities. A major effort with capacity building and community education is required where these problems occur. Technical “fixes such as tamper-proof meters have been tried but they are not the long-term answer as they often encourage more ingenious methods of obtaining water.

In rural areas, where metering of connections or standpipes is not usually implemented, it is often appropriate to charge a small flat fee to cover operational costs especially where groundwater pumping is involved (e.g. Tonga where fees are collected by village water committees).

Community education and awareness programs highlighting the need for water conservation and the wise use of water are an essential part of sustainable water resources management.

Other practical measures that assist in reduction of leakage and water demand management are:

- Designs of water supply systems should ensure adequate but not excessive pressure, as leakage rates increase with water pressure.
- Use of pipe materials that allow for effective and fewer joints should be encouraged. An example is the use of polythene pipes with mechanical compression joints rather than PVC pipes with solvent-welded (glued) joints. The former is available in long coils for diameters less than 100 mm leading to fewer joints (and less leakage). Also, in many PICs the use of non-standard jointing methods to connect PVC pipes (by heating of pipe ends over open fires to form sockets) has led to serious leakages at joints.
- Measures to reduce leakage in plumbing systems in houses and other buildings (e.g. offices, schools) can have a beneficial impact on operational costs for pumped systems. In Niue, for instance, a saving in water usage and pumping costs of over 50% was achieved by repairing leaks in household taps, showers and toilet cisterns (SOPAC, 2000).
- Water saving devices, such as spring loaded taps for standpipes and improved household plumbing fixtures (low and dual-flush toilet cisterns, low-flow taps and shower heads) can assist in water conservation. Where appropriate, introduction of dry composting toilets can reduce household consumption by 30% or more.

Some water supply systems are so dilapidated and suffering from leakage through poor joints, cracks in pipes and illegal connections that partial or whole replacement of pipe networks is required. A recent example of a full pipe network replacement occurred on the island of Mauke, Cook Islands (AMD, 2009). There the existing public water supply system consisting of a variety of pipe materials which had been installed in the 1960s and later was suffering from leaks, inadequate water quality and frequent breakdowns. The pipe network was replaced with polyethylene pipes. At the same time, old diesel powered groundwater pumps were replaced with solar powered pumps to lower operational costs and remove the source of hydrocarbon pollution from the groundwater pumping zone.

7.7 Drought and flood planning

Planning and preparation for droughts and, where applicable, floods are essential components of strategies to deal with disaster risk reduction under current climate variability and potential climate change.

Planning and preparation for droughts should include:

- Preparation of response plans.
- Forecasting (e.g. using the SCOPIC seasonal climate outlook software developed and disseminated to PICs under PI-CPP).
- Dissemination of information via community meetings, radio and other means to the public including encouragement of simple measures such as conservation of rainwater in tanks.
- Appropriate response measures including possible water restrictions and reductions in groundwater pumping. In the more extreme cases, this may also include the preparation for use of stored desalination units (e.g. RMI, Tuvalu). Reacting after a drought has commenced by declaring emergencies, as has happened in the past (e.g. Kiribati) is not a useful measure. Droughts are a reality and measures should be taken well in advance to cope with them.

Planning for floods should involve preparation of flood plain maps and response plans, as well as education and awareness of communities at risk about the impacts of floods and necessary actions to be taken if intense rainfall occurs.

7.8 Capacity building and training

As outlined in section 3.5.6, limited human and financial resource capacities are major impediments to effective water management and, as such, are major risks to water security.

There is an urgent, large and long-term need for capacity building and training within water and sanitation agencies. A combination of in-country training and development programs for technical and professional staff combined with appropriate external courses are required to build the capacity of these agencies.

Recruitment, training and on-going development of professional and technical staff in the water sector should allow for the loss of well-trained staff to more lucrative offers with consulting firms and external opportunities.

7.9 Community education, awareness and participation

As outlined in section 3.5.7, lack of, or limited community participation can lead to water management and water supply problems. There is an ongoing need to engage communities at all stages of water supply projects development and implementation as well as the long-term management of water resources and water supply systems.

Ongoing community education and awareness programs are required with emphasis on responsible water use, conservation and protection of water sources and water supply infrastructure.

7.10 Other water supply strategies for specific circumstances

Other currently available and possible water supply strategies to improve water security in specific circumstances include:

- Use of commercially available, low-pressure, easily operated and maintained water treatment systems for degraded water sources. Membrane filtration systems are available which can filter out bacteria, sediment and algae from water supplies. These filtration units can be readily installed in small island water supply systems where polluted water is prevalent. An example is the Skyhydrant membrane filtration system (Skyjuice; 2008, 2011) which has been used to treat turbid and polluted water from streams, groundwater and polluted rainwater in a number of countries within the study region (Kiribati; Fiji, and East Timor).

- Use of simple 'solar stills' to produce freshwater from seawater or brackish groundwater. They can supply basic potable water needs of households during droughts, particularly on small, remote islands or remote coastal communities on larger islands. Such systems are not difficult or expensive to construct and some companies manufacture and sell these systems. Daily freshwater production rates of 2 to 5 litres per square metre are achievable.
- A more ambitious method of producing additional fresh groundwater on coral atolls is to construct an island from lagoon sediments. Provided the land surface is similar in elevation to existing islands and of sufficient size, a freshwater lens will naturally develop over a number of years from rainfall. Approximately 5-10 years would be required before such an island could be used for groundwater pumping using infiltration galleries. The gradual "development" of fresh groundwater in "constructed islands" has been proven from reclamation studies in atolls of the Maldives where newly created land areas adjacent to existing islands, formed from dredged or excavated lagoon sand, have developed freshwater lenses (e.g. Falkland, 2000). Such an island has been suggested, for instance, in Tarawa lagoon as an option for augmenting groundwater supplies for South Tarawa (e.g. Falkland, 2003) and a proposal to conduct hydrodynamic and environmental studies as part of a pilot study was proposed as part of the Kiribati Adaptation Programme (Falkland, 2005). Advantages of such a project would be (a) the land would be owned by the government and there would be no need to pay annual rental to land owners and (b) the island's land use could be restricted to non-polluting activities such as sports fields. Disadvantages are (a) large cost of construction and (b) possible environmental impacts from dredging or removing sediment from the lagoon. This option was considered as one of a number of options in the recently completed Tarawa Water Master Plan (White, 2011). It was found that the unit production cost of water was greater than for seawater desalination. As desalination has lower costs and less potential environmental impacts, it was the preferred long-term option. There may be specific circumstances where a constructed island could be a suitable option in the future.

8. Identification of Gaps and Future Needs

8.1 Outline

This section identifies information gaps and research needs for a better understanding of the implications of climate change on water security into the future. These gaps and needs are presented according to the following categories:

- Climate change projection deficiencies and needs
- Water resources data deficiencies and needs
- Other data deficiencies and needs
- Research into impacts on surface water and groundwater resources
- Further development of effective water supply technologies.

8.2 Climate change projection gaps, deficiencies and needs

The following gaps, deficiencies and needs are identified:

- Projections of evaporation are not yet available from PCCSP.
- Current GCMs are unable to project changes in ENSO activity and hence changes to future climate variability, which is of most significance for future droughts and high rainfall periods. Also, it is "difficult to use GCMs to make robust regional projections for tropical cyclone activity under climate change" (PCCSP, 2011a). Further research and development of GCMs is required before the projections can be of significant benefit to the selected countries in terms of water resources.
- The scale of current GCMs is too coarse for the size of most of the countries within the study region. More accurate models at regional scale (approximately 50 km) and better still at a scale of approximately 10-20 km are required to be of significant benefit to water resources impact studies for small islands or significant catchments on larger islands.

8.3 Water resources data deficiencies and needs

The following deficiencies and needs are identified:

- Available rainfall data is of good quality and long duration (generally from the late 1940s or early 1950s) at a number of key locations in the study region. Other locations have shorter or discontinued records. Unfortunately, recent records from outer islands in a number of countries is of doubtful or poor quality or has ceased altogether. This is in part due to reliance on automatic raingauges in remote islands which are not visited often enough to prevent loss of data. There is a real need for a return to, or to continue, manually read (daily) raingauges in key outer islands in some of the countries (e.g. Penrhyn, northern Cook islands where regular, good quality records were discontinued in 2007).
- Available streamflow data from the selected countries is of variable quality and length. Very little is of sufficient length to be useful for climate impact studies (requiring at least 25-30 years). The longest reasonable quality streamflow records are in the order of 10-15 years. Much of the data is of poor quality and there is evidence that some data has been fabricated. While efforts have been made in recent years (e.g. though the now-ended Pacific HYCOS project in some PICs) to establish or rehabilitate stream gauging stations and provide training to local staff, it will take many more years for these stations to produce useful data. However, it is essential to continue these efforts.
- Additional streamflow gauging stations should be installed in key streams and rivers. Advice regarding appropriate sites should be obtained from national water agencies and, for the 14 PICs, from SPC-SOPAC.
- Analysis of runoff coefficients for all available surface water catchments and compilation of results into a database. This could be done through combined efforts of relevant individual

water resource agencies and SPC-SOPAC for PICs, and through the Directorate of Water Resources, Ministry of Infrastructure, Timor-Leste.

- Existing groundwater monitoring networks are not regularly monitored except during the passage of short-term projects. These include networks in Kiribati (Tarawa and Kiritimati atolls); Nauru, Niue and Tonga (Tongatapu, Lifuka and Vava'u islands). Insufficient staff, inadequate support from management, lack of transport and failure of equipment are all factors contributing to the shortage of regular monitoring data.
- Long-term funding arrangements (20 years or more) through external donors are required to support the national water resources agencies in operating and maintaining networks of streamflow gauging stations and groundwater monitoring sites. The overall costs of operating and maintaining such sites is small compared to the development costs required for surface water and groundwater schemes for urban and village water supply, agriculture and, where appropriate, hydropower projects.
- Further funding to support a regional agency such as SPC-SOPAC to continue the work of the Pacific HYCOS project in the Pacific is also required to enable support to the countries with analysis of data, training and equipment repairs. This should also be a long-term funding arrangement unlike the recent short-term (four year) Pacific HYCOS project. Similar funding arrangements should also apply to East Timor.

8.4 Other data deficiencies and needs

Topographic information for many “low islands” and low-lying parts of high islands is not of sufficient resolution to accurately assess the areas which are vulnerable to inundation due to projected sea level rise (refer section 5.6) . There is a need for improved survey information to produce topographic maps with better vertical resolution (to 0.1 m accuracy).

8.5 Research into impacts on water resources

Further research into the effects of climate variability and change on surface water and groundwater resources is warranted. The research and analysis should include the following:

- Research into relevant streamflow multipliers (refer section 5.4.2) applicable to catchments in countries of the study region with surface water resources, for use in estimating reductions or increases in mean streamflow based on mean rainfall data. This work should use relevant rainfall-runoff models and the longest available streamflow and rainfall data sets. As most data records are relatively short, use of longer streamflow records from nearby catchments in similar hydrological and environmental settings could be used. Streamflow and rainfall data for 22 New Caledonia catchments with data extending over periods from 15 to 52 years (Terry and Wotling, in press) and for catchments in the Hawaiian Islands (Oki, 2011) could possibly be used for developing streamflow multipliers applicable to similar catchments in the relevant PICs.
- Further groundwater catchment research into evaporation and recharge to groundwater (perched and basal aquifers, including freshwater lenses). This should build on earlier detailed work done in Tarawa in the mid-1990s (White et al., 2002) in a range of hydrogeological and environmental conditions.
- Ongoing research work into the vulnerability of the shorelines on low islands and low-lying parts of high islands to projected sea level rise and extreme events, such as cyclone driven waves (refer section 5.6).

8.6 Further research and development of water supply technologies

Further research and development of effective water supply technologies is required. In particular, research and development leading to improved efficiency of desalination (reverse osmosis or other methods), primarily to reduce the operational costs, is warranted. There is significant potential for desalination technology to resolve water supply problems of urban areas, particularly those on crowded atoll islands. However, current systems suffer from high operational costs and maintenance requirements.

9. Summary and Conclusions

9.1 Diversity between the selected countries

There is considerable diversity between and within the 15 selected countries in physiographic, geological, demographic and hydrologic characteristics, all of which have impacts on water resources availability and water supply systems. The land masses vary from large, mountainous islands with considerable surface water and groundwater resources to small, low-lying coral sand and limestone islands with very limited groundwater resources and no surface water resources. The populations of each country vary from 1,500 to over 6.7 million. Average country-wide population densities vary from 20 to 500 people/km^2 with some urban areas having very high densities of over 10,000 people/km^2. The percentage of urban and rural populations in the 15 countries varies from 80% rural to 100% urban.

9.2 Freshwater sources and use

The main sources of freshwater throughout the region are naturally occurring groundwater and surface water and rainwater harvested from roofs and other surfaces. Surface water is only available in some countries but fresh groundwater is available, even in limited quantities, in all countries. Desalination is not common and is only used as a primary source of water in one country. Some countries use desalination as an emergency source in droughts for urban centres. Importation of water to some small islands occurs via pipeline as a regular source of water or via barge or boat in droughts.

Water resources availability is most critical in the small coral sand and limestone islands within the region, especially in densely populated areas on some atoll islands.

The main consumptive use of freshwater in the selected countries is water supply for urban and rural communities. The conjunctive use of rainwater, when available, for potable purposes and other sources for non-potable purposes is common in some islands. Brackish water and seawater are used in some islands as a source of supplementary water for some non-potable uses.

Only 50% of the total population across all the selected 15 countries had access to improved water supplies in 2010 which is significantly less than the world average of 86%. For individual countries, the access to improved water supplies varies from about 40% to 100%.

Freshwater is also used for agriculture (mainly for subsistence crops but some irrigated agriculture), industry (limited in most countries) and mining (limited to some larger countries) and hydroelectricity generation (some countries only).

9.3 Current water security issues

Water security in the selected countries is impacted at present to various degrees from current climate variability, geological hazards and human factors. The most vulnerable groups include densely populated urban and peri-urban settlements and remote communities.

Droughts associated with El Niño and La Niña episodes are a major problem for many countries, causing severe water shortages in some. For some of the smaller islands, emergency measures such as use of desalination and importation of water via barge or boat is required. Droughts also severely impact on agriculture in many islands and can also cause major reduction in hydroelectricity generation (e.g. Fiji).

Floods caused by tropical storms and cyclones are a major problem in some of the countries, particularly for urban centres located near major rivers.

Volcanic eruptions, earthquakes and resulting tsunamis and landslides have caused major short to medium-term impacts in some countries. Resulting destruction and damage of infrastructure including water supply systems, and temporary salinisation of groundwater resources has occurred in small islands and coastal areas of larger islands.

Human factors are already having a large impact on water security, particularly in urban and peri-urban areas where rapidly increasing populations place increasing demands on water resources. Inadequate water supply systems, often suffering from large pipeline losses, mean that many people do not have access to safe water in adequate quantities. High population densities and inadequate sanitation facilities lead to pollution of nearby groundwater and surface water resources and resultant water quality degradation. Population pressures mean that adjacent areas reserved for water resources development are also polluted due to human activity and settlement within them. As a result, the incidence of water-borne disease is high in some countries. The incidence rate of diarrhoeal diseases in the PICs, linked to contaminated drinking water and poor sanitation conditions, is about four to five times higher than in developed countries such as Australia and New Zealand.

Other sources of pollution include oil and fuel leaks and spills and agricultural chemical on rural land. Over-pumping causing salinisation of groundwater is a problem in some islands

Damage to water infrastructure, particularly associated with land disputes between land owners and government authorities, is another human-induced problem in some countries.

Poor water governance and management is also a major factor in decreasing current water security. Problems include lack of water policy, plans and legislation and ineffective coordination and administration of water sector agencies. Most countries suffer from insufficient knowledge of national water resources due to limited effort and resources being applied to water resources assessment and monitoring. Ineffective or no water source protection measures increase the vulnerability of water resources to contamination from human settlements and activities. Human and financial resource capacity limitations often prevent even essential tasks from being undertaken. Insufficient training, education and ongoing development of water sector personnel and loss of such personnel to more lucrative positions within or outside the country are ongoing problems.

Lack of, or limited community education, awareness and participation in freshwater management, conservation and protection are additional problems which impact on water security.

9.4 Climate change projections

The impacts of projected climate change and associated mean sea level rise on water resources and water supply systems have been considered to the year 2030 based on interim climate projections provided by the Pacific Climate Change Science Program (PCCSP). These interim projections are based on “most likely” and ““largest change” conditions from the outputs of 18 global climate models (GCMs). The parameters of most relevance for water security are mean rainfall, rainfall intensity, mean temperature and mean sea level change. No projections are available yet from PCCSP for other relevant parameters i.e. evaporation and tropical cyclone activity. Also, El Niño Southern Oscillation (ENSO) activity, the main driver of current climate variability in the selected countries, is assumed by PCCSP to remain the same as at present due to a lack of consensus in the GCMs.

The PCCSP interim projections to 2030 for the 15 countries are summarised below.

<u>Mean annual rainfall</u>

- For the “most likely” condition, three countries (Tonga, Vanuatu and East Timor) show relatively small reductions. Nine countries (Cook Islands, FSM, Fiji, Niue, Palau, RMI, Samoa, Solomon Is and Tuvalu) show relatively small increases and three countries (Kiribati, Nauru and PNG) show larger increases.
- For the “largest change” condition, five countries (Fiji, Niue, Tonga, Vanuatu and East Timor) show small to moderate reductions while the other ten countries show small to large increases.

<u>Mean dry season rainfall</u>

- For the “most likely” condition, four countries (Fiji, Tonga, Vanuatu and East Timor) show small to moderate reductions and a further two countries (Palau and Solomon Islands) show very small reductions. The other nine countries showed small to large increases with the highest increases indicated for Kiribati, Nauru and parts of PNG.

- For the "largest change" condition, four countries (Fiji, Niue, Tonga and Vanuatu) show relatively small reductions while East Timor shows a large reduction.

Mean wet season rainfall

- For the "most likely" condition, all 14 PICs show small to moderate increases. East Timor shows a very small reduction.
- For the "largest change" condition, four countries (Fiji, Niue, Tonga and Vanuatu) show small reductions while the other 11 countries show small to large increases. The largest increases are shown for Kiribati and Nauru.

Mean monthly rainfall intensity

- For the "most likely" condition, most countries show increases in either all or most months. Where decreases are shown, these are relatively small. Vanuatu and East Timor show the most months with decreases.
- For the "largest change" condition, most countries again show increases in either all or most months. The largest changes are shown for PNG (moderate to high increases in all months) and East Timor (small to moderate decreases in most months).

Mean monthly temperature

- For the "most likely" condition, all 15 countries show increases between 0.6ºC and 1.1ºC.
- For the "largest change" condition, all 15 countries show increases between 0.6ºC and 1.2ºC. The highest increases are shown for Kiribati and Nauru.

Mean sea level

- Increases are shown to be in the range from 0.03 m to 0.17 m within the 15 countries.

Projections made in some other studies were also reviewed and the results are presented in the report.

9.5 Climate change impacts on water resources by 2030

Impacts on surface and groundwater resources availability due to projected changes to rainfall, temperature and mean sea level rise were assessed. This was done by assessing impacts on streamflow and groundwater recharge, the main drivers of (or inputs to) these water resources, using water balance approaches.

Emphasis was placed on the five countries showing a reduction in mean rainfall under the "most likely" or "largest change" conditions (i.e. Fiji, Niue, Tonga, Vanuatu and East Timor). The other 10 countries are projected to have small to large increases in mean rainfall which will have beneficial effects on water resources.

Key findings regarding projected impacts on streamflows, and hence surface water availability, are:

- Small mean annual streamflow reductions (up to 5%) for Tonga, Vanuatu and East Timor under the "most likely" condition and a small increase for Fiji. Higher reductions of up to 15% under the "largest change" condition for the three PICs and nearly 40% for East Timor.
- Significant reductions in mean dry season streamflow (up to about 25%) for East Timor under the "most likely" condition and much higher reductions under the "largest change" condition (60% to 100%, with the latter value appearing unreasonably high).
- Lesser reductions in mean dry season streamflow for Fiji, Tonga and Vanuatu of up to 15% and 20% for the "most likely" and "largest change" conditions, respectively.

Key findings regarding projected impacts on groundwater recharge, and hence groundwater availability, are:

- Small reductions in mean annual groundwater recharge for Tonga, Vanuatu and East Timor (up to 2%) under the "most likely" condition.

- Moderately significant reductions in mean annual groundwater recharge for Fiji, Niue, Tonga and Vanuatu (up to 12%) and significant reductions for East Timor (20%) under the "largest change" condition

The estimated streamflow and recharge changes due to projected mean rainfall changes are rather coarse. However, such estimates are considered reasonable given the uncertainties inherent in the interim projections of rainfall and the scale at which they are available, the lack of projections regarding evaporation and the assumption that climate variability due to ENSO activity will be the same as at present.

Impacts from projected increases in rainfall intensity in most countries are likely to be:

- Increased flooding and consequent problems including damage to infrastructure (including water infrastructure), increased land erosion, especially in cleared, steep catchments, and sedimentation of downstream reaches of streams and rivers and the coastal environment.
- Beneficial impacts due to enhanced groundwater recharge to freshwater lenses on coral sand and limestone islands and to coastal aquifers in high islands.
- Beneficial effects for lakes and larger water storages on high islands from higher streamflows.

It is not possible to estimate impacts on streamflow and recharge conditions at catchment scale given the resolution of the projected rainfall conditions (2.5° of latitude x 2.5° of longitude or approximately 280 km x 280 km at the equator). This scale is larger, and in most cases much larger, than the size of the islands within the study region except for the main island of PNG.

9.6 Mean sea level impacts on groundwater resources by 2030

The impact of projected mean sea level rises is not expected to have a significant impact on groundwater resources in small islands and coastal areas of larger islands except where land surface elevations are currently very low. Rising sea levels will not adversely impact on groundwater resources unless there is loss of land. Groundwater modelling studies have shown that a loss of land width by say 20% would lead to about 30% loss in groundwater storage.

Hence, the main issue is whether or not land will be lost. An inundation study for Bonriki island (the current major groundwater resource for South Tarawa, Kiribati) showed some loss of land by 2030. Based on this, a recent water master plan study for Tarawa assumed a reduction in groundwater sustainable yield of 20%. However, these estimates are based on interpolation of existing relatively coarse topographical information. It also assumes that natural accretion and/or coastal protection works would not be implemented as adaptation measures.

Further work is required to assess the vulnerability of shorelines to erosion due to mean sea level rise. Erosion of shorelines due to extreme events such as major waves from storms or cyclones is more likely to affect low-lying coastal areas and small islands than a gradual change in sea level. A better understanding of the processes and impacts on coastlines due to sea level rise is required, particularly on small islands.

9.7 Climate change impacts on water demand by 2030

Projected air temperature increases are unlikely to have a significant impact on water demand especially when compared with the water demand increase due to population increases and losses in pipe networks. An increase in water demand of 2% due to projected temperature increase was used in a recent water master plan study for Tarawa, Kiribati.

9.8 Comparisons of risks to water security by 2030

Key findings from an analysis and comparison of risks to water security due to climate and non-climate related factors are:

- In general, the highest risks to water security are from increasing water demands due to population increase and other activities and pollution of water resources.

- Increasing water demands based on current annual population growth rates in some urban areas have the potential to increase water demands in 2030 by between 70% and 240%. These increases are higher than those due to reductions in streamflow and groundwater recharge, especially under the "most likely" condition where the worst scenario is a 25% reduction in streamflow in East Timor.
- The loss of freshwater resources due to pollution is hard to quantify. In most cases, water treatment systems can be installed to improve the water quality so the impact is one of additional cost rather than total loss of the resource.
- Contamination of fresh groundwater due to seawater intrusion from over-pumping is reversible if pump rates are reduced to sustainable levels. The main impact would be the cost of developing additional water sources once the pump rates were reset in order to meet the required water demand.
- The reduction in water resources availability due to mean sea level rise is hard to quantify. If the assumption made for Tarawa of a 20% reduction in groundwater sustainable yield is applied to other similar small islands, the impact of this projected climate change is again significant but relatively small compared to the large demand on water resources due to population increase.
- Leakage from many urban pipe distribution systems is 50% or higher. This loss of potential usable freshwater is greater than the effect of projected climate change impacts on streamflow, groundwater recharge and the assumed loss of 20% of groundwater resources on low islands.
- The impact of temperature rise on water demand based on the 2% increase used for Tarawa is insignificant compared with the other impacts.
- Impacts of natural hazards such as overtopping waves due to cyclones and tsunamis, while devastating in the short to medium-term, may not lead to a long-term loss in groundwater resources unless major changes in landform are experienced. Also, damaged infrastructure can be repaired or new infrastructure installed if communities have and use the opportunity to resettle to higher ground.
- Impacts from poor water governance and management are considered to be moderate to high on overall water security. While these factors do not directly lead to a loss of water resources, they can lead to poor decisions about water resources development and protection. This can cause further water quality degradation on existing developed water resources due to lack of action regarding encroachment onto water protection areas. Poor governance can also lead to other problems including delays in implementing much needed water augmentation works for existing populations.
- Impacts from vandalism are also considered to be moderate on overall water security. Vandalism can cause damage to infrastructure with temporary loss or reduction in water supply services. Damaged infrastructure can be repaired or replaced but this can be expensive and time consuming.
- Impacts from works that alter existing coastlines making them more vulnerable to erosion, or gravel mining that exposes shallow groundwater to direct evaporation can potentially lead to a loss of groundwater resources due to man-induced erosion of land or increased evaporation.

In summary, non-climate related factors of increasing water demand due to increasing population and leakage from pipe systems pose the greatest risks to water security.

9.9 Water security implications for vulnerable groups

The main vulnerable groups of people in terms of water security from both climate and non-climate related factors are those living in:

- Crowded urban and peri-urban areas, which are at major risk because of lack of adequate water supply and the need to use polluted sources for some water uses.

- Remote islands, which are at risk during droughts if the local water resources are depleted (e.g. rainwater tanks) or become saline (groundwater) and require importation of water.
- Remote parts of larger islands, which are at risk during droughts if water resources are depleted and food crops fail, due to the difficulty of access for emergency assistance and the time taken to regrow crops once rainfall returns to normal.
- Very low level parts of islands, which are at risk of overtopping, erosion and temporary salinisation of groundwater from waves caused by cyclones or tsunamis in addition to potential inundation from projected sea level rise.

9.10 Review of experiences to improve water security

The report outlines major regional water sector programmes and initiatives in the Pacific region within the past decade. Most of these have been co-ordinated through SPC-SOPAC Division (formerly SOPAC). Country-based programmes and activities are also considered with reference to those in East Timor and in Kiribati (the Kiribati Adaptation Programme).

Many recent programmes and initiatives in the water sector have been implemented with recognition of potential climate change impacts but with a primary focus on more immediate needs such as providing improved water supplies to cater for population growth and development. Many projects have focused on water governance, water resources assessment, water supply development and management, capacity building and training, and community education and awareness. These improvements are required regardless of the additional stresses imposed due to climate change. The ultimate aim of these projects is the improvement of water supply for rural and urban communities, agriculture and, in some cases, hydroelectricity generation for the current and future populations. Other projects have been or are being implemented to install new water supply systems or reconstruct/rehabilitate existing systems for communities devastated by natural disasters.

Water sector projects which aim to improve water security through proper planning, design and implementation and which cater for current climate variability are also building resilience into physical and human systems which can assist in coping with future climate change.

Some examples of good and poor practices are presented.

9.11 Practical strategies to improve water security

A number of strategies for managing the implications of climate change in addition to existing stresses on water security for the countries in the study region are outlined in the report under the following categories:

- Water governance
- Assessment and monitoring of water resources
- Management and protection and of water resources
- Appropriate water supply systems
- Demand management
- Drought and flood planning
- Capacity building and training
- Community education, awareness and participation
- Other water supply strategies for specific circumstances.

Key principles for these strategies are:

- Ensuring that the water sector in each of the selected countries is resilient to current climate variability, in addition to major pressures from increasing water demand and stresses from water pollution associated with human settlements, is the most effective overall adaptation strategy to cope with future climate change.

- Strategies to reduce vulnerability of the water sector to climate change and, thus, increase water security are essential components of good water management practice, and are required whether climate changes or not.
- There are “no simple technical fixes” or no single action that will improve water security. Rather a range of strategies are required including improved water governance; effective assessment, development, management, protection and conservation of water resources; effective operation, maintenance and management of water supply systems and other water development schemes; enhanced community participation in the water sector and improved community education and awareness.
- Although there are some regional similarities between countries, each country is different and some have wide variations in water resources and water security between different parts of the country (e.g. high islands and low islands). The mix of potential strategies to improve water security must be adapted to suit local circumstances taking account of population growth and the pattern of settlement and development.
- Introduction of new technologies requires parallel investment in training, education and awareness to gain community and government acceptance.
- In specific circumstances, particularly in countries with limited land and water resources (e.g. crowded low-lying islands and remote islands), there are a number of options to assist in development and management of water resources.

9.12 Identification of gaps and future needs

Information gaps and research needs, aimed at a better understanding of the implications of climate change on water security, are identified according to the following categories:

- Climate change projection deficiencies and needs
- Water resources data deficiencies and needs
- Other data deficiencies and needs
- Research into impacts on surface water and groundwater resources
- Further development of effective water supply technologies.

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11. References

Ali M, Hay J, Maul G and Sem G (2001). Chapter 9: Small Island States In R.T. Watson, M.C. Zinyowera, R.H. Moss, D.J. Dokken (Eds). IPCC Special Report on the Regional Impacts of Climate Change. An Assessment of Vulnerability. UNEP and WMO.

ABoM (2011). Tropical cyclones, Climate data Online. Australian Bureau of Meteorology website www.bom.gov.au/jsp/ncc/climate_averages/tropical-cyclones/index.jsp.

ADB (2011). Federated States of Micronesia: Pohnpei Power Sector Development Project, Concept paper. Project Number: 45112-001, April 2011.

Adler R.F., Huffman G.J., Chang A., Ferraro R., Xie P., Janowiak J., Rudolf B., Schneider U., Curtis S., Bolvin D., Gruber A., Susskind J., and Arkin P. (2003). The Version 2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979–Present). Journal of Hydrometeorology, 4: 1147–1167.

AIDAB (1993). Field Appraisal, Kiribati – South Tarawa Sanitation and Project Request. Pacific Regional Team, Centre for Pacific Development and Training, June 1993. unpublished report, Canberra, Australian International Development Assistance Bureau.

Alam K. and Falkland A. (1997). Vulnerability to Climate Change of the Bonriki Freshwater Lens, Tarawa. Report No HWR97/11, ECOWISE Environmental, ACTEW Corporation, prepared for Ministry of Environment and Social Development, Republic of Kiribati, April 1997, 19pp.

AMD (2009). Final Design Report, Upgrading of Mauke Water Supply System. prepared by Ngateina Rani, Aid Management Division, Ministry of Finance and Economic Management, Government of the Cook Islands, July 2009, 97pp.

APCTT-UNESCAP (2010). Fiji Renewable Energy report, Asian and Pacific Centre for Transfer of Technology, United Nations Economic and Social Commission for Asia and the Pacific, 62pp.

AMRC (2007). Integrated Water Resources Management in the Mekong. Mekong Brief No. 7, Australian Mekong Resource Centre, University of Sydney, September 2007, 4pp. Website: http://sydney.edu.au/mekong/documents/mbrief7_iwrm.pdf.

Baisyet P.M. (1994). Overview of Watershed Management in the South Pacific Island Countries. in Proceedings of the Pacific Water Sector Planning Workshop. UNESCO/SOPAC/UNDDSMS Honiara, Solomon Islands, pp 173-179.

Bari M.A., Amirthanathan G.E. and Timbal B. (2010). Climate change and long term water availability in Western Australia - An experimental projection. 2010 International Congress on Environmental Modelling and Software Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada (eds.) Swayne D.A, Wanhong Yang, Voinov A.A., Rizzoli A., Filatova T. (Eds.), Website: www.iemss.org/iemss2010/index.php?n=Main.Proceedings.

Barnett J., Dessai S. and Jones R.N. (2007). Vulnerability to Climate Variability and Change in East Timor, Ambio 36 (5): 372-378.

Barr J, 1999, Drought assessment: the 1997-98 El Nino drought in Papua New Guinea and the Solomon Islands, Australian J Emergency Management, 14(2): 31-37

Burns W.C.G. (2002). Pacific Island Developing Country Water Resources and Climate Change, in The World's Water (Peter Gleick, ed., 3rd Edition, 2002), pp113-132. Website http://www.internationalwildlifelaw.org/BurnsChapterPDF.pdf.

Cardno Acil (2010). Preparing the Road Network Development Project, Volume III, Climate Change Assessment. Prepared by: Cardno Acil in association with KWK Consulting for Ministry of Infrastructure, Timor-Leste. ADB TA 7100-TIM, 229pp. Website: www.adb.org/Documents/Reports/...TIM/38618-07-TIM-TACR.pdf.

Carpenter C., Stubbs J. and Overmars M. (2002) (eds). Papers and Proceedings of the Pacific Regional Consultation on Water in Small Island Countries, co-ordinated by SOPAC and ADB, Sigatoka, Fiji, 29 July-3 August 2002 (published on CD-Rom).

Carpenter C. and Jones P. (2004). An Overview of Integrated Water Resources Management in Pacific Island Countries: A National and Regional Assessment Status Report for GWP – Integrated Water Resources Management (IWRM), SOPAC Miscellaneous Report 554, January 2004, 37pp.

Chiew F.H.S. (2006). Estimation of rainfall elasticity of streamflow in Australia. Hydrological Sciences Journal, 51(4): 613-625.

Costin G. and Powell B. (2006). Timor Leste Situation Analysis Report. Australian Water Research Facility, International Water Centre, Brisbane, 85pp.

Crennan L. and Berry G. (2002). A Synopsis of Information Relating to Waste Management, pollution Prevention and Improved Sanitation with a Focus on Communities in the Pacific Islands Region. Prepared for the International Waters Programme. IWP Technical Report 2002/03. In Wright A. and Stacey N. (eds). Issues for Community-based sustainable resource management and conservation: considerations for the Strategic Action Programme for the International Waters of the Pacific Small Island Developing States. The International Waters Programme, South Pacific Regional Environment Programme, 108pp.

CSIRO (2011). Sea level rise, Understanding the past – Improving projections for the future, CSIRO National Research Flagships Wealth from Oceans. Website: http://www.cmar.csiro.au/sealevel/sl_proj_21st.html.

Davies H.L., Davies J.M., Lus W.Y., Perembo R.C.E., Joku N., Gedikile H., and Nongkas M. (2001). Learning from the Aitape tsunami. Proceedings of the International Tsunami Symposium, Seattle, Washington, USA, August 2001, pp 415-424.

Detay M., Alessandrello E., Come P. and Groom I. (1989). Groundwater contamination and pollution in Micronesia. Journal of Hydrology 112: 149-170.

Dwan P (2008). Lessons Learned Analysis, Timor-Leste Rural Water Supply and Sanitation Program (RWSSP), WaterAid Australia, February 2008.

Falkland A. (1992). Review of Tarawa Freshwater Lenses, Republic of Kiribati. Report HWR92/681. Hydrology and Water Resources Branch, ACT Electricity and Water. prepared for Australian International Development Assistance Bureau.

Falkland A. (2000). Addu Atoll, Maldives – Report on Groundwater Investigations, Regional Development Project, First Phase, October-December 2000. prepared on behalf of MacAlister, Elliott and Partners for Asian Development Bank and Ministry of Planning and National Development, Republic of Maldives, December 2000.

Falkland A. (2002a). A Synopsis of Information on Freshwater and Watershed Management Issues in the Pacific Islands region. IWP Technical Report 2002/02. *In* Wright A. and Stacey N. (eds). Issues for Community based sustainable resource management and conservation: considerations for the Strategic Action Plan for the International Waters of the Pacific Small Island Developing States. International Waters Programme, South Pacific Regional Environment Programme. 132pp.

Falkland A. (2002b). Water Resources Management. Theme 1 paper. Proceedings of the Pacific Regional Consultation on Water in Small Island Countries (ed. C. Carpenter, J. Stubbs and M. Overmars), co-ordinated by SOPAC and ADB, Sigatoka, Fiji, 29 July-3 August 2002, 76pp.

Falkland A. (2003). Review of Groundwater Resources Management for Tarawa. Kiribati SAPHE Project : Mid-Term Review, Loan No 1648-KIR (SF). Ecowise Environmental report No EHYD 2003/10, prepared on behalf of Asian Development Bank, March 2003.

Falkland A. (2005). Water Resources Investments Report. Kiribati Adaptation Program, Preparation for Phase II Project, GEF-PPG Grant TF053994, report prepared for Government of Kiribati and World Bank, July 2005.

Falkland A. (2006). Manihiki, Cook Islands, Report on Water Investigations, November 2005 – September 2006. Ecowise Environmental report No EHYD 2006/91, prepared for AusAID and Cook Islands Government, September 2006, 182pp.

Falkland A (2007). Report on Water Investigations, Weno, Chuuk State, Federated States of Micronesia. November 2006 – February 2007. Prepared for Asian Development Bank as part of RSC-C60725 (FSM): Loan Water Supply and Sanitation Project, Chuuk Water Supply Follow-up Investigation, March 2007, 118pp.

Falkland A. and Brunel J.P. (1993). Review of Hydrology and Water Resources of Humid Tropical Islands. in Hydrology and Water Management in the Humid Tropics (editors M. Bonell, M. M. Hufschmidt and J.S. Gladwell), Cambridge University Press and UNESCO, pp135-163.

Falkland A. and Woodroffe C. D (1997). Geology and hydrogeology of Tarawa and Christmas Island, Kiribati, Chapter 19, in Geology and Hydrogeology of Carbonate Islands, Developments in Sedimentology 54 (editors Vacher, H.L. and Quinn, T.M.), Elsevier, Amsterdam.

Furness L.J. (2004). A preliminary assessment of the sustainable groundwater yield of Timor-Leste. Report prepared under ADB Technical Assistance TIM 3986 – Timor-Leste Integrated Water Resource Management Project.

Furness L.J. (2011). Climate change in Timor-Leste – a brief overview on future climate projections by D. Kirono (prepared for the Department of Climate Change and Energy Efficiency by CSIRO, September 2010). Water Resources and Climate Adaptation Advisor, Directorate of Water Resources, Ministry of Infrastructure, Timor-Leste.

Furness L.J. and Helu S.P. (1993). The Hydrogeology and Water Supply of the Kingdom of Tonga. Ministry of Lands, Survey and Natural Resources, Nuku'alofa, February 1993, 143 pp.

Geoscience Australia (2011). South Pacific Sea Level and Climate Monitoring GPS Coordinate Time Series. National Geospatial Reference Systems Project, Geospatial & Earth Monitoring Division, Geoscience Australia, February 2008, 14pp.

Gerber F. (2010). An Economic Assessment of Drinking Water Safety Planning Koror-Airai, Palau. SOPAC Technical Report 440, November 2010, 42pp.

GHD (2007). Dili Urban Water Supply Study, Project Preparation Technical Assistance, ADB TA 4646-TIM Dili Urban Water Supply Sector Project, Asian Development Bank, December 2007.

GHD (2008). Inception Report for the Dili Water Supply Performance Improvement, Technical Assistance, ADB TA 4869-TIM, Asian Development Bank, September 2008.

Government of Kiribati (2008a). National Water Resources Policy, Water for Healthy Communities, Environments and Sustainable Development. prepared by Ian White, Coordinated by the National Water and Sanitation Committee through the Ministry of Public Works and Utilities, Government of the Republic of Kiribati, November 2008.

Government of Kiribati (2008b). National Water Resources Implementation Plan, Sustainable Water Resource Management, Use, Protection and Conservation – A 10 Year Plan. prepared by Ian White, Coordinated by the National Water and Sanitation Committee through the Ministry of Public Works and Utilities, Government of the Republic of Kiribati, November 2008.

Government of Kiribati (2011). Drought Response Plan for South Tarawa. Prepared by the Government of Kiribati Drought Committee (pending formal adoption by the National Disaster Council), March 2011. 32pp.

Government of Samoa (2007). Samoa Floodplain Management: A Guideline for Planning and Development Assistance with special reference to Vaisigano River, Guidelines for Floodplains Planning and Development Assessment, 2007. Prepared by Ministry of natural Resources and environment in collaboration with Pacific Islands Applied Geoscience Commission, 59pp.

Global Water Partnership (2000). Integrated Water Resources Management, Technical Advisory Committee, Background Paper, No. 4, 71pp.

Global Water Partnership (2007). Policy Brief No 5, Climate Change Adaptation and Integrated Water Resource Management, 12pp.

Government of Timor-Leste (2008). Timor-Leste Rural Water, Sanitation and Hygiene Sector Strategy 2008-2011. 19pp.

GWP Consultants (2010). Banaba Island: Rainwater Harvesting and Island Master Plan. Prepared for Government of Kiribati, KAPII Project, March 2010, 51pp.

GWP Consultants (2011). Water Resources Assessment, Buariki, North Tarawa. Prepared for Government of Kiribati, KAPII Project (draft), June 2010, 93pp.

Harp E.L., Reid M.E. and Michael J.A. (2004). Hazard Analysis of Landslides Triggered by Typhoon Chata'an on July 2, 2002, in Chuuk State, Federated States of Micronesia. U.S. Geological Survey Open-File Report 2004-1348, 22pp.

Hay J. (2009). Technical Report, Implementation of the Pacific Adaptation to Climate Change (PACC) Project: Process, Status and Assessment. Prepared for Pacific Regional Environment Programme (SPREP), December 2009.

Hay J.E., Mimura N., Campbell J., Fifita S., Koshy K., McLean R., Nakalevu T., Nunn P and de Wet N. (2003). Climate Variability and Change and Sea-level Rise in the Pacific Islands Region, A Resource. South Pacific Regional Environment programme and Ministry of the Environment, Japan, 2003, 108pp.

HECEC (1997). Power Development Plan. Final Report Vol. 2. Institutional Strengthening & Power Development of the Electric Power Corporation, Western Samoa. By Hydro Electric Commission Enterprises Corporation in association with John Worrall Pty Ltd, Tasman Asia Pacific and Cillis-Delaney-Brown, ADB TA No. 2267-SAM, 201pp.

Hein J.R., Gray S.C. and Richmond B.R. (1997). Geology and hydrogeology of the Cook Islands. Chapter 16. In: Vacher HL, Quinn TM (eds) Geology and hydrogeology of carbonate islands. Developments in Sedimentology 54. Elsevier, Amsterdam, pp 503–535.

Higgins C., Planitz A. and Biliki R. (1999). Vanuatu earthquake and tsunami, 27 November 1999. Mission Report, United Nations Disaster Assessment and Coordination Team, December 1999, 33pp.

Hunter J.R. (2010). Estimating Sea-Level Extremes Under Conditions of Uncertain Sea-Level Rise. Climatic Change, 99: 331-350, doi:10.1007/s10584-009-9671-6.

IDSS (2010). Timor-Leste Rural Water Supply & Sanitation Program (BESIK), Whole of Program Life Work Plan 2, 2010-2012 (draft). Prepared by IDSS Pty Ltd in partnership with GHD Pty Ltd, October 2010.

IETC (1998). Source book of alternative technologies for freshwater augmentation in Small Island Developing States. International Environmental Technology Centre, UNEP in collaboration with South Pacific Applied Geoscience Commission and the Water Branch of UNEP, Technical Publication Series No. 8, 223pp.

IFRC (2007). Solomon Islands: Earthquake and Tsunami Response; Preliminary Appeal no. MDRSB001, International Federation of Red Cross and Red Crescent Societies 3 April 2007, 6pp.

IPCC (2000). Emission Scenarios - Summary for Policymakers, A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, 21pp. Website: http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf.

IPCC (2007). Climate change 2007: Synthesis Report. Intergovernmental Panel on Climate Change. Website: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

Javier E.L., San Valentin G., Kapukha P., Monaghan B., Palmer B., Piggin C., Tilman de sa Benevides F., Da Silva D. and De Oliveira A. (2003). Selection of better rice for East Timor. Agriculture: New Directions for a New Nation — East Timor (Timor-Leste) Ed. H. da Costa, C. Piggin, C.J da Cruz and J.J. Fox, Workshop Proceedings, Dili, East Timor, October 2002, Australian Centre for International Agricultural Research, October 2003, pp 79-83.

JICA (2008). JICA Timor-Leste Information Sheet, Working Together with People in Timor-Leste, November 2008.

Jones R.N., Chiew F.H.S., Boughton W.C. and Zhang L (2005). Estimating the sensitivity of mean annual runoff to climate change using selected hydrological models, Advances in Water Resources, 29: 1419-1429.

Katzfey J., McGregor J., Nguyen K., and Thatcher M. (2010). Regional climate change projection development and interpretation for Indonesia. Final Report to AusAID. CSIRO Climate Adaptation Flagship, Australia.

Kenny G., Ye W., Warrick R. and de Wet N. (2000). FIJICLIM Description and Users Guide. International Global Change Institute, University of Waikato, New Zealand, 35pp.

Kirono D. (2010). Climate change in Timor-Leste – a brief overview on future climate projections. Prepared for the Department of Climate Change and Energy Efficiency by CSIRO, September 2010.

Kley K. (2007b). Data Summary of Four Automatic Rainfall Sites on Rarotonga, NIWA Client Report: CHC2009-075, May 2009.

Kley K. (2007b). Statistical characterisation of the flow of the Rarotonga streams Avatiu, Matavera and Totokoitu, NIWA Client Report: CHC2009-070, May 2009.

Knutson T.R., McBride J.L., Chan J., Emanuel K., Holland G., Landsea C., Held I., Kossin J.P., Srivastava A. K. and Sugi M. (2010). Tropical cyclones and climate change, Nature Geoscience 3: 157-163.

Landers M.A. and Khosrowpanah S. (2004). Rainfall climatology for Pohnpei Islands, Federated States of Micronesia, Water and Energy Research institute of the Western Pacific, Guam, Technical Report No. 100, October 2004, 51pp.

Marconnet M. (2007). Integrating Renewable Energy in Pacific Island Countries. Masters thesis, Victoria University of Wellington, New Zealand.

Miller F D., Moravcik P.S., Siren N. and William S. (1991). Bacterial Contamination of Water Resources on Moen, Truk Islands, Federated States of Micronesia. Technical Memorandum Report No. 83, Water Resources Research Centre, University of Hawaii at Manoa, Hawaii, 45pp.

Mimura N., Nurse L., McLean R.F., Agard J., Briguglio L., Lefale P., Payet R. and Sem G. (2007). Small Islands. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson (eds.). Cambridge, UK: Cambridge University Press. 687-716.

Ministry of Infrastructure (2010). National Water Supply Policy, draft (version 1). Prepared by Ministry of Infrastructure, Government of Timor-Leste with support from Rural Water Supply and Sanitation Program, March 2010, 14pp.

Ministry of Infrastructure (2011). National Water Resources Policy, draft (version 3). Prepared by Ministry of Infrastructure, Government of Timor-Leste, July 2011, 11pp.

Nath D., Mudaliar M. and Ioan C. (2006). Vanuatu Water Supply Description, Water Safety Plan Programme, Implemented by SOPAC, WHO and Department of Geology Mines & Water Resources, Vanuatu, funded by AusAID, 29pp.

NIWA (2008a). High Intensity Rainfall and Drought, Information for Climate Risk Management. Kiribati Adaptation Programme Phase II. Report WLG 2008-12, National Institute for Water and Atmosphere Research Ltd, New Zealand, July 2008.

NIWA (2008b). Sea-levels, waves, run-up and overtopping, Information for Climate Risk Management. Kiribati Adaptation Programme Phase II. Report HAM 2008-22, National Institute for Water and Atmosphere Research Ltd, New Zealand, September 2008.

NSD (2010). Population and Housing Census 2010, Preliminary Results. National Statistics Directorate (NSD), General Directorate of Policy Analysis and Research, General Directorate of Policy Analysis and Research, Government of Timor-Leste supported by United Nations Population Fund, October 2010.

Nullet D. (1987). Water balance of Pacific atolls. Water Resources Bulletin, 23(6): 1125-1132.

Oberdorfer J.A. and Buddemeier R.W. (1988). Climate change, effects on reef island resources. Sixth Internat. Coral Reef Symposium, Townsville, Australia. 3: 523-527.

Oki D. (2011). Surface Water In Hawaii, U.S. Geological Survey. Website: http://pubs.usgs.gov/fs/fs04503/pdf/fs045-03.pdf

Overmars M. and Gottlieb S.B. (2009). Adapting to climate change in water resources and water services in Caribbean and Pacific small island countries. Perspectives on water and climate change adaptation. Pacific Islands Applied Geoscience Commission and GEF-IWCAM Project Coordination Unit, 16pp.

PCCSP (2010a). Pacific Climate Change Science Program brochure. produced for the 41st Pacific Islands Forum August 2010, Port Vila, Vanuatu, Australian Government (AusAID, Bureau of Meteorology and Department of Climate Change and Energy Efficiency). Website http://www.cawcr.gov.au/projects/PCCSP/publications/PCCSP_%20PIF_Brochure.pdf.

PCCSP (2010b). Pacific Climate Change Science Program – Climate Variability and Change in the Pacific island and East Timor. Australian Government (AusAID, Bureau of Meteorology and Department of Climate Change and Energy Efficiency). Website http://www.cawcr.gov.au/projects//PCCSP/publications/PCCSP%20_COP.pdf.

PCCSP (2011a). Interim climate projections, 25 March 2011. CSIRO and Bureau of Meteorology, Pacific Climate Change Science Program (supplied in email from Martin Sharp, Director, International Adaptation Strategies Team, Adaptation, Land and Communications Division, Department of Climate Change and Energy Efficiency on 17th May 2011).

PCCSP (2011b). Document “PCCSP projections for PASAP v3.xls”. CSIRO and Bureau of Meteorology, Pacific Climate Change Science Program (supplied in email from Martin Sharp, Director, International Adaptation Strategies Team, Adaptation, Land and Communications Division, Department of Climate Change and Energy Efficiency on 17th May 2011).

PCCSP (2011c). Climate change in the Pacific. First Order Draft. CSIRO and Bureau of Meteorology, Pacific Climate Change Science Program. Prepared for Department of Climate Change and Energy Efficiency.

Peterson F.L. (1997) Hydrogeology of the Marshall Islands, Chap. 20. In: Vacher H. L., Quinn T.M. eds) Geology and hydrogeology of carbonate islands. Developments in Sedimentology 54. Elsevier, Amsterdam, pp 611–636.

Pipeline Network Analysis (2010). Unaccounted for water and leakage assessment, prepared for KAPII Project, Tarawa, Kiribati, Pipeline Network Analysis, Southport, Queensland, Australia, 42pp.

Powell B., Davies P., Costin G., Wairiu M. and Ross H. (2006). Interdisciplinary approaches to catchment risk management: case studies of Timor Leste and the Solomon Islands, Internat. River Symposium, September 2006, 13pp. Website: http://www.watercentre.org/resources/publications/papers-presentations

Presley T.K. (2005). Effects of the 1998 Drought on the Freshwater Lens in the Laura Area, Majuro Atoll, Republic of the Marshall Islands. Scientific Investigations Report 2005–5098. U.S. Geological Survey, Reston Virginia, USA, prepared in cooperation with theMajuro Water and Sewer Company, Majuro Atoll, Republic of the Marshall Islands, 40pp.

Priestley C.H.P. and Taylor R.J. (1972). On the assessment of surface heat flux and evaporation using large-scale parameters. Monthly Weather Review 100:81-92.

PRIF (2009). Pacific Region Infrastructure Facility brochure, AusAID, NZAID, ADB and World Bank Group.

PRIF (2010). Solomon Islands Water Authority. Financial and Operational Strengthening, Draft Terms of Reference, December 2010, 13pp.

Prüss-Üstün A., Bos R., Gore F. and Bartram J. (2008). Safer water, better health: costs, benefits and sustainability of interventions to protect and promote health. World Health Organization, Geneva.

Ripper I.D., Anton L., Letz H.and Moihoi M. (2001). Preliminary account of the scientific investigations of the 17 July 1998 Sissano Lagoon (Aitape) Tsunami. Report 2001/1, Geological Survey of Papua New Guinea, 35pp.

Samoa Ministry of Finance (2011). Strategic Program for Climate Resilience. Prepared for the Pilot Programme for Climate Resilience (PPCR). February 2011.

Scott D. (2002). Island Vulnerability. Theme 2 paper. Papers and Proceedings of the Pacific Regional Consultation on Water in Small Island Countries (ed. C. Carpenter, J. Stubbs and M. Overmars), co-ordinated by SOPAC and ADB, Sigatoka, Fiji, 29 July-3 August 2002, 25pp.

Scott D., Overmars M., Falkland A. and Carpenter C. (2003). Pacific Dialogue on Climate and Water. Synthesis Report. SOPAC, February 2003, 36pp.

Scott G.A. and Rotondo G.M. (1983). A model to explain the differences between Pacific plate island-atoll types. Coral Reefs. 1:139-150.

Seeds of Life (2010). Predicted changes to rainfall and temperature in Timor-Leste due to climate change and its impact on agriculture. Ministry of Agriculture and Fisheries, Comoro Nicolao Loubato, Dili, Timor, 8pp. Website: http://www.seedsoflifetimor.org/research/CC_SoL%208-page%20FINAL.pdf.

Singh R.B.K., Hales, S, de Wet N., Raj R., Hearnden M. and Weinstein P. (2001). The Influence of Climate Variation and Change on Diarrheal Disease in the Pacific Islands , Environmental Health Perspectives, 109:109:155-159, doi:10.1289/ehp.01109155February 2001.

Skyjuice (2008). Report on the provision of low cost water purification units by the Skyjuice Foundation Inc. for Kiribati Ministry of Public Works and Utilities and the Pacific Islands Applied Geoscience Commission (SOPAC). Skyjuice Foundation Inc, 4pp.

Skyjuice (2011). SkyHydrant™ Water Purification Unit. Skyjuice Foundation Inc. Website: http://www.skyjuice.com.au/skyhydrant.htm.

SNC-Lavalin International (2001). Feasibility and Engineering Study in Respect of Rehabilitation of Identified Irrigation Schemes in East Timor. Agricultural Affairs Department. United Nations Transitional Administration in East Timor.

SOPAC (1999). Water Demand Management Workshop, Nadi, Fiji, June 1999. ed. H. Schölzel and R. Bower, Miscellaneous Report 345, 41pp + annexes.

SOPAC (2000). Water and Sanitation Newsletter, Vol.3, No.2, December 2000.

SOPAC (2003). El Niño, Oil Prices put pinch on Fiji. Pacific Energy News, No 1, March 2003.

SOPAC (2004a). Harvesting the Heavens: Guidelines for Rainwater Harvesting in Pacific Island Countries. SOPAC Joint Contribution Report 178. prepared by the South Pacific Islands Applied Geoscience Commission and the Secretariat of the Pacific Community (SPC).

SOPAC (2004b). Harvesting the Heavens: A manual for participatory training in rainwater harvesting. SOPAC Miscellaneous Report 544. prepared by the South Pacific Islands Applied Geoscience Commission for the United Nations Environment Programme (UNEP) in conjunction with the Tonga Community Development Trust (TCDT) and funded by the Swedish Development Agency (SIDA).

SOPAC (2007a). National Integrated Water Resource Management Diagnostic Report, Republic of the Marshall Islands, Sustainable Integrated Water Resources and Wastewater Management in Pacific Island Countries, SOPAC Miscellaneous Report 639, November 2007, 51pp..

SOPAC (2007b). Pacific HYCOS, Project Implementation Plan. December 2007.

SOPAC (2009). Implementation of the Hyogo Framework for Action and the Pacific Disaster Risk Reduction and Disaster Management Framework for Action 2005 – 2015, Report for the period 2007 – 2009, SOPAC Miscellaneous Report 674, June 2009, 52pp.

SOPAC (2010). Country Implementation Plan for Improving Water Security in the Republic of Nauru. Prepared by Tony Falkland and John Tagiilima for SOPAC as part of the Multi-Country Project “Support to Disaster Risk Reduction in Eight Pacific ACP States, funded by the European Commission from the EDF9 National B-Envelope, January 2010, 74pp.

SOPAC (2011). Water, Sanitation and Hygiene website http://www.pacificwater.org/.

SOPAC & ADB (2003). Pacific Regional Action Plan on Sustainable Water Management. Prepared following the regional consultation at Sigatoka, Fiji In preparation for the 3rd World Water Forum, Kyoto, Japan. South Pacific Applied Geoscience Commission and Asian Development Bank, February 2003.

Sousa C.E. (1972). Esboco Duma Caracterizacao Agroclimatica da Provincia de Timor. Comunicacoes – Missao de Estudos Agronomicos do Ultramar.

SPC (2011a). Data sheet “Pocket-summary2010webFINAL.pdf”, Statistics for Development website http://www.spc.int/sdp/, Secretariat of the Pacific Community.

SPC (2011b). 2011 populations & demographic indicators in spreadsheet "SPC-SDP_populations_data_sheet_2011.xls". Statistics for Development website http://www.spc.int/sdp/, Secretariat of the Pacific Community.

SPC-SOPAC (2011). Pacific HYCOS Project, Final Report (draft). Applied Geoscience and Technology Division, Secretariat of the Pacific Community.

Spennemann D.H.R. and Marschner I.G. (2000). Stormy years: on the association between the El Niño/Southern Oscillation phenomenon and the occurrence of typhoons in the Marshall Islands. Website: http://marshall.csu.edu.au/Marshalls/html/typhoon/Stormy_Years.html Marshalls, Digital Micronesia. (first published in 1994 as a report to the Federal Emergency Management Agency. Region IX, San Francisco. Johnstone Centre of Parks, Recreation and Heritage, Report N 9).

SPSLCMP (2009). Sea Level Data Summary Report, July 2008 – June 2009. South Pacific Sea Level and Climate Monitoring Project. Prepared by National Tidal Centre, Australian Bureau of Meteorology.

SPSLCMP (2010). Pacific Country Report (Kiribati), Sea Level and Climate: Their Present State, Sea Level Data Summary Report, December 2009. South Pacific Sea Level and Climate Monitoring Project. Prepared by National Tidal Centre, Australian Bureau of Meteorology. [Note similar reports are available for the other PICs with SEAFRAME recorders].

SPSLCMP (2011). Monthly Data Report No. 190, April 2011. South Pacific Sea Level and Climate Monitoring Project. Prepared by National Tidal Centre, Australian Bureau of Meteorology.

Stewart B. (1993). The Hydrology and Water Resources of Humid Northern Australia and Papua New Guinea. in Hydrology and Water Management in the Humid Tropics (editors M. Bonell, M. M. Hufschmidt and J.S. Gladwell), Cambridge University Press and UNESCO, pp 67-83.

Storey D. and Hunter S. (2010). Kiribati: an environmental 'perfect storm'. Australian Geographer, 41(2): 167-181.

Sullivan C.A. and Guglielmi F. (2007). Pacific Island Water Resources: An Overview of East Timor, Kiribati, Solomon Islands, Tuvalu and Vanuatu. Working Paper, Australian Water Research Facility and Oxford University, December 2007, 59pp.

Takasaki K.J. (1989). Groundwater resources of selected high volcanic islands of Truk with emphasis on small village supplies. U.S. Geological Survey Water Resources Investigation Report 88-4163. Honolulu, Hawaii, U.S.A., April 1989, 60pp.

Taulima F. (2002). Water management in Tuvalu with special emphasis on rainwater harvesting. Case study presented as part of Theme 1, Water Resources Management, at the Pacific Regional Consultation Meeting on Water in Small Island Countries, Sigatoka, Fiji, 29 July – 3 August 2002.

Terry J.P., ed. (1998). Climate and Environmental Change in the Pacific. School of Social and Economic Development, The University of the South Pacific, 144pp.

Terry J.P. (2002). Water resources, climate variability and climate change in Fiji. Asia Pacific Journal on Environment and Development, 9: 86-120.

Terry J.P. (2007). Tropical Cyclones: Climatology and Impacts in the South Pacific. Springer, New York, 210pp.

Terry J.P. and Feresi J. (1999). Chapter 5, Water Resources. in Feresi J. et al. (eds.). Climate Change Vulnerability and Adaptation Assessment Report for the Fiji Islands. South Pacific Regional Environment Programme, Pacific Islands Climate Change Assistance Programme (PICCAP), Fiji Department of Environment, and International Global Change Institute, University of Waikato, New Zealand, pp 53-74.

Terry J.P. and Raj R. (2002). The 1997–98 El Niño and drought in the Fiji Islands. In:Hydrology and Water Management in the Humid Tropics, Proc. Second International Colloquium, 22-26 March 1999, Panama, Republic of Panama, IHP-V Technical Documents in Hydrology No 52, UNESCO, Paris, 2002, pp. 80–93.

Terry J.P., McGree S. and Raj R. (2004). The exceptional floods on Vanua Levu Island, Fiji, during Tropical Cyclone Ami in January 2003. Journal of Natural Disaster Science, 26: 27–36.

Terry J.P. and Falkland A. (2010). Responses of atoll freshwater lenses to storm-surge overwash in the Northern Cook Islands, Hydrogeology Journal, 18: 749-759.

Terry J.P. and Wotling, G. (in press). Rain-shadow hydrology: Influences on river flows and flood magnitudes across the central massif divide of La Grande Terre Island, New Caledonia. Journal of Hydrology (2011), doi:10.1016/j.jhydrol.2011.04.022.

Thompson C.S. (1986a). The Climate and Weather of Tonga. New Zealand Meteorological Service, Misc. Publication 188 (5), Wellington, New Zealand, 60 pp.

Thompson C.S. (1986b). The Climate and Weather of the Northern Cook Islands. New Zealand Meteorological Service, Misc. Publication 188 (3), New Zealand, 45 pp.

Thompson C.S. (1986c). The Climate and Weather of the Southern Cook Islands. New Zealand Meteorological Service, Misc. Publication 188 (2) , New Zealand, 69 pp.

TWB (2000). An Outline of Recent Water Supply Improvements for Pangai-Hihifo, Lifuka, Kingdom of Tonga. prepared by A. Falkland and S. Helu, Tonga Water Board, August 2000.

TWB (2011). Water production and consumption data for 2010. Tonga Water Board, unpublished data.

UNESCO (1991). Hydrology and water resources of small islands, a practical guide. Studies and reports on hydrology No 49. prepared by A. Falkland (ed.) and E. Custodio with contributions from A. Diaz Arenas and L. Simler and case studies submitted by others. Paris, France, 435pp.

UNICEF (2009a). Intermediate post-disaster water supply, South eastern region Upolu, Samoa. Final report. Submitted to Samoa Water Authority by RedR on behalf of UNICEF, December 2009, 27pp.

UNICEF (2009b). Long term water supply, South eastern region Upolu and Manono Island, Samoa. Preliminary concept report. Submitted to Samoa Water Authority by RedR on behalf of UNICEF, December 2009, 20pp.

UNICEF & WHO (2008). Progress on Drinking Water and Sanitation: Special Focus on Sanitation. Joint Monitoring Programme for Water Supply and Sanitation (JMP), World Health Organization and United Nations Children's Fund. UNICEF, New York and WHO, Geneva, 2008.

United Nations (2000). Millennium Declaration. United Nations General Assembly Resolution 55/2, 18 September 2000.

USAID (2009). Adaptation to Climate Change: Case Study – Freshwater resources in Majuro, RMI, United States Agency for International Development, August 2009.

USAID (2010). FEMA / USAID Disaster Mitigation, Relief and Reconstruction Program. Disaster Digest, Vol 1, 4th quarter, 2010, 5pp.

Vacher H.L. and Quinn T.M., eds. (1997). Geology and Hydrogeology of Carbonate Islands, Developments in Sedimentology No. 54, Elsevier, Amsterdam, 948 pp.

van der Brug O. (1983a). Water Resources of the Truk Islands. U.S. Geological Survey Water Resources Investigation Report 82-4082. Honolulu, Hawaii, U.S.A. 223pp.

van der Brug O. (1983b). Water Resources of the Yap Islands. U.S. Geological Survey Water Resources Investigation Report 82-357. Honolulu, Hawaii, U.S.A. 187pp.

van der Brug O. (1984a). Water Resources of Ponape, Caroline Islands. U.S. Geological Survey Water Resources Investigation Report 84-4139. Honolulu, Hawaii, U.S.A., March 1984, 171pp.

van der Brug O. (1984b). Water Resources of Kosrae, Caroline Islands. U.S. Geological Survey Water Resources Investigation Report 83-4161. Honolulu, Hawaii, U.S.A., March 1984, 143 pp.

van der Brug O. (1984c). Water Resources of the Palau Islands. U.S. Geological Survey Water Resources Investigation Report 84-4140. Honolulu, Hawaii, U.S.A. 223pp.

van der Brug O. (1986). The 1983 drought in the Western Pacific. U.S. Geol. Survey Open-File Rpt. 85-418. Honolulu, Hawaii, U.S.A. 89 pp

Voss C.I. (1984). SUTRA, A finite-element simulation model for saturated-unsaturated, fluid-density-dependent ground-water flow with energy transport or chemically-reactive single- species solute transport. USGS Water Resources Investigations Report 84-4389, 409pp.

Voss C.I., Boldt D. and Sharpiro A.M. (1997). A Graphical-User Interface for the US Geological Survey's SUTRA Code using Argus ONE (for Simulation of Variable –Density Saturated-Unsaturated Ground-Water Flow with Solute or Energy Transport), U S Geological Survey, Open-File Report 97-421, Reston, Virginia.

WA DoW (2010). The effects of climate change on streamflow in south-west Western Australia, Projections for 2050. Department of Water, Government of Western Australia, Surface water hydrology series, Report no. HY34, September 2010.

Wallace L., Sundaram B. and Dawson S. (2010a). Assessment of Impacts of Climate Change on Groundwater in Timor-Leste: a summary report (draft). Geoscience Australia, 37pp.

Wallace L., Sundaram B. and Dawson S. (2010b). Hydrogeology of Timor-Leste (draft). Geoscience Australia, 66pp.

Waterman E., Thulstrup H., Overmars M. and Berdejo L. (2007). HELP in the context of the Pacific Regional Action Plan for Sustainable Water Management, A Framework for Action. Proceeding of the Pacific HELP Symposium, organised by SOPAC, ENESCO and Landcare Research, New Zealand, November 2005, 39pp.

Webb A.P. and Kench P.S. (2011). The dynamic response of reef islands to sea-level rise: Evidence from multi-decadal analysis of island change in the Central Pacific. Global and Planetary Change 72 (2010) 234–246.

White I. (2010). Tarawa Water Master Plan: Te Ran, Groundwater, Prepared for the Kiribati Adaptation Programme Phase II Water Component 3.2.1, Australian National University, December 2010, 82pp.

White I. (2011a). Tarawa Water Master Plan, 2010-2030. Prepared for the Kiribati Adaptation Programme Phase II Water Component 3.2.1, Australian National University, February 2011, 49pp.

White I. (2011b). Te Ran-Maitira ae Kainanoaki, Future Water Demand, Tarawa Water Master Plan. Prepared for the Kiribati Adaptation Programme Phase II Water Component 3.2.1, Australian National University, February 2011, 59pp.

White I. (2011c). Inception Report, Development of a National Water, Sanitation and Hygiene Policy Framework and Implementation Plan for the Republic of Nauru Pacific Integrated Water Resources Management (IWRM) National Planning Programme, prepared by Ian White, Australian National University, April 2011, 59pp.

White I., Falkland A., Crennan L., Jones P., Etuati B., Metai E., and Metutera T. (1999). Groundwater recharge in low coral islands, Bonriki, South Tarawa, Kiribati: Issues, traditions, and conflicts in groundwater use and management. UNESCO IHP-V, Technical Documents in Hydrology no. 25. UNESCO, Paris, France, 37pp.

White I., Falkland A., Etuati B., Metai E. and Metutera T. (2002). Recharge of fresh groundwater lenses: field study, Tarawa Atoll, Kiribati. In: Hydrology and Water Resources Management in the Humid Tropics, Proc. Second International Colloquium, 22-26 March 1999, Panama, Republic of Panama, IHP-V Technical Documents in Hydrology No 52, UNESCO, Paris, 2002, 299-332.

White I., Falkland A., Metutera T., Metai E., Overmars M., Perez P. and Dray A. (2007a). Climatic and Human Influences on Groundwater In Low Atolls. Vadose Zone Journal, 6:581–590.

White I., Falkland A., Perez P., Dray A., Metutera T., Metai E., and Overmars M. (2007b). Challenges in freshwater management in low coral atolls. Journal of Cleaner Production, 15: 1522 – 1528.

White I., Falkland A., Metutera T., Katatia M., Abete-Reema T., Overmars M., Perez P. and Dray A. (2008). Safe water for people in low, small island Pacific nations: The rural-urban dilemma. Development, 51: 282-287.

White I., Falkland A. and Fatai T. (2009). Groundwater Evaluation and Monitoring Assessment, Vulnerability of Groundwater in Tongatapu, Kingdom of Tonga. SOPAC/EU EDF8 Reducing the Vulnerability of Pacific APC States, Australian National University, Canberra, Australia, June 2009, 351pp.

White I. and Falkland A. (2010). Management of freshwater lenses on small Pacific islands. Hydrogeology Journal, 18: 227-246.

WHO (2004) Guidelines for drinking-water quality. 3rd edn., including addenda in 2006 and 2008. World Health Organization, Geneva, Switzerland.

WHO (2005). Pacific Framework For Action on Drinking Water Quality Monitoring. WHO Regional Workshop on Drinking Water Quality Standards and Monitoring in Pacific Island Countries, Nadi, Fiji, World Health Organization, February 2005.

WHO (2006). Mortality Country Fact Sheet 2006, Timor-Leste. World Health Organization, 2pp.

WHO (2009). World Health Statistics. World Health Organization, 149pp.

WHO & SOPAC (2008). Sanitation, hygiene and drinking-water in the Pacific Island Countries – Converting Commitment into Action. World Health Organization and Pacific Islands Applied Geoscience Commission, 2008.

WHO & UNICEF (2008). Coverage Estimates, Improved Drinking-Water Sources, Vanuatu, Updated July 2008. Joint Monitoring Programme for Water Supply and Sanitation (JMP), World Health Organization and United Nations Children's Fund. Website www.wssinfo.org.

WHO & UNICEF (2010a). Estimates for the use of Improved Drinking-Water Sources, Marshall Islands, Updated March 2010. Joint Monitoring Programme for Water Supply and Sanitation (JMP), World Health Organization and United Nations Children's Fund. Available through website www.wssinfo.org.

WHO & UNICEF (2010). Estimates for the use of Improved Drinking-Water Sources, Fiji, Updated March 2010. Joint Monitoring Programme for Water Supply and Sanitation (JMP), World Health Organization and United Nations Children's Fund. Website www.wssinfo.org.

WMO (2006). Statement on Tropical Cyclones and Climate Change. Chapter 2, Proceedings of the Sixth WMO International Workshop on Tropical Cyclones (IWTC-VI), San José, Costa Rica, 21-30 November 2006, World Weather Research Programme, World Meteorological Organization, WMO/TD - No. 1383, WWRP 2007–1, 92pp.

Woodroffe C.D. (2008). Reef-island topography and the vulnerability of atolls to sea-level rise. Global Planetary Change, 62:77–96.

World Bank (2000). Adapting to Climate Change. Vol. IV in Cities, Seas and Storms, Managing Change in Pacific Island Economies. Papua New Guinea and Pacific Island Country Unit, The World Bank, 135pp.

World Bank (2009). Disaster Risk Management Programs for Priority Countries. Global Facility for Disaster Reduction and Recovery, World Bank and International Strategy for disaster Reduction, 306pp.

World Bank (2011). Tina River Hydro-Power Development Project (TRHDP). The World Bank Group, Solomon Islands Portfolio Overview, February 2011.

Wright E.P. (1989a). Small high islands. Ch. 12. in Comparative hydrology: an ecological approach to land and water resources (eds. M. Falkenmark and T. Chapman). Unesco, Paris, 295-322.

Wyrtki K. (1990). Sea level rise: the facts and the future. Pacific Science. 44 (1): 1-16.

Xie P.P. and Arkin P.A. (1997). Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. Bulletin of the American Meteorological Society, 78: 2539-255.

Yance S. (2004). Assessment of water availability and water demand in Timor-Leste at river basin level. Report prepared under ADB Technical Assistance TIM 3986 – Timor-Leste Integrated Water Resource Management Project, August 2004, 69pp. [Available from East Timor Agriculture Network and Virtual Library]

Yeo S.W., Blong R.J. and McAneney K.J. (2007). Flooding in Fiji: findings from a 100-year historical series. Hydrological Sciences Journal, 52(5): 1004-1015.

Yin X., Gruber A. and Arkin P. (2004). Comparison of the GPCP and CMAP Merged Gauge–Satellite Monthly Precipitation Products for the Period 1979–2001. Journal of Hydrometeorology, 5: 1207–1222. doi: 10.1175/JHM-392.1.

Annex A

Scope of Services

Introduction

The Scope of Services for the report, as shown below, are from the Request for Proposal No 6 “Water security and climate change in the Pacific and East Timor” as prepared by the Department of Climate Change and Energy Efficiency in September 2010 and revised following discussion with Martin Sharp and Laura Gerstenberg of the Adaptation, Science & Communications Division, DCCEE on 12th January 2011.

Details

The Scope of Services required is to produce a paper (5-8,000 words exclusive of any supporting material) which provides an overview analysis of the sensitivity to climate change of water resources in the selected region comprising Pacific Island Countries[1] and East Timor.

Drawing on the extensive water security analysis and program activity already undertaken or underway in the selected region, the paper will:

1. Provide an overview of water resources and water supply systems.
2. Provide an overview of baseline water security issues under current climate across the region, including pressures associated with:
    (a) Current climate variability;
    (b) Natural disasters;
    (c) Population growth, development patterns and urbanisation (including pollution from liquid and solid waste);
    (d) Water demand and adequacy of supply;
    (e) Water infrastructure (including adequacy and investment needs);
    (f) Water and energy;
    (g) Governance issues; and
    (h) In-country human resource capacity to manage water resources.
3. Describe how climate change is likely to exacerbate existing pressures on water resources including a description of water security implications for vulnerable groups in urban and peri-urban areas, outer islands and remote communities;
4. Describe any significant regional variability or common needs or issues with respect to the climate change implications for water security across the region;
5. Review experience and practice to date in addressing the climate change implications for water security in the region, including examples of mal-adaptation or good practice responses to climate change in the water sector;
6. Identify practical adaptation options for managing the implications of climate change for water security in the region in the short to medium term and longer term;
7. Identify information gaps and research needs for better understanding of the implications of climate change for water security into the future; and
8. Provide conclusions and recommendations based on the findings of the study.

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[1] Cook Islands, Federated States of Micronesia (FSM), Fiji, Kiribati, Nauru, Niue, Palau, Papua New Guinea (PNG), Republic of Marshall Islands (RMI), Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu

Annex B

Projected mean rainfall changes for 2030

Table B1 Projected mean monthly rainfall changes (mm)

Month	Cook Is		FSM		Fiji	Kiribati			Nauru	Niue	Palau	PNG	RMI		Samoa	Solomon Is	Tonga	Tuvalu	Vanuatu	East Timor
	Northern Islands	Southern Islands	West	East		Gilbert Group	Phoenix Group	Line Group					Northern Islands	Southern Islands						
(a) "Most likely" future condition																				
January	-11.2	-3.3	38.1	8.2	2.0	12.7	23.4	19.6	30.2	5.7	-3.6	14.5	5.9	19.3	35.3	11.1	4.8	-3.9	-10.9	6.2
February	1.6	-6.7	11.3	2.4	11.1	9.7	9.4	13.8	20.4	6.7	-12.2	16.7	3.4	6.1	14.5	20.1	5.9	1.9	8.7	0.5
March	16.1	13.7	9.7	2.1	3.9	8.0	15.7	15.1	15.4	6.8	-3.9	28.5	6.6	-2.6	-15.2	5.6	0.3	24.2	3.5	-1.1
April	-11.4	3.9	1.9	6.4	5.2	17.0	14.0	17.6	11.5	-0.4	5.8	27.7	-3.4	3.9	11.7	17.5	0.9	23.2	5.7	3.7
May	-3.6	2.1	-4.0	17.0	-7.5	17.4	15.8	18.7	11.0	6.7	0.8	18.2	-16.8	5.4	38.0	10.8	-9.0	22.0	-18.4	9.1
June	5.2	1.8	1.7	36.9	-10.4	22.7	22.0	16.4	18.4	-3.5	7.1	16.1	-0.1	7.8	-20.7	0.3	-9.8	19.1	-5.7	4.4
July	1.3	7.2	6.9	28.6	-1.9	34.1	23.2	14.1	21.8	7.1	11.9	-2.8	9.0	8.1	-2.2	-12.5	-3.7	2.1	0.5	-8.7
August	-3.2	11.0	8.2	18.4	-1.4	23.1	13.1	14.9	19.0	5.1	3.4	5.5	5.5	13.2	-7.9	-4.3	-5.7	-2.9	0.4	-12.9
September	0.4	2.8	-9.6	23.8	-0.6	18.4	14.0	14.9	20.0	2.4	22.4	19.4	4.0	5.4	6.0	6.6	-2.3	-4.2	-1.9	-5.1
October	5.0	-5.7	3.4	17.9	-4.6	18.3	19.6	6.5	20.9	-7.8	3.6	1.4	0.1	7.0	0.1	-1.8	-9.1	1.6	2.2	-7.9
November	22.3	-2.7	-3.6	19.8	9.7	16.5	9.4	16.1	12.3	1.0	1.2	13.2	10.8	3.3	4.6	7.0	1.7	8.5	-2.1	-5.1
December	49.9	0.9	16.5	8.0	2.1	7.7	1.7	9.3	15.4	0.5	-0.2	3.5	10.9	7.9	5.2	6.5	3.8	8.9	2.9	-4.7
Average	**6.0**	**2.1**	**6.7**	**15.8**	**0.6**	**17.1**	**15.1**	**14.8**	**18.0**	**2.5**	**3.0**	**13.5**	**3.0**	**7.1**	**5.8**	**5.6**	**-1.8**	**8.4**	**-1.3**	**-1.8**
Maximum	**49.9**	**13.7**	**38.1**	**36.9**	**11.1**	**34.1**	**23.4**	**19.6**	**30.2**	**7.1**	**22.4**	**28.5**	**10.9**	**19.3**	**38.0**	**20.1**	**5.9**	**24.2**	**8.7**	**9.1**
Minimum	**-11.4**	**-6.7**	**-9.6**	**2.1**	**-10.4**	**7.7**	**1.7**	**6.5**	**11.0**	**-7.8**	**-12.2**	**-2.8**	**-16.8**	**-2.6**	**-20.7**	**-12.5**	**-9.8**	**-4.2**	**-18.4**	**-12.9**
(b) "Largest change" future condition																				
January	47.5	2.4	1.6	3.9	-3.9	32.9	32.7	26.2	30.3	9.2	17.9	14.8	4.0	32.9	16.3	14.4	-5.6	18.8	-8.0	2.2
February	7.6	4.6	-2.9	6.9	-0.7	28.0	24.2	11.7	34.3	7.9	12.4	17.1	3.6	17.6	7.9	5.2	-12.1	8.7	1.8	29.3
March	1.8	11.2	1.2	8.1	-3.3	43.2	23.4	11.0	39.8	-22.8	10.0	8.4	2.1	42.9	6.4	9.2	-9.5	2.4	-15.7	0.5
April	8.2	3.4	3.4	-2.1	-24.7	48.0	39.5	14.1	48.4	-5.5	13.0	3.9	-2.6	25.2	8.7	-1.2	-15.6	5.4	-29.7	-11.3
May	13.3	8.8	11.1	5.8	-22.0	51.1	29.5	28.3	61.3	-3.8	8.6	7.8	-5.7	15.6	21.6	2.1	-14.5	7.9	-16.4	-26.5
June	-5.1	3.1	29.6	-1.4	-6.3	49.1	43.5	31.0	50.1	-6.6	17.2	3.4	-9.9	33.3	5.2	5.4	-5.4	8.8	-3.7	-47.0
July	3.4	4.0	35.3	12.9	-12.1	59.1	42.7	23.0	51.3	-10.5	32.9	14.2	-8.8	45.7	0.7	9.7	-9.2	11.5	-5.4	-50.6
August	7.5	0.2	21.9	2.8	-2.9	51.0	39.1	15.3	50.7	-11.1	27.4	9.0	19.2	24.6	-2.3	10.8	-7.5	15.4	1.7	-19.3
September	6.0	2.8	17.9	5.3	-9.3	24.1	30.2	9.0	39.1	-8.4	25.8	9.6	24.5	13.8	4.5	7.7	-7.2	14.0	-5.2	-11.9
October	10.6	2.0	15.5	11.0	-10.3	28.5	21.6	4.6	42.1	-13.8	23.7	12.5	37.2	20.7	8.6	6.4	-8.2	16.1	-10.5	-17.3
November	20.5	0.8	18.6	0.1	-3.4	24.7	20.4	5.9	26.3	-14.5	27.6	10.4	31.2	20.1	13.8	2.7	-3.7	6.9	4.6	-14.4
December	48.3	-0.4	7.1	19.2	-6.8	27.5	23.0	14.7	19.9	-0.6	35.3	25.9	15.3	28.6	24.5	-1.7	-2.7	2.6	3.0	-6.1
Average	**14.1**	**3.6**	**13.4**	**6.0**	**-8.8**	**38.9**	**30.8**	**16.2**	**41.1**	**-6.7**	**21.0**	**11.4**	**9.2**	**26.8**	**9.6**	**5.9**	**-8.4**	**9.9**	**-7.0**	**-14.4**
Maximum	**48.3**	**11.2**	**35.3**	**19.2**	**-0.7**	**59.1**	**43.5**	**31.0**	**61.3**	**9.2**	**35.3**	**25.9**	**37.2**	**45.7**	**24.5**	**14.4**	**-2.7**	**18.8**	**4.6**	**29.3**
Minimum	**-5.1**	**-0.4**	**-2.9**	**-2.1**	**-24.7**	**24.1**	**20.4**	**4.6**	**19.9**	**-22.8**	**8.6**	**3.4**	**-9.9**	**13.8**	**-2.3**	**-1.7**	**-15.6**	**2.4**	**-29.7**	**-50.6**
Legend	**0 > Monthly rain change > -10**					**-10 > Monthly rain change > -25**					**Monthly rain change < -25**					**All monthly rain changes >= 0**				

Table B2 Projected mean annual and seasonal rainfall changes (mm)

Total change for period	Cook Is		FSM		Fiji	Kiribati			Nauru	Niue	Palau	PNG	RMI		Samoa	Solomon Is	Tonga	Tuvalu	Vanuatu	East Timor
	Northern Islands	Southern Islands	West	East		Gilbert Group	Phoenix Group	Line Group					Northern Islands	Sourthern Islands						
Annual																				
(a) "Most likely"	72	25	80	190	8	205	181	177	216	30	36	162	36	85	69	67	-22	100	-15	-22
(b) "Largest change"	169	43	160	72	-106	467	370	195	494	-81	252	137	110	321	116	71	-101	118	-84	-172
Wet season																				
(a) "Most likely"	67	6	7	143	34	71	74	92	105	20	49	104	2	47	56	68	17	63	8	0
(b) "Largest change"	134	22	131	36	-43	204	163	84	199	-26	149	80	54	179	77	29	-49	45	-44	0
Dry season																				
(a) "Most likely"	5	19	74	47	-26	134	108	86	111	10	-13	58	34	38	13	-1	-40	38	-23	-21
(b) "Largest change"	36	21	29	36	-63	263	207	111	295	-54	116	56	54	167	38	42	-52	74	-40	-173
Legend	0 > Rainfall change > -10					-10 > Rainfall change >-25					Rainfall change < -25									

Annex C

Projected rainfall intensity changes for 2030

Table C1 Projected mean monthly rainfall intensity changes (mm)

Month	Cook Is		FSM		Fiji	Kiribati			Nauru	Niue	Palau	PNG	RMI		Samoa	Solomon Is	Tonga	Tuvalu	Vanuatu	East Timor
	Northern Islands	Southern Islands	West	East		Gilbert Group	Phoenix Group	Line Group					Northern Islands	Sourthern Islands						
(a) "Most likely" future condition																				
January	5.7	-0.7	9.2	0.9	1.3	-3.2	0.9	1.0	2.3	1.0	-0.3	0.8	1.6	1.7	0.0	1.5	1.6	-1.9	-0.3	-0.4
February	6.1	0.4	5.4	0.0	2.5	-1.6	-0.6	1.4	0.4	0.9	-0.4	0.3	0.9	0.6	0.2	0.8	1.6	0.7	1.5	2.4
March	4.4	3.0	3.3	-0.3	1.8	0.9	0.8	1.1	0.1	4.6	3.0	1.7	1.8	0.5	-1.0	0.2	2.0	3.8	0.5	0.9
April	0.3	4.4	2.4	-0.4	1.5	0.7	0.9	2.3	-0.2	3.2	2.4	2.5	0.5	1.1	2.1	2.4	1.1	3.1	2.2	0.8
May	2.5	0.7	2.6	1.0	0.0	2.5	2.8	3.1	0.6	1.8	1.1	0.9	-0.3	1.4	2.2	1.9	-0.6	4.6	-0.1	-0.1
June	3.7	3.1	3.6	3.3	-1.0	3.8	1.1	3.5	2.1	-0.6	0.4	2.0	1.0	1.1	-1.6	1.1	-1.6	2.1	-1.1	2.6
July	0.6	3.1	4.8	2.8	0.1	6.4	4.4	1.8	1.4	2.3	2.0	-0.4	3.7	1.3	-0.5	1.3	0.7	0.6	-0.7	-0.3
August	0.4	1.8	1.5	2.2	-0.1	5.6	3.2	3.9	1.4	1.5	-0.5	1.3	0.5	2.6	-1.5	1.4	-1.0	0.4	-0.9	-0.7
September	0.1	-0.2	1.5	2.4	0.1	5.1	4.4	4.2	1.5	-0.4	2.9	2.7	3.3	0.9	0.2	1.0	-0.8	0.0	-0.7	0.2
October	0.3	-2.3	-0.3	0.1	-0.3	0.7	3.6	3.7	2.4	-2.9	0.3	0.1	1.4	1.0	-0.6	0.5	-1.2	0.7	0.6	-0.3
November	2.0	-1.6	-0.5	0.9	-0.2	3.0	3.1	3.1	1.3	-1.3	1.4	1.4	2.1	1.2	-0.9	0.8	0.6	0.7	-0.1	-1.1
December	8.7	0.1	4.8	0.3	-0.7	3.0	2.1	2.8	1.8	0.1	-0.7	0.0	3.7	0.8	1.7	-0.8	0.6	-0.1	-1.5	-1.8
Average	**2.9**	**1.0**	**3.2**	**1.1**	**0.4**	**2.2**	**2.2**	**2.6**	**1.2**	**0.9**	**1.0**	**1.1**	**1.7**	**1.2**	**0.0**	**1.0**	**0.2**	**1.2**	**0.0**	**0.2**
Maximum	**8.7**	**4.4**	**9.2**	**3.3**	**2.5**	**6.4**	**4.4**	**4.2**	**2.4**	**4.6**	**3.0**	**2.7**	**3.7**	**2.6**	**2.2**	**2.4**	**2.0**	**4.6**	**2.2**	**2.6**
Minimum	**0.1**	**-2.3**	**-0.5**	**-0.4**	**-1.0**	**-3.2**	**-0.6**	**1.0**	**-0.2**	**-2.9**	**-0.7**	**-0.4**	**-0.3**	**0.5**	**-1.6**	**-0.8**	**-1.6**	**-1.9**	**-1.5**	**-1.8**
(b) "Largest change" future condition																				
January	12.9	3.7	0.7	1.8	5.0	2.5	2.2	1.4	1.4	8.3	1.2	17.7	0.4	3.9	9.3	2.2	4.3	0.1	4.5	1.4
February	4.5	0.9	0.0	2.1	1.9	3.2	2.4	0.4	2.0	1.1	0.9	22.3	0.1	3.7	3.7	2.6	-1.9	5.8	3.8	3.8
March	3.1	2.1	0.2	1.6	6.7	3.7	2.1	1.3	1.9	-0.6	1.3	9.1	-0.2	3.4	7.1	-0.4	3.3	-0.5	0.4	-0.7
April	1.7	0.3	0.0	-0.1	2.0	4.2	3.3	1.4	4.5	3.5	0.1	11.8	-1.4	2.4	3.6	0.6	1.1	1.4	2.4	-1.3
May	4.5	2.7	0.4	2.2	-0.6	4.9	2.4	1.9	6.3	1.2	0.4	15.0	-1.2	1.2	5.2	2.2	-1.0	1.3	-0.5	-0.7
June	0.5	2.5	1.8	1.3	0.2	4.9	2.3	0.5	7.5	4.0	0.7	15.1	-0.4	1.3	3.9	-0.4	0.4	-1.5	-0.2	-7.8
July	-0.7	0.5	2.3	4.3	-1.0	5.9	3.5	1.3	6.8	0.1	1.7	20.4	0.6	4.3	3.5	2.9	-0.2	1.7	0.1	-6.9
August	0.9	-0.1	2.3	2.1	0.4	4.8	2.6	1.0	5.1	0.5	2.0	15.1	0.9	0.7	-0.6	1.0	-0.1	1.2	1.8	-5.1
September	0.6	0.8	2.2	1.2	-1.8	4.4	2.9	1.0	6.2	-3.7	1.9	25.9	4.0	2.7	1.8	1.2	-1.1	1.6	-0.6	-2.2
October	1.4	-1.1	1.7	2.5	-1.0	4.3	2.7	0.2	2.3	-5.2	1.7	22.8	6.0	0.5	4.4	1.6	-2.8	0.6	0.1	-4.7
November	4.6	0.6	0.3	1.4	-1.2	4.0	0.2	-1.3	3.6	2.1	2.7	10.1	3.6	0.2	6.3	-0.1	0.0	2.7	2.0	-3.8
December	13.9	1.0	0.1	3.3	0.8	2.9	2.4	1.1	1.5	0.4	3.9	10.8	3.0	1.4	10.7	0.4	3.1	0.1	4.0	6.7
Average	**4.0**	**1.2**	**1.0**	**2.0**	**1.0**	**4.1**	**2.4**	**0.9**	**4.1**	**1.0**	**1.5**	**16.3**	**1.3**	**2.1**	**4.9**	**1.1**	**0.4**	**1.2**	**1.5**	**-1.8**
Maximum	**13.9**	**3.7**	**2.3**	**4.3**	**6.7**	**5.9**	**3.5**	**1.9**	**7.5**	**8.3**	**3.9**	**25.9**	**6.0**	**4.3**	**10.7**	**2.9**	**4.3**	**5.8**	**4.5**	**6.7**
Minimum	**-0.7**	**-1.1**	**0.0**	**-0.1**	**-1.8**	**2.5**	**0.2**	**-1.3**	**1.4**	**-5.2**	**0.1**	**9.1**	**-1.4**	**0.2**	**-0.6**	**-0.4**	**-2.8**	**-1.5**	**-0.6**	**-7.8**
Legend	**0 < Rain Intensity Change <5**					**Rain Intensity Change > 5**					**Rain Intensity Change <= 0**									

Table C2 Projected mean annual and seasonal rainfall intensity changes (mm)

Average change for period	Cook Is		FSM		Fiji	Kiribati			Nauru	Niue	Palau	PNG	RMI		Samoa	Solomon Is	Tonga	Tuvalu	Vanuatu	East Timor
	Northern Islands	Southern Islands	West	East		Gilbert Group	Phoenix Group	Line Group					Northern Islands	Sourthern Islands						
Annual																				
(a) "Most likely"	2.9	1.0	3.2	1.1	0.4	2.2	2.2	2.6	1.2	0.9	1.0	1.1	1.7	1.2	0.0	1.0	0.2	1.2	0.0	0.2
(b) "Largest change"	4.0	1.2	1.0	2.0	1.0	4.1	2.4	0.9	4.1	1.0	1.5	16.3	1.3	2.1	4.9	1.1	0.4	1.2	1.5	-1.8
Wet season																				
(a) "Most likely"	4.5	1.0	2.3	2.0	1.0	0.5	1.2	2.0	0.9	1.4	1.0	1.1	1.6	1.4	0.3	0.8	1.3	1.1	0.4	0.1
(b) "Largest change"	6.8	1.4	1.5	1.9	2.5	3.4	2.1	0.7	2.5	2.5	1.2	13.6	1.2	1.9	6.8	0.9	1.6	1.6	2.8	1.0
Dry season																				
(a) "Most likely"	1.2	1.0	4.1	0.2	-0.2	4.0	3.2	3.3	1.6	0.3	0.9	1.1	1.8	1.0	-0.3	1.2	-0.8	1.4	-0.5	0.2
(b) "Largest change"	1.2	0.9	1.8	2.3	-0.6	4.9	2.8	1.0	5.7	-0.5	1.4	19.0	1.7	1.8	3.0	1.4	-0.8	0.8	0.1	-4.6

Legend 0 < Rain Intensity Change <5 Rain Intensity Change > 5 Rain Intensity Change <= 0

Notes

For Southern Hemisphere (all but FSM, Palau & RMI)
(a) wet season is November to April
(b) dry season is May to October

For Northern Hemisphere (FSM, Palau & RMI)
(a) wet season is taken to be May to October
(b) dry season is taken to be November to April

Annex D

Projected mean temperature changes for 2030

Table D1 Projected mean monthly temperature changes (mm)

Month	Cook Is		FSM		Fiji	Kiribati			Nauru	Niue	Palau	PNG	RMI		Samoa	Solomon Is	Tonga	Tuvalu	Vanuatu	East Timor
	Northern Islands	Southern Islands	West	East		Gilbert Group	Phoenix Group	Line Group					Northern Islands	Southern Islands						
(a) "Most likely" future condition																				
January	0.64	0.74	0.90	0.72	0.87	1.01	1.08	1.05	0.98	0.79	0.97	0.93	0.85	0.97	0.83	0.87	0.91	0.64	0.83	0.64
February	0.67	0.78	0.87	0.71	0.85	1.03	1.09	1.07	0.96	0.82	1.00	0.94	0.83	0.95	0.81	0.84	0.88	0.68	0.87	0.61
March	0.62	0.87	0.84	0.69	0.83	1.04	1.11	1.12	0.88	0.88	1.00	0.93	0.77	0.95	0.91	0.84	0.85	0.72	0.80	0.67
April	0.61	0.81	0.84	0.70	0.80	1.13	1.14	1.11	0.88	0.81	0.99	0.98	0.71	0.94	0.93	0.89	0.81	0.72	0.78	0.69
May	0.63	0.83	0.82	0.68	0.75	1.10	1.11	1.07	0.86	0.84	0.97	0.95	0.73	0.94	0.83	0.84	0.75	0.70	0.76	0.67
June	0.64	0.76	0.88	0.69	0.84	1.13	1.11	1.05	0.89	0.80	0.96	0.96	0.82	0.95	0.83	0.84	0.84	0.65	0.83	0.65
July	0.63	0.74	0.88	0.68	0.84	1.16	1.14	1.03	0.87	0.77	0.99	0.92	0.83	0.93	0.71	0.85	0.81	0.64	0.86	0.62
August	0.67	0.77	0.89	0.70	0.76	1.10	1.10	0.98	0.92	0.77	0.95	0.91	0.86	0.93	0.67	0.82	0.75	0.61	0.82	0.59
September	0.69	0.78	0.87	0.71	0.70	1.05	1.04	0.95	0.89	0.82	0.98	0.90	0.88	0.97	0.69	0.76	0.71	0.59	0.74	0.59
October	0.71	0.77	0.87	0.70	0.72	1.01	1.00	0.92	0.82	0.79	0.96	0.95	0.87	1.00	0.75	0.78	0.73	0.59	0.77	0.60
November	0.71	0.76	0.85	0.71	0.80	0.94	0.94	0.92	0.78	0.82	0.97	0.91	0.86	0.99	0.75	0.83	0.83	0.59	0.80	0.63
December	0.69	0.74	0.89	0.68	0.83	0.92	0.93	0.91	0.74	0.79	0.96	0.88	0.86	0.99	0.80	0.82	0.87	0.57	0.79	0.65
Average	**0.7**	**0.8**	**0.9**	**0.7**	**0.8**	**1.1**	**1.1**	**1.0**	**0.9**	**0.8**	**1.0**	**0.9**	**0.8**	**1.0**	**0.8**	**0.8**	**0.8**	**0.6**	**0.8**	**0.6**
Maximum	**0.7**	**0.9**	**0.9**	**0.7**	**0.9**	**1.2**	**1.1**	**1.1**	**1.0**	**0.9**	**1.0**	**1.0**	**0.9**	**1.0**	**0.9**	**0.9**	**0.9**	**0.7**	**0.9**	**0.7**
Minimum	**0.6**	**0.7**	**0.8**	**0.7**	**0.7**	**0.9**	**0.9**	**0.9**	**0.7**	**0.8**	**1.0**	**0.9**	**0.7**	**0.9**	**0.7**	**0.8**	**0.7**	**0.6**	**0.7**	**0.6**
(b) "Largest change" future condition																				
January	0.78	0.91	0.63	0.74	0.66	1.12	1.11	1.00	1.13	0.68	0.67	0.80	0.90	0.91	0.93	0.77	0.64	0.84	0.66	0.82
February	0.76	0.95	0.63	0.74	0.64	1.18	1.16	1.02	1.21	0.59	0.67	0.80	0.80	0.91	0.94	0.72	0.58	0.79	0.64	0.74
March	0.76	0.97	0.63	0.77	0.56	1.22	1.20	1.06	1.26	0.53	0.66	0.83	0.78	0.88	0.95	0.80	0.52	0.84	0.57	0.75
April	0.74	0.91	0.64	0.78	0.61	1.26	1.22	1.07	1.30	0.64	0.67	0.80	0.79	0.88	0.91	0.77	0.61	0.80	0.61	0.82
May	0.74	0.94	0.62	0.75	0.59	1.30	1.23	1.07	1.33	0.53	0.66	0.79	0.84	0.90	0.90	0.76	0.54	0.78	0.66	0.73
June	0.76	0.90	0.62	0.76	0.70	1.30	1.25	1.09	1.27	0.56	0.69	0.78	0.88	0.90	0.90	0.75	0.64	0.79	0.72	0.68
July	0.77	0.86	0.56	0.79	0.67	1.23	1.15	1.03	1.19	0.46	0.70	0.74	0.94	0.85	0.86	0.72	0.57	0.76	0.77	0.60
August	0.77	0.98	0.56	0.77	0.64	1.17	1.08	1.02	1.16	0.42	0.71	0.71	0.98	0.87	0.91	0.71	0.52	0.72	0.76	0.60
September	0.79	0.94	0.58	0.80	0.59	1.14	1.06	1.00	1.15	0.49	0.74	0.73	0.98	0.92	0.91	0.66	0.55	0.70	0.68	0.65
October	0.81	0.98	0.61	0.84	0.67	1.11	1.06	0.99	1.15	0.58	0.77	0.79	0.98	0.92	0.90	0.69	0.62	0.69	0.75	0.71
November	0.82	1.02	0.66	0.78	0.63	1.04	1.01	0.95	1.04	0.63	0.78	0.77	0.95	0.89	0.97	0.67	0.64	0.72	0.65	0.80
December	0.81	0.96	0.65	0.75	0.71	1.01	0.98	0.92	1.02	0.78	0.74	0.77	0.96	0.90	0.92	0.68	0.74	0.79	0.67	0.90
Average	**0.8**	**0.9**	**0.6**	**0.8**	**0.6**	**1.2**	**1.1**	**1.0**	**1.2**	**0.6**	**0.7**	**0.8**	**0.9**	**0.9**	**0.9**	**0.7**	**0.6**	**0.8**	**0.7**	**0.7**
Maximum	**0.8**	**1.0**	**0.7**	**0.8**	**0.7**	**1.3**	**1.3**	**1.1**	**1.3**	**0.8**	**0.8**	**0.8**	**1.0**	**0.9**	**1.0**	**0.8**	**0.7**	**0.8**	**0.8**	**0.9**
Minimum	**0.7**	**0.9**	**0.6**	**0.7**	**0.6**	**1.0**	**1.0**	**0.9**	**1.0**	**0.4**	**0.7**	**0.7**	**0.8**	**0.9**	**0.9**	**0.7**	**0.5**	**0.7**	**0.6**	**0.6**
Legend	**Temperature change < 0.75**						**0.75 < Temperature change < 1.0**						**Temperature change > 1.0**							

Table D2 Projected mean annual and seasonal temperature changes (mm)

Average change for period	Cook Is		FSM		Fiji	Kiribati			Nauru	Niue	Palau	PNG	RMI		Samoa	Solomon Is	Tonga	Tuvalu	Vanuatu	East Timor
	Northern Islands	Southern Islands	West	East		Gilbert Group	Phoenix Group	Line Group					Northern Islands	Sourthern Islands						
Annual																				
(a) "Most likely"	0.7	0.8	0.9	0.7	0.8	1.1	1.1	1.0	0.9	0.8	1.0	0.9	0.8	1.0	0.8	0.8	0.8	0.6	0.8	0.6
(b) "Largest change"	0.8	0.9	0.6	0.8	0.6	1.2	1.1	1.0	1.2	0.6	0.7	0.8	0.9	0.9	0.9	0.7	0.6	0.8	0.7	0.7
Wet season																				
(a) "Most likely"	0.7	0.8	0.9	0.7	0.8	1.0	1.0	1.0	0.9	0.8	1.0	0.9	0.8	1.0	0.8	0.8	0.9	0.7	0.8	0.6
(b) "Largest change"	0.8	1.0	0.6	0.8	0.6	1.1	1.1	1.0	1.2	0.6	0.7	0.8	0.9	0.9	0.9	0.7	0.6	0.8	0.6	0.8
Dry season																				
(a) "Most likely"	0.7	0.8	0.9	0.7	0.8	1.1	1.1	1.0	0.9	0.8	1.0	0.9	0.8	1.0	0.7	0.8	0.8	0.6	0.8	0.6
(b) "Largest change"	0.8	0.9	0.6	0.8	0.6	1.2	1.1	1.0	1.2	0.5	0.7	0.8	0.9	0.9	0.9	0.7	0.6	0.7	0.7	0.7
Legend	**Temperature change < 0.75**						**0.75 < Temperature change < 1.0**						**Temperature change > 1.0**							
Notes	For Southern Hemisphere				(a) wet season is November to April															
	(all but FSM, Palau & RMI)				(b) dry season is May to October															
	For Northern Hemisphere				(a) wet season is taken to be May to October															
	(FSM, Palau & RMI)				(b) dry season is taken to be November to April															

Annex E

Communiqué on the Pacific Regional Consultation on Water in Small Island Countries, August 2002

Adopted by Ministers and Island Country Delegations and representatives of civil society groups meeting in the final High-Level Session of the Pacific Regional Consultation on Water in Small Island Countries, Sigatoka, Fiji Islands, 3rd August 2002, as part of the preparatory process for the 3rd World Water Forum

Recognising, the unique geographic and physical characteristics, as well as the fragile nature of water resources in small and vulnerable island countries which impact on the health and well-being of our peoples, environment and the development of our island economies;

We, Ministers and Island Country Delegations and representatives of civil society groups, with responsibilities for water affairs from 18 small island developing states from the Pacific, as well as East Timor, and Maldives, met in Sigatoka, Fiji Islands 29 July – 3 August to share knowledge particularly within and across the small island country regions, and agree to an action plan for sustainable water management in our islands.

We acknowledge the work of national governments, supported by regional and international intergovernmental organizations, and civil society groups to achieve sustainable resource management of water.

We recommit ourselves to sustainable water management components of Agenda 21 agreed to ten years ago in Rio de Janeiro, Brazil and the Global Action Plan for Small Island Developing States agreed to in Barbados 1994 and the outcomes of the 5-year reviews undertaken in 1997 and 1999.

We associate and reaffirm as appropriate ourselves with the outcomes of the meeting on freshwater held in Bonn, Germany, in December 2001, which identified financing, capacity building and governance as key constraints. This Consultation recognises these as important in small island countries and adds political will as another important constraint which makes a set of four key constraints that need to be overcome for sustainable management of the region's water resources.

We urge the international community to pursue the achievement of the Millennium Development Goals that target the vital role of sustainable water management contributing to reducing poverty, improving health and livelihoods for all people.

Recognising that the World Summit on Sustainable Development (WSSD) is to take place in Johannesburg, South Africa, later this month, 26 August - 5 September and the 3rd World Water Forum in Kyoto, Japan in March 2003, decide that:

For water resources management the following are key:

1. Strengthen the capacity of small island countries to conduct water resources assessment and monitoring as a key component of sustainable water resources management.
2. Implement strategies to utilise appropriate methods and technologies for water supply and sanitation systems and approaches for rural and peri-urban communities in small islands.
3. Implement strategies to improve the management of water resources, and surface and groundwater catchments (watersheds) for the benefit of all sectors including local communities, development interests and the environment.

For island vulnerability the following are key:

1. There is a need for capacity development to enhance the application of climate information to cope with the impacts of climate variability and change.
2. Change the paradigm for dealing with Island Vulnerability from disaster response to hazard assessment and risk management, particularly in Integrated Water Resource Management.

For awareness the following are key:

1. A high quality participatory framework should be adopted at the National level to allow for open participation of communities in sustainable water and wastewater management.
2. Access to, and availability of information on sustainable water and wastewater management should be provided to all levels of society.
3. Water and sanitation education should be mainstreamed into the formal education system.
4. Improve communication and coordination of all stakeholders in sustainable water and wastewater management including government, civil society and the private sector.

For technology the following are key:

1. Appropriate and well-governed institutions, infrastructure and information will support sustainable water and wastewater management.
2. Utility collaboration in regional partnership to reduce unaccounted for water will significantly improve the sustainability of utilities and reduce the need for developing new water resources.
3. Island specific regional training programmes should be developed, resulting in sustainable levels of skilled and knowledgeable people and communities within the water and wastewater sector.

For institutional arrangements the following are key:

1. Work together through a comprehensive consultative process, encompassing good governance to develop a shared National vision for managing water resources in a sustainable manner.
2. Develop national instruments including national visions, policies, plans and legislation appropriate to each small island countries taking into account the particular social, economic, environmental and cultural needs of the citizens of each country.
3. Promote and establish appropriate institutional arrangements resourced sufficiently to enable effective management of water resources and the provision of appropriate water services.
4. Recognise and share the water resource management knowledge and skills of all stakeholders at a National and regional level in the process of developing and implementing the National Vision.
5. National and regional leadership in water resource management should be recognised and encouraged.

For financing the following are key:

1. Create a better and sustainable environment for investment by both the public and private sector, by developing and implementing National, sector and strategic plans that identify the economic, environmental and social costs of different services and to develop pricing policies, which ensures the proper allocation of resources for the water sector.
2. Establish financially viable enterprises for water and sanitation that result in improved performance by developing appropriate financial and cost recovery policies, tariffs, billing and collection systems, financial and operating systems.
3. Reduce costs through improved operational efficiency, using benchmarking, development of water loss reduction programmes and improved work practices.
4. Ensure access for the poor to water and sanitation services by developing pro poor policies that include tariffs with lifeline blocks and transparent and targeted subsidies.
5. Achieve sustainable rural water and sanitation services at a community level through developing strategies that incorporate mechanisms for appropriate financing and capacity building.

We endorse the Regional Action Plan prepared during the Consultation, to address these key issues for the water sector in the pursuit of sustainable development in our islands. (Copy of the Regional Action Plan attached to this Communiqué).

We urge each country representative to actively promote the priorities outlined in this Communiqué with their country delegations attending (i) the Pacific Island Forum Leaders Meeting in Suva, later this month, and (ii) attending the World Summit on Sustainable Development.

We agree that the Type 2 Partnership/Initiative on water being submitted by the Pacific delegations at the WSSD must provide an opportunity to secure support to implement the Regional Action Plan and urge donors and partners to do likewise.

Acknowledging the valuable contribution of the International Secretariat of the Dialogue on Water and Climate and the Caribbean delegates to the importance given to island vulnerability, we commend this Plan to the Caribbean Consultative Meeting to be held in October 2002 as part of the preparations for the 3rd World Water Forum, and support partnerships between the small island regions.

We request the organisers of this Consultation, SOPAC and the ADB, to transmit this Communiqué and the Regional Action Plan to the 3rd World Water Forum, in order that the priority actions needed to support sustainable water resources management in our small island countries are endorsed.

Finally, we acknowledge that the above meetings and for a are important steps on the road to addressing the vital water issues confronting our small island countries, and reaffirm our commitment to strive towards the realisation of sustainable water resources management for the benefit of the peoples of the small island countries.