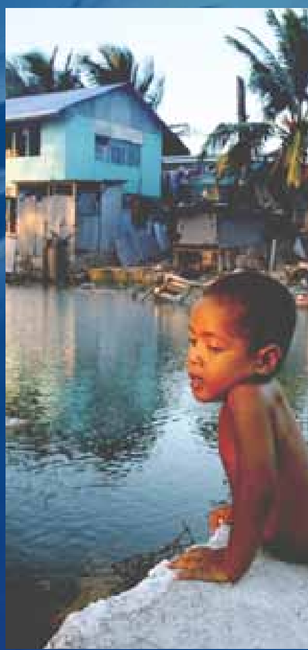
FRESHWATER under THREAT

PACIFIC ISLANDS

Vulnerability Assessment of Freshwater Resources to Environmental Change



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Foreword

Water is essential for life. It is also essential to most of the Millennium Development Goals (MDGs). Yet the world's freshwater resources remain vulnerable and a reliable assessment of its current vulnerability is needed. Major constraints to such an assessment have been the lack of an operational framework for vulnerability assessment and widespread lack of accurate and timely data at basin, and more significantly, sub-basin scale. However, progress in our understanding of what exactly is meant by vulnerability, as well as data gathering and processing techniques offer promising avenues to overcome these constraints.

The United Nations Environment Programme (UNEP) joined hands with a number of regional partners from Africa and Asia to address the issue of vulnerability of water resources on these continents. This assessment of freshwater resources vulnerability of the Pacific Islands, produced in collaboration with the Secretariat of the Pacific Community is one of the outcomes of this partnership.

The 14 Pacific Island Countries (PICs) are home to over 9 million people, the majority of whom live in rural areas. These countries have about 1,000 islands covering a land area of just over 500 thousand square kilometres, spread across 180 million square kilometres of ocean, more than one third of the earth surface. The term Small Islands Developing States (SIDS) recognizes the specific social, economic and environmental vulnerabilities of the 14 PICs. This Assessment concludes that their greatest vulnerability is the lack of freshwater resources in low-lying islands, exacerbated by limited human, financial and management resources, and increasing population densities. It includes a focused analysis of selected islands, which concludes that the Pacific island nations' economies, fragile ecosystems and livelihoods are particularly vulnerable to climate variability and change.

The water challenge is real and immense in PICs. This report reveals that about 10% of all deaths of children under five in the Pacific island countries are attributable to diarrhoeal diseases, and about 90% of these diseases are due to poor hygiene, lack of adequate sanitation treatment systems and high levels of poor quality drinking water.

The study finds that there is no one solution for the Pacific and a unique mix of policy intervention and preferred management measures is available to reduce water vulnerability in each Island State. It is our hope that this pioneering assessment will lead to a long-term process of periodic review and update, providing an authoritative picture of water-related vulnerability, and contribute to the empirical basis for sustainable development in the Pacific.

Young-Woo Park

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Regional Director and Representative for Asia and the Pacific
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Acronyms and Abbreviations

ADB	Asian Development Bank
CV	Coefficient of Variation
DALY	Disability Adjusted Life Years: a WHO measure of the loss of life and quality of life associated with diseases
DP	Development Pressures
DPSIR	Driver, pressure, status, impact response
EH	Ecological Health
ENSO	El Niño Southern Oscillation
ES	Ecological Insecurities
EU	European Union
FSM	Federated States of Micronesia
GDP	Gross Domestic Product
GEO	Global Environment Outlook (UNEP)
GEF	Global Environment Facility
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
MC	Management Challenges
MDG	Millennium Development Goal
ODA	Official Development Assistance
P	Population
PICs	Pacific Islands Countries
PIFS	Pacific Islands Forum Secretariat
PNG	Papua New Guinea
R	per capita water resources ($m^3.annum^{-1}.person^{-1}$)
RMI	Republic of the Marshall Islands
RS	Resource Stresses
SIDS	Small Island Developing States
SOPAC	Pacific Islands Applied Geoscience Commission; or SPC Applied Geoscience and Technology Division
SPC	Secretariat of the Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme
STAR	Science, Technology and Resources Network
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNICEF	The United Nations Children's Fund
UN-OHRLLS	UN Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States
USGS	United States Geological Survey
VI	Vulnerability Index
WHO	World Health Organization

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Executive Summary

The fourteen developing Pacific Island Countries (PICs) of the Pacific Region are home to over 9 million people, speaking about 1 200 languages, with the majority of Pacific islanders (about 80%) living in rural areas. These Pacific Island countries have about 1 000 islands covering a land area of just over half a million square kilometres, spread across 180 million square kilometres of ocean. The ecosystems supported across these islands are unique and among the most endangered in the world.

The water resources of the PICs represent global extremes, with annual water availability in Papua New Guinea around 120 000 m^3 per person versus Fongafale Islet in Tuvalu and Nauru having no confirmed freshwater resources, reliant on rainwater harvesting and desalination.

The PICs face similar challenges managing freshwater resources to other developing countries. Access to sanitation and safe drinking water, protecting sensitive ecosystems and generating productive use of variable water resources are among these issues. Often the challenges are associated with simply too little or too much water. Nevertheless, constrained by their remoteness, small size, fragility, natural vulnerability and limited human and financial resources, PICs face unique challenges managing water resources. These challenges require innovative approaches and tailoring of solutions not just to the region, but often to the complex combination of geographical and socioeconomic constraints of an individual island.

This study undertakes a vulnerability assessment of the freshwater resources of the PICs, based on input from technical experts and regional resource managers. The approach assumes that the vulnerability of freshwater resources is dependent upon the resources available to meet the productive, consumptive and environment uses; the pollution and development pressures; and the management capacity to respond to these pressures. This approach highlights the importance of drivers such as climate variability and change, population growth, urban migration and economic development to water resource vulnerability through their influence on the state of freshwater resources and the associated pressures.

Throughout the Pacific water resources are typically managed on an island-by-island basis as inter-island transfers across hundreds of kilometres of ocean are generally impractical and cost-prohibitive. Accordingly, this assessment has reviewed the water resource vulnerability of individual islands. A selection of islands was chosen for the study, representative of the two main island forms: (i) atolls and limestone islands dependent on rainwater and groundwater – Nauru, Majuro Atoll (in Republic of the Marshall Islands) and Fongafale Islet (Tuvalu); and (ii) volcanic islands with river systems – including Rarotonga (Cook Islands), Viti Levu (Fiji), New Guinea (Papua New Guinea) and Upolu (Samoa).

In compiling this water resource vulnerability index, it was necessary to make a range of assumptions to enable assessment of islands with significant variation in hydrology, geography, environment, socio-economic status and management practices. At the highest level, the assumption has been made that the selected islands are broadly representative of freshwater vulnerability in the Pacific region, and that the main islands within these countries provide an indication of the vulnerability across countries. Further, in many cases, limited data from a limited number of rainfall gauges has been adopted as being representative of island hydrology, where differences in rainfall depths across an island over 100% are common. The limited availability of some data has been partially off-set by use of expert opinion and ground-truthing in-country and supported by country experts. Whilst all reasonable attempts have been made to obtain data, and to ensure accuracy of assessments, the procedure of this vulnerability assessment is sufficiently robust and flexible to incorporate a moderate degree of uncertainty in data.

Resource Stresses

The greatest vulnerability is reflected in the lack of water resources in low-lying islands. Six island countries – Nauru, Niue, Kiribati, Tonga, Tuvalu and the Republic of the Marshall Islands – have no significant surface water resources and of these, only Tonga and Niue have significant groundwater resources. The almost total dependence upon rain-fed agriculture across all of the Pacific island nations means that their economies and peoples' livelihoods are particularly vulnerable to drought and rainfall variability and ultimately to climate variability and change pressures. At the other extreme, the intense rainfall and runoff experienced in several large volcanic islands causes flooding on the coastal plains.

The annual rainfall variability of many islands (as high as 54% in Nauru) means that rain cannot be relied upon to meet water demands. For populations on islands with no surface water or significant groundwater resources, this variability of the sole natural source represents a significant threat to island sustainability. On larger islands such as New Guinea, high spatial variability means that significant infrastructure is required to capture, store and distribute water to meet demands. Several islands have adopted desalination to provide greater security, but at a very high operating cost, which is further impacted by the variability of electricity supply and global fuel costs. The already high rainfall variability on many islands will mean that climate variability and change will become an increasingly important driver in water resource planning and decision making.

Development Pressures

The development challenges within the larger volcanic islands of Viti Levu and New Guinea are largely related to meeting basic human rights for access to improved water supply. The predominantly rural populations across these large rugged islands are clearly stretching the capacity to deliver safe drinking water supplies, with access to improved drinking water sources in Fiji and Papua New Guinea at 40% and 47%, respectively (about half the global average of 87%) and almost no change since 1990. Significant investment in these areas has seen a considerable increase in the number of people with access to drinking water; however, population growth has matched this over the same period. It is anticipated that both Papua New Guinea and Fiji will fall significantly short of the Millennium Development Goal (MDG) for improved drinking water access. Currently, development within river systems of large volcanic islands has limited impacts on flows and almost no associated stress; however, significant hydropower and mining developments have the potential to alter this situation.

Small atoll and raised coral islands typically make maximum use of the limited resources available. The extreme stress on water resources means that resources outside the traditional surface water and groundwater resources have been developed, including a high dependence on rainwater harvesting and desalination. The small populations and targeted investment strategies have enabled these islands to achieve relatively high levels of access to drinking water supply, with most of these countries on track to meet the relevant MDG targets. Nevertheless, whilst access levels are high, the extended periods of minimal water access during periods of extended drought (often months) indicate significant scope for improvement.

Smaller volcanic islands experience low to moderate stress on water resources associated with extractive use; however, seasonal variability in water resources on Upolu and Rarotonga mean that rivers and streams can be significantly stressed over the dry season. The challenge to water resource managers is to find mechanisms to access and harvest this resource to meet development and household supply needs. Whilst this is generally occurring, Samoa is not on track to meet the improved drinking water access MDG.

Ecological Insecurities

Ecologically, the smaller islands are also under greatest stress, with 85% to 90% of vegetation cleared on Majuro Atoll, Nauru, Fongafale and Upolu, reflecting the high population densities of these islands, which range from 124 to 2 600 people km^{-2}. These islands also have the smallest capacity to absorb wastewater generated from urban areas, polluting critical groundwater lenses.

The lower population densities, high runoff and limited development of large islands have generally allowed them to provide a higher level of protection for vulnerable ecosystems. Impacts on these islands tend to be localised to areas of intense development associated with mining, urban expansion and tourism; however, the experiences of mining development in the Fly River, Papua New Guinea, indicate that these local impacts can be extreme.

Management Challenges

Probably the greatest challenge facing PICs in water resource management is limited technical and governance capacity. The remoteness of these islands and small populations may limit options to manage resource pressures. Combined with emigration of skilled professionals out of the region there is minimal capacity within regional countries to respond to the day-to-day vulnerability threats, let alone the frequent natural disasters experienced in some countries. Many countries have small administrations dealing with the varying complexities of main and outer island issues, without the access to economies of scale available to many larger countries tackling similar issues. The broad lack of enabling national policies and legislation, and the lack of capacity to implement existing strategies must be tackled to reduce regional, national and island freshwater vulnerability.

The management challenges are reflected in the rates of access to improved sanitation on several islands. Nauru and New Guinea are at 50% and 45%, respectively. There has been no improvement in regional access since 1990.

The efficiency of rainwater resource use is assessed as the productivity against a basket group of islands and island nations located in the Pacific Ocean with high productivity (Japan, Singapore, Hong Kong and New Zealand). Against this benchmark, only Funafuti and Nauru were able to match or better the productivity per unit of rainfall, reflecting the effective use of rainwater as a core resource on these islands. The productivity of all other islands was low, reflecting the minimal investment in intensive agriculture and industry development in these countries.

Vulnerability Index

The overall Vulnerability Index (VI) is determined by considering equally resource stresses (RS), development pressures (DP), ecological insecurities (ES), and management challenges (MC). The individual components and the VI for each island were then broadly classified on a scale from 0 to 1 (Good to Severe).

Water resources management provides the greatest challenge regionally, across nearly all islands. The other significant challenge is the delivery of fundamental human needs, improved drinking water and sanitation. Collectively, the islands can be considered as three broad groups:

- Low-lying islands under severe resource and environmental stress, with significant development pressure and a need for improved water management and governance (Fongafale, Majuro Atoll and Nauru)
- Larger volcanic islands with adequate water resources, but significant to severe water management and governance challenges in managing available resources, in particular provision of drinking water and sanitation (New Guinea and Viti Levu)

- Moderate-sized volcanic islands with adequate water resources, significant water management and governance challenges in managing the available resources, but a high-level of provision of improved drinking water and sanitation (Rarotonga and Upolu)

Recommendations

Several attempts have been made in the past to provide regional solutions to water resource management problems. Increasingly it is being recognised, as is highlighted by this assessment, that the region consists of a myriad of islands and countries, each with a combination of water resource, ecological, development and management pressures. These are in turn overlaid by the range of interlinked cultural, geographical and climatic environments and associated stresses and vulnerabilities. From a resource management approach, the largest unit that practically is suited to a consistent approach is a country level, due in part to shared culture and consistent governance framework. It is recommended that a country-based approach be pursued in managing water resources, and in addressing water resource development. Whilst programmes and projects may necessarily operate regionally to provide critical mass on resourcing, individual strategies are required for each country, and commonly at an island or island group level, to support development of water resources which reflects inherent vulnerability.

Management continues to be one of the greatest challenges addressing regional water resource vulnerability. The isolation of many islands, combined with limited local resources means that islands and countries in the region struggle to develop and retain a sustainable level of technical and management capacity. Long-term strategies to address this weakness are fundamental to developing a sustainable management capacity in the region. Further, this must be supported by high-level engagement to ensure political commitment to developing and implementing sustainable policies and legislation.

Improving water use efficiency is crucial to maintaining basic human needs on the most stressed islands and supporting sustainable development elsewhere. This area would benefit from the application of strategic cost-benefit analyses, to drive efficiency programmes, together with high-level political engagement.

Delivery of Integrated Water Resources Management (IWRM) within a model adapted to the Pacific is critical to delivery of many of the recommendations discussed in this report. Ensuring communication and knowledge exchange across government agencies, the private sector and communities, together is critical in delivering strategies that require these stakeholders to work in an integrated manner. The delivery of IWRM in PICs may also require varying degrees of institutional and utility reform to optimise governance and management arrangements.

The low delivery level of improved drinking water and sanitation into several countries, together with the water resource stress evident in low-lying countries supports investment in infrastructure. The type of investment is likely to be at a household or community level in low-lying islands, and probably a combination of household level and centralised infrastructure on larger islands. Utility reform associated with cost-recovery and improved efficiency and aligned with infrastructure investment, mainstreaming IWRM and infrastructure management and maintenance would enable countries to maximise development opportunities associated with water resources and better meet basic human rights.

Disaster risk management needs to be integrated into national planning and water resource management needs to be integrated into disaster risk management to provide PICs with resilience that reduces the costs, which are as high as 46% of GDP. Again, communities need to be an integral component in the planning and delivery of disaster management plans to ensure those same communities are protected.

Currently there is minimal feedback nationally and regionally on progress towards addressing major water resource issues. Indicator frameworks are required at national and regional levels to provide critical feedback to decision-makers on the success (or otherwise) of policy decisions and implementation. These frameworks need to be integrated to optimise the value obtained from the information transfer from the local to the global level.

Greater networking, information exchange and collaborative approaches at a sub-regional and regional level would enable progress to be built on the collective work of several countries addressing similar issues, such as sanitation and household drinking water safety planning. Whilst ad hoc initiatives are addressing these on an issue-by-issue basis, utilising regional bodies to coordinate efforts offers a more efficient and cost-effective use of limited resources.

Whilst management of existing resources is fundamental to alleviating freshwater vulnerability in PICs, several key areas of research may offer opportunities for improving the regional status of water resources and management. These include improvements in rainwater harvesting and storage (considering both traditional and innovative options); management and appropriate technology options for the whole island water cycle; optimising use of rainwater, surface water, groundwater (including brackish resources) and wastewater; assessing the role of desalination in both everyday supply and emergency situations; and developing governance and management frameworks that suit the technological solutions and the unique Pacific socio-economic environment.

Finally, the good initiatives originating in many countries, particularly via the European Union (EU) and Global Environment Facility (GEF) Pacific IWRM Projects, need to be recognised and supported, both to build capacity and to develop the most appropriate solutions to many of the problems facing the region. Examples of these are numerous, but include the integration of rainwater, sanitation and groundwater resource management on Nauru and Fongafale to balance the critical freshwater resources, sanitation needs, alternative water sources and protecting vulnerable ecosystems.

1.

Introduction



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1.1 Rationale

Developing economies, isolation, large distances between neighbouring islands, movement of professionals to developed countries and variable rainfall of PICs present unique challenges in water resource management.

The Pacific island nations are particularly vulnerable to pressures on water resources as a result of limited surface water resources and a high dependence upon rain-fed agriculture. Six island countries – Nauru, Niue, Kiribati, Tonga, Tuvalu and the Republic of Marshall Islands – have no significant surface water resources and, all but Niue and Nauru, rely on limited groundwater resources. The almost total dependence upon rain-fed agriculture in all PICs means economies and peoples' livelihoods are particularly vulnerable to drought and rainfall variability and ultimately to climate variability and change pressures.

Population growth and development are placing increasing pressure on the limited available water in many Pacific islands. Pollution; water extractions for domestic, commercial and agricultural uses; modified river flows for hydropower; and modified land use compromising habitats, rivers and groundwater are all increasing the vulnerability of the Pacific's freshwater resources.

The developing Pacific nations are particularly vulnerable to water resource pressures, with large challenges to addressing poverty disparities in water and sanitation access, providing resource management infrastructure and a strong reliance on local ecosystem sustainability for food, materials and livelihoods. The nature of small island countries means that water management is critical to not only support land-based activities, but will also directly affect lagoon and coastal fisheries and mangrove systems central to country food supplies.

Against this backdrop, sound water resource management is critical to ensuring ongoing sustainability of the Pacific Small Islands Developing States (SIDS). Yet there are clear signs that water resource management is also stressed in many countries. The delivery of water supplies and sanitation services in many Pacific countries currently falls well short of Millennium Development Goal (MDG) targets, suggesting that significant improvements are required (WHO/UNICEF 2010).

This study has been undertaken by the United Nations Environment Program (UNEP) in partnership with the Pacific Islands Applied Geoscience Commission (SOPAC) to assess the vulnerability of freshwater resources in the Pacific islands countries. Specifically, the objectives of the study were to:

- pilot a methodology for assessing freshwater vulnerability in the Pacific;
- assess the vulnerability of Pacific freshwater resources and underlying drivers; and
- provide scientifically-based evidence to support water resource management policy development.

A selection of islands was chosen for the study, representative of the two main island forms: (i) atolls and limestone islands dependent on rainwater and groundwater – Nauru, Majuro Atoll (in Republic of the Marshall Islands) and Fongafale Islet (Tuvalu); and (ii) volcanic islands with river systems – including Rarotonga (Cook Islands), Viti Levu (Fiji), New Guinea (Papua New Guinea) and Upolu (Samoa). As the distances between islands are often large, the water resources of each island are generally managed independently of other islands. Accordingly, where countries are constituted of many islands, this study focused on the most populated island within each country.

1.2 The Assessment Process

This study adopted a modified form of approach for river basin vulnerability[1] assessment outlined in the "Methodological Guidelines," developed by UNEP and Peking University (UNEP 2009), and with input from SOPAC.

The approach was presented at the 26th annual Science, Technology and Resources Network (STAR) session of SOPAC (Port Vila, 2009) for initial input from regional experts and country representatives. A working group at this session recommended a selection of countries representative of the two main island forms, atolls and limestone islands dependent on rainwater and groundwater (Nauru, Republic of Marshall Islands and Tuvalu); and volcanic islands with river systems (Cook Islands, Fiji, Papua New Guinea and Samoa).

[1] Vulnerability – the characteristics of water resources that challenge system functions under socio-economic and environmental changes (UNEP 2009).

A desk study was undertaken on the available scientific and technical studies, national and sub-national reports and statistics and maps. The desk study was supported by in-country visits to ground-truth available information, to engage country water managers in the assessment process and to facilitate information exchange. A conceptual framework was developed to describe water processes and management responses, based on conceptual models of the island hydrology for both the atolls and the larger volcanic islands.

A DPSIR (driver, pressure, state, impact, response) model was developed to form the basis of analysis and discussion. From this model, detailed quantitative and qualitative assessments were undertaken to identify the key areas of freshwater vulnerability in Pacific islands. A freshwater vulnerability index was then developed based on the assessment and the conceptual framework.

The report has been reviewed by regional and country water resource experts to ensure that it appropriately reflected country and regional vulnerability. The collective information obtained has been synthesised with inputs from these experts and stakeholders to deliver the final freshwater vulnerability assessment.

1.3 Scope and Limitations

In compiling a high-level water resource vulnerability index, it is necessary to make a range of assumptions to enable assessment of islands with significant variation in hydrology, geography, environment, socio-economic status and management practices.

At the highest level, the assumption has been made that the selected countries are broadly representative of freshwater systems in the Pacific region, and that the main islands within these countries provide an indication of the vulnerability across countries. Further, in many cases, limited data from a limited number of rainfall gauges has been adopted as being representative of island hydrology, where differences of up to 100% in rainfall depths across an island are common (see Table 2.4).

Where available, relevant data have been synergised into the assessment to increase the accuracy of the assessment. The limited availability of some data has been partially off-set by use of expert opinion and ground-truthing in-country and supported by country experts.

Whilst all reasonable attempts have been made to obtain data, and to ensure accuracy of assessments, the procedure of this vulnerability assessment is sufficiently robust and flexible to incorporate a moderate degree of uncertainty in data.

A high-level assessment of water resources assumes that a limited range of indicators is representative of the systems that it measures. By careful selection of indicators it is considered possible to provide a reasonable indication of the vulnerability of freshwater resources; however, it should be noted that some individual aspects of freshwater systems, such as biodiversity, are not necessarily directly addressed through this process. Rather, it is intended that the vulnerability assessment provides information on freshwater systems and components of systems most under stress. Through this approach it is intended that this study will guide more focussed studies and policies to protect the most stressed areas and sectors.

The Methodologies Guidelines (UNEP 2009) were originally developed to assess freshwater resources of river basins, rather than islands. In adapting this methodology to assess the freshwater resource vulnerability of the Pacific islands it was necessary to review two of the core indicators of the methodology. Notably, it is considered that these changes reflect the limitations of applying indicators developed for river basins to Pacific islands and the unique nature of the vulnerability of island water resources, rather than differences in the level of vulnerability.

1.4 Structure of the Report

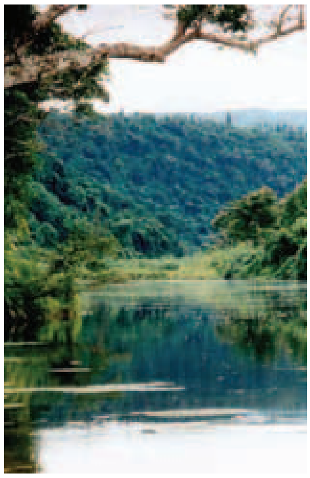
This report is divided into six chapters. The first chapter introduces the study, outlining why vulnerability is important and the approach adopted to assess freshwater vulnerability in the Pacific. Chapter two presents the geographic and socio-economic context of the Pacific island nations and the status of, and the challenges in, managing the freshwater resources, focussing on the countries targeted in this study. This chapter also presents a DPSIR assessment of the water resources in atolls and larger islands.

The third chapter describes the method of assessment and the development of the composite Vulnerability Index, including changes to the methodology adopted for assessing river basin vulnerability. These changes reflect the DPSIR analysis undertaken in chapter two. There is also a discussion in this section of the importance of climate variability and change pressures to island freshwater resource vulnerability. The fourth chapter details the vulnerability assessment for the selected islands: Rarotonga of the Cook Islands, Viti Levu of Fiji, Nauru, Majuro Atoll of Marshall Islands, New Guinea of Papua New Guinea, Upolu of Samoa and Fongafale of Tuvalu. These assessments identify the significance and relevance of climatic, socio-economic and geographic drivers to island freshwater vulnerability.

Chapter five consolidates the key resource and ecosystem pressures, development drivers and management responses into a composite vulnerability index for each of the countries. The final chapter synergises the information obtained through the vulnerability index assessment to provide conclusions on Pacific islands freshwater vulnerability and provides options for future directions to increase regional resilience and reduce freshwater resource vulnerability.

2.

Overview of Freshwater Resources of the Pacific



Photos credits: SOPAC, David Duncan and SOPAC.

The fourteen developing PICs of the Pacific Region are home to over 9 million people, speaking about 1 200 languages (Tryoll 2006), with the majority of Pacific islanders (about 80%) living in rural areas (WHO/SOPAC 2008). These Pacific Island countries have about 1 000 islands[2] covering a land area of just over half a million square kilometres, spread across 180 million square kilometres of ocean (Figure 2.1). The ecosystems supported across these islands are unique and among the most endangered in the world (McIntyre 2005).

The PICs face similar challenges managing freshwater resources to other developing countries. Access to sanitation and safe drinking water, protecting sensitive ecosystems and generating productive use of variable water resources are among these issues. Nevertheless PICs face unique challenges managing water resources, constrained by their remoteness, small size, fragility, natural vulnerability and limited human and financial resources (SOPAC 2006). These challenges require innovative approaches and tailoring of solutions not just to the region, but often to the complex combination of geographical and socio-economic constraints of an individual island.

2.1 Geography and Socio-economics

2.1.1 Geography and Biodiversity

The PICs are unique geographically, biologically, socio-economically and culturally. The region is characterised by dramatically different small islands spread across the world's largest ocean, supporting numerous diverse ecosystems and high biodiversity; by a high degree of economic and cultural dependence on the natural environment and resources; by vulnerability to a wide range of natural disasters; and by a diversity of cultures, languages, traditional practices and customs which is central to the close and special relationship of the Pacific people with their environments (SPREP 1992).

The links between the Pacific people and their environments are heavily influenced by the geological characteristics of the islands. The PICs could be considered a combination of four main forms, namely high volcanic, uplifted limestone, low-lying coral island and atolls and mixed combinations of these forms (Figure 2.2). The island form significantly influences many aspects of island life, from historical and cultural development to providing unique contemporary constraints to population growth and economic development. The high volcanic islands tend to have the largest and most varied biodiversity, associated with larger ecosystems and a greater range of habitats; however, the isolation of low-lying islands has often resulted in intense speciation to form many new species resulting in levels of endemism[3] that are unique globally (McIntyre 2005)

The vulnerability of island biodiversity means that the ecosystems of the Pacific are among the most endangered in the world, whilst amongst the systems under the highest risk (Brooks et al 2002), to the point where extinctions are amongst the highest in the world (Kingsford et al 2009).

Table 2.1 provides a summary of the Pacific SIDS islands geographical characteristics. Of the 953 significant islands identified for the PICS (UNEP 2010), over half of these are less than 10 km^2 in area while many, particularly coral islands and atolls, are less than 1 km^2.

[2] The definition of island varies dramatically from source to source, and the number of cited islands varying accordingly. In this report, the UN System-Wide Earthwatch Web Site Island Directory numbers are used (http://islands.unep.ch/).

[3] Endemism is the degree to which a species or ecosystem is unique to a specific area, typically an island or local habitat.

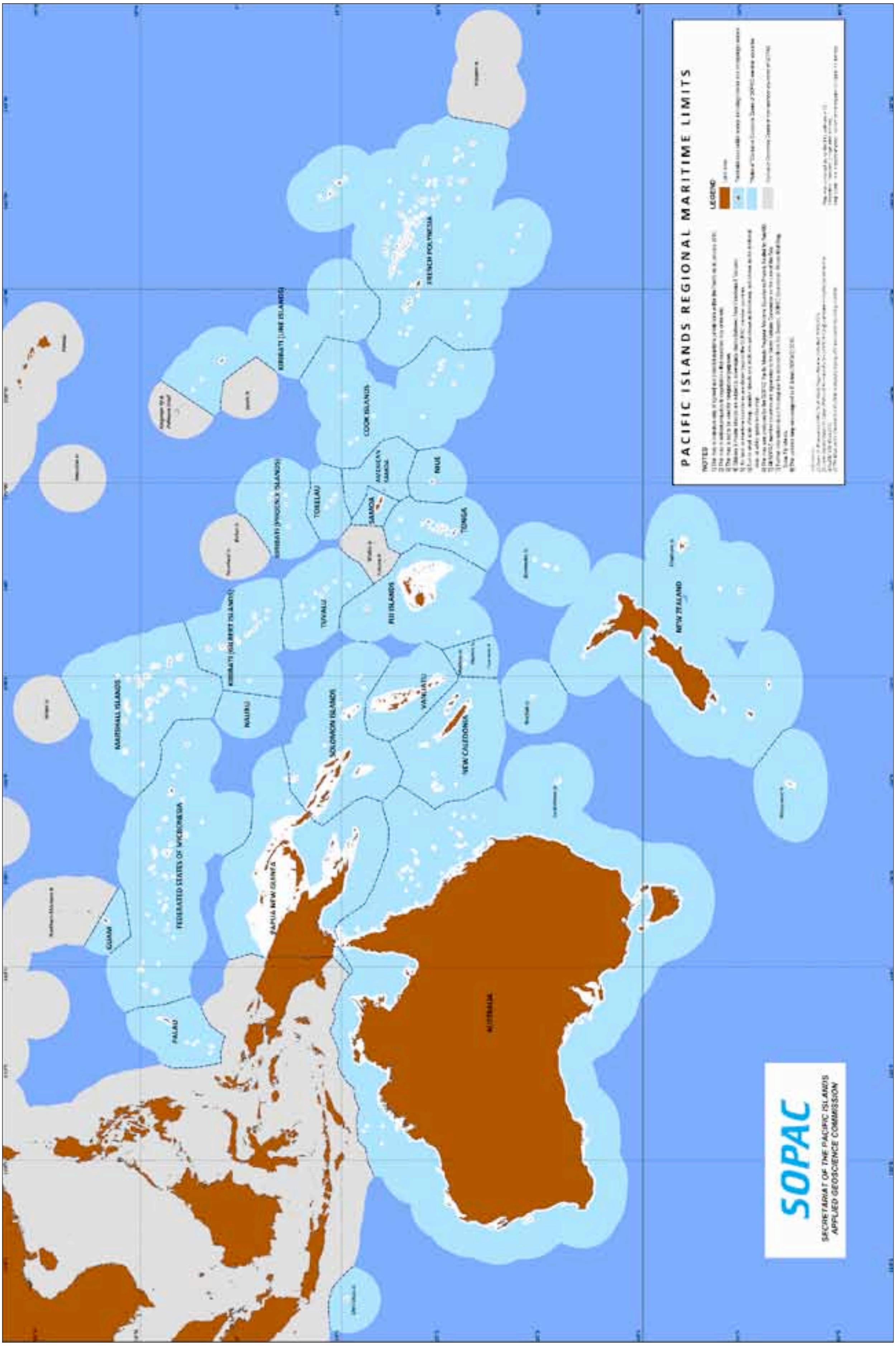


Figure 2 1 – South Pacific Region.

Figure 2.2 – Representative photos of different island forms
Left – atoll (Fongafale Island, Tuvalu); Right – high volcanic (Rarotonga, Cook Islands); below – raised limestone island (Nauru left and Niue right).

Note high energy coastline on ocean side (right) of atoll and calmer lagoon side (left).

Photos credit: David Duncan

Photos credit: Cook Islands Department of Environment

The features of the raised limestone islands include a raised central plateau, steep coastal fringes and a reef shelf. In the case of Nauru (below), this shelf extends to a small coastal plain.

Photos credit: David Duncan

Photos credit: SOPAC

Table 2.1: Pacific SIDS geographical features.

Country	Sub-Region	Population ('000s)[1]	Area (km²)	Islands[2]	Form[3]
Cook Islands	Polynesia	20	237	15	Volcanic, volcanic & limestone, atoll
Federated States of Micronesia	Micronesia	111	701	59	Volcanic, atoll, mixed
Fiji	Melanesia	864	18 273	322	Volcanic, limestone, atoll, mixed
Kiribati	Micronesia	100	811	36	Atoll, coral island, limestone
Marshall Islands	Micronesia	64	181	34	Atoll and coral islands
Nauru	Micronesia	10	21	1	Limestone
Niue	Polynesia	1	259	1	Limestone
Palau	Micronesia	21	444	31	Volcanic, limestone
Papua New Guinea	Melanesia	6 745	462840	151	Volcanic, limestone, atoll, coral island
Samoa	Polynesia	179	2 785	7	Volcanic
Solomon Islands	Melanesia	550	30 407	138	Volcanic, limestone, atoll
Tonga	Polynesia	104	650	67	Limestone, volcanic, mixed
Tuvalu	Polynesia	10	26	10	Atoll
Vanuatu	Melanesia	245	12 281	81	Volcanic, limestone

Notes: (1) SPC 2010b.

(2) UN System-Wide Earthwatch Web Site Island Directory (http://islands.unep.ch/)[4].

(3) Falkland et al (2002). The form listed first is that of the main island or greatest land mass. The form descriptions are generalised. For example, several of the larger volcanic islands also have coastal sand plains.

The high volcanic islands are generally large in area, consisting mainly of volcanic rock, forested with fertile soils with high rainfall and freshwater availability. The low coral islands and atolls are typically small with limited freshwater availability and resources and poor soil.

The isolated evolution of island ecosystems has led to unique biodiversity and ecosystems in PICs (McIntyre 2005). The close relationship between Pacific people and their environments means that biodiversity is not only critical for the maintenance of essential ecosystem functions, but also for social and economic development.

2.1.2 Socio-economics

All fourteen of the Pacific island countries (PICs) are recognised as small island developing states (SIDS) by UN-OHRLLS[5], acknowledging their specific social, economic and environmental vulnerabilities. The SIDS status reflects the unique constraints in their sustainable development efforts, including as a narrow resource base depriving them of the benefits of economies of scale; small domestic markets and heavy dependence on a few external and remote markets; high costs for energy, infrastructure, transportation, communication and servicing; long distances from export markets and import resources; low and irregular international traffic volumes; little resilience to natural disasters; growing populations; high volatility of economic growth; limited opportunities for the private sector and a proportionately large reliance of their economies on their public sector and fragile natural environments (UN-OHRLLS 2010).

In addition to these constraints, Pacific island countries are in general characterised by small land areas and populations and, in some cases, by relatively high population densities (Table 2.2). For many countries the population statistics would be even higher were it not for emigration, either for temporary employment or permanently.

[4] Note that published numbers of islands varies significantly for countries such as Palau (which is cited as high as approximately 200), depending on the specific definition adopted.

[5] UN-OHRLLS – United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States (http://www.un.org/special-rep/ohrlls/sid/list.htm).

Table 2.2: Key regional socio-economic indicators[1].

Country	Population Density (Capita.km^{-2})	Population Growth (%)	Urban Population (%)	Urban Population Growth (%)[2]	Net Migration Rate[3] (%)
Cook Islands	66	0.6	72	2.6	0.1
Federated States of Micronesia	159	0.4	22	-2.2	-2.1
Fiji	46	0.5	51	1.5	-1.0
Kiribati	124	1.8	44	1.9	0.0
Marshall Islands	301	0.7	65	1.6	-1.9
Nauru	475	2.1	100	-2.1	-2.1
Niue	6	-2.3	36	-1.1	-4.1
Palau	46	0.6	77	0.0	0.1
Papua New Guinea	15	2.1	13	2.8	0.4
Samoa	66	0.3	21	-0.6	-2.4
Solomon Islands	18	2.7	16	4.2	0.1
Tonga	159	0.3	23	0.5	-1.8
Tuvalu	429	0.5	47	1.4	-1.1
Vanuatu	20	2.5	21	4.0	0.6

Notes: (1) Data from the 2010 Pocket Statistical Summary unless otherwise stated (SPC 2010a).
(2) Data from Secretariat of Pacific Community (SPC) Estimates and projections for economic indicators (2010).
(3) Data from Population, migration and development in Asia, with special emphasis on the South Pacific: the impact of migration on population and the MDGs (Rallu 2008).

Emigration is a significant factor in maintaining capacity within PICs with a loss of skilled and educated workers particularly evident in this region (Rallu 2008). This 'brain drain' is an additional hindrance to development in Pacific countries, with several countries reliant on overseas aid support to provide necessary skills. To some degree this has been offset by regional political cooperation in the development of regional councils responsible for technical and policy support.

Almost 81% of the Pacific population live in rural or outer island communities (WHO/SOPAC 2008); however, the migration towards urban areas in most Pacific countries places further stress on already limited agricultural capacity and urban infrastructure, including water supply and sanitation systems. This movement is somewhat offset by the net national emigration of some countries; however, the largest countries are recording both net immigration and high urban growth (Table 2.2).

Agriculture and fisheries are the primary economic sectors in most PICs, and for many communities and countries these activities represent the sole source of income and exports (Table 2.3). Mining, forestry, textiles and tourism are also important regionally. A review of official development assistance (ODA) into the Pacific island countries portrays how heavily dependent many countries are on overseas support, with half of the fourteen countries receiving ODA exceeding 30% of their GDP. This support reflects in part the lack of capacity within countries exacerbated by the emigration of skilled islanders, but also the economic vulnerability of many of the islands.

Table 2.3: Key regional economic indicators[1].

Country	GDP per Capita USD$	GDP Growth (%)	ODA as %age of GDP (%)[2]	Key Economic Sectors[3]
Cook Islands	10 875	-1.2	4	Tourism, black pearls, offshore finance centre
Federated States of Micronesia	2 183	-2.9	49	Fisheries, tourism, copra
Fiji	3 499	0.2	2	Tourism, sugar, textiles
Kiribati	1 490	3.8	35	Copra, fisheries, agriculture
Marshall Islands	2 851	1.2	35	Copra, fisheries, tourism
Nauru	2 071	-0.1	113	Mining, coconuts
Niue	9 618	5.6	88	Tourism, handicrafts
Palau	8 423	2.0	14	Tourism, agriculture, fishing
Papua New Guinea	897	7.0	5	Agriculture, petroleum, mining, forestry, fisheries, copra, palm oil
Samoa	2 672	4.5	7	Fisheries, tourism, textiles, automotive parts
Solomon Islands	1 014	7.3	63	Forestry, fisheries, palm, copra, mining
Tonga	2 629	1.2	12	Agriculture, fisheries, tourism
Tuvalu	1 831	2.5	44	Fisheries, copra
Vanuatu	2 218	6.6	13	Tourism, agriculture, offshore financial centre, fisheries, forestry

Notes: (1) Data from the 2010 Pocket Statistical Summary unless otherwise stated (SPC 2010a).
(2) Data from Tracking governance and development in the Pacific (AusAID 2009).
(3) Business Advantage International (2010).

Pacific island countries are amongst the most vulnerable in the world to natural disasters, in a region where disasters are becoming more intense and more frequent (Bettencourt et al 2006). Costs to the region associated with natural disasters in the 1990s alone were approximately US$2.8 billion (Bettencourt et al 2006). The economic impacts are potentially a significant constraint to the growth of several countries, with the average economic impact of natural disasters in Samoa at 6.6% of GDP and Vanuatu at 4.4% (Bettencourt et al 2006), compared with global averages typically at 1.2% (Okuyama and Sahin 2009). The costs associated with natural disasters are exacerbated by little or lack of attention paid by Pacific island governments to disaster risk management (PIFS 2009).

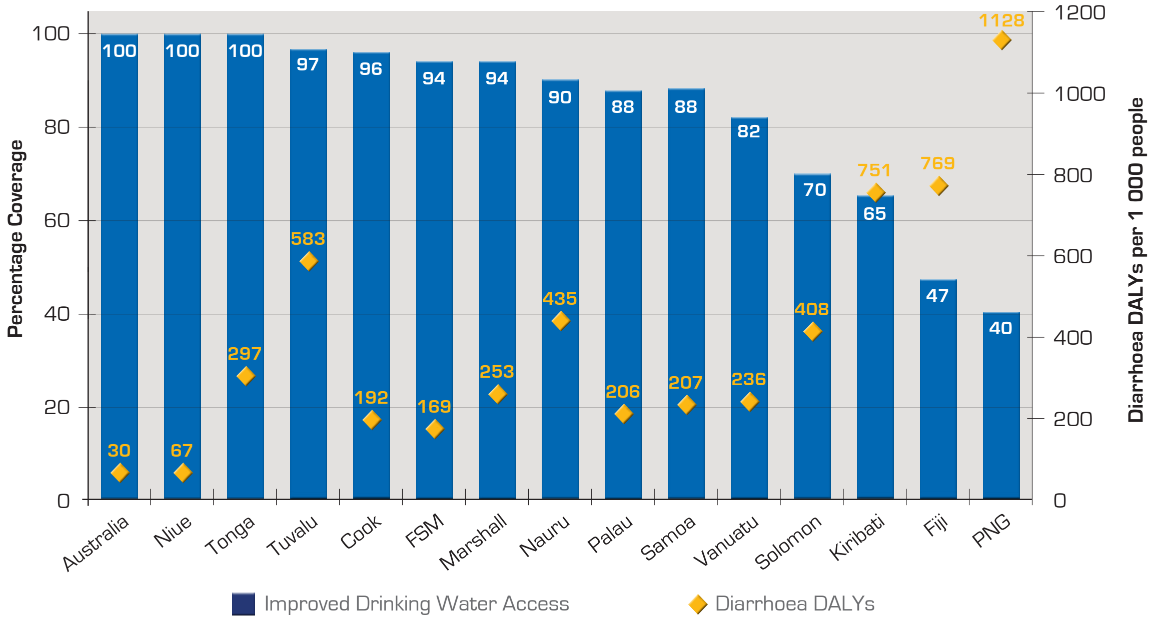
Critically, some of the Pacific countries at greatest risks to natural disasters are those that are the least developed to manage these risks. Five of the fourteen Pacific SIDS (Kiribati, Samoa, Solomon Islands, Tuvalu and Vanuatu) are amongst the United Nations' least developed countries, reflecting low incomes, weak human assets (nutrition, health, school enrolment and adult literacy) and economic vulnerability (UNCTAD 2005).

Photos credit: David Duncan

Access to improved sanitation and safe drinking water supply are fundamental to reducing disease and improving living conditions. Despite significant efforts to improve sanitation and drinking water access in the Pacific, overall access to sanitation (53% of population) and drinking water (50%) remains low, with virtually no change over the past 20 years (WHO and UNICEF 2010).

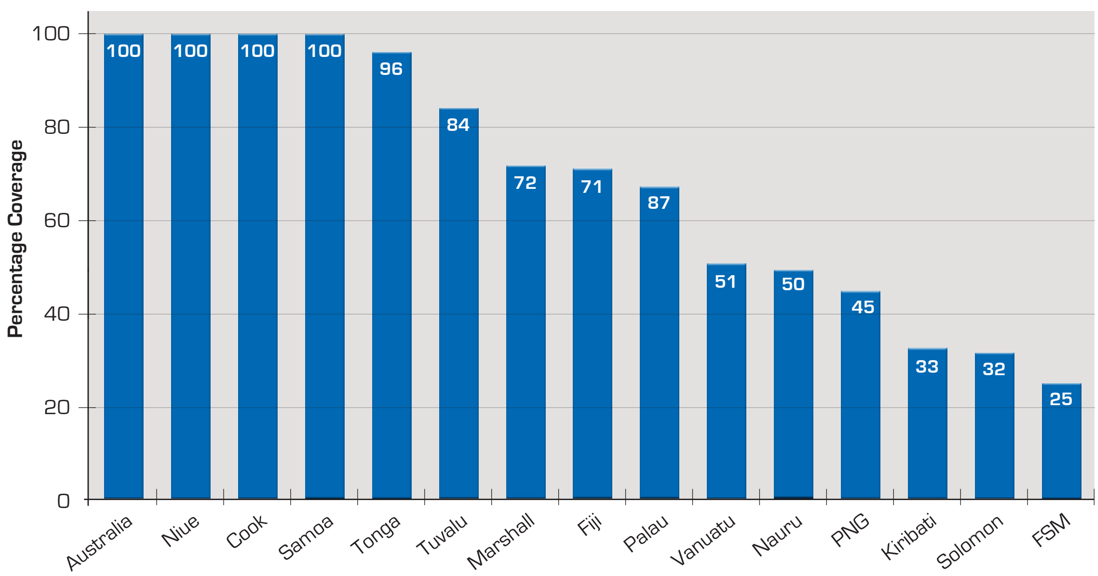
The low rates of improved sanitation are consistent with elevated rates of water-borne diseases compared with regional developed countries such as Australia (WHO/SOPAC 2008). There is a reasonable correlation between diarrhoeal DALYs and access to improved drinking water (Figure 2.3).

Figure 2.3: Improved Drinking Water Access and Diarrhoeal DALYs[6].
DALY data from WHO (2009) and Drinking Water Access from WHO and UNICEF (2010).



Typically about 10% of all deaths of children less than five years old in the Pacific island countries are attributable to diarrhoeal diseases (WHO/SOPAC 2008). About 90% of these diseases can be attributed to the lack of sanitation treatment systems, high levels of unimproved drinking water and poor hygiene (WHO/SOPAC 2008), although the overall health impacts may be significantly higher with an indirect influence of these risk factors on many other causes of death (Prüss-Üstün et al. 2008).

Figure 2.4: Improved Sanitation Access (Data from WHO and UNICEF 2010).



Land availability and tenure are both an impediment to, and provides unique opportunities for, poverty alleviation and sustainable development of land (UNESCAP 2010). In Pacific island countries, land tenure is typically very high (e.g. traditional tenure in Papua New Guinea is 97% (Boydell 2001) and traditional land tenure regimes in urban centres generally do not readily adapt to the needs of rural and outer island immigrants, leading to the development of insecure squatter settlements with very poor solid waste, water, sanitation, electricity, and other urban services (ADB 2009). Complex land tenure frameworks, combined with high population densities and limited land availability place particular stress on systematic water management in the low coral islands and atolls. Even in larger islands, obtaining adequate land access can be a barrier for public infrastructure projects.

[6] DALYs – Disability adjusted life years: a WHO measure of the loss of life and quality of life associated with diseases.

2.2 State of Freshwater Resources

Water resource availability differs dramatically across the region, with parts of large islands reliably receiving over 10 m rainfall annually and annual run-offs in excess of 2 000 mm (Hall 1984), to several atolls with no significant surface or groundwater resources and variable rainfall patterns (Table 2.4). Whilst runoff may be high across several of the larger islands receiving high rainfall, the infrastructure is generally not in place to capture, store and distribute the water.

Table 2.4: State of water resources of Pacific countries.

Country	Total Renewable Water Resources[1] Mm^3·yr^{-1}	Average Rainfall[1] mm.yr^{-1} (spatial range)	Water Use[1] Mm^3.yr^{-1}	Total Rainfall Mm^3.yr^{-1}	Rainfall Productivity[2] \$.m^{-3}	Primary Water Resources[3]
Cook Islands	56[4]	2 040[4] (1 574 to 3 063)	4.4[5]	140	0.48	SW, GW, RW
Federated States of Micronesia	2 034[6]	4 115[6] (3 028 to 5 000)	na	2 900	0.08	SW, GW, RW, D
Fiji	28 600	3 040 (2 000 to 10 000)[7]	70	56 000	0.05	SW, GW, RW
Kiribati	21[8]	2 000[8] (1 000 to 3 200)	na	1600	0.09	GW, RW, D
Marshall Islands	1.6[9]	3 378[9] (3 028 to 5 000)	1.7[10]	610	0.24	RW, GW, D
Nauru	-[11]	2 167[11]	0.42[12]	48	0.42	D, RW, GW
Niue	132[13]	2 180[6]	0.002[14]	570	0.03	GW, RW
Palau	1 160[15]	3 784[6]	5.5[16]	1 700	0.10	SW, GW, RW
Papua New Guinea	801 000	3 142 (1 000 to 8 000)	392	1 100 000	0.01	SW, GW, RW
Samoa	1 328[17]	3 000[18] (2 500 to 6 000)	12.4[19]	8 400	0.06	SW, GW, RW
Solomon Islands	44 700	3 028 (2 000 to 4 500)[20]	na	92 000	0.01	SW, GW, RW
Tonga	401[21]	2 062[22] (3 028 to 5 000)	na	1 300	0.20	GW, RW
Tuvalu	1.0[23]	2 850[24] (2 737 to 3 498)	0.2[24]	74	0.24	RW, GW, D
Vanuatu	9 970[26]	2 338[27] (1 400 to 4 000)	12[27]	29 000	0.18	SW, GW, RW

Notes: (1) FAO Aquastat country factsheets (FAO 2011) unless otherwise stated: Cook Islands (Carter and Sheen, 1984); (2) National GDP (SPC 2010) per m^3 rainfall; (3) SW: Surface water; GW: Groundwater; RW: Rainwater, D: Desalination; (4) After Falkland (1993), Clement and Bouguet (1992), SOPAC (2000); (5) SOPAC (2007g); (6) van der Burg (1982, 1983, 1984), Lander and Khosrowpanah (2004); (7) ADB (2005); (8) Falkland (2003); (9) Hamlin and Anthony (1987), Peterson and Hunt (1981) and Peterson (1997); (10) SOPAC (2007k); (11) Nauru has limited brackish groundwater with temporary fresh groundwater lenses (Bouchet and Sinclair, 2010); (12) Falkland (2010); (13) SOPAC (2008); (14) SOPAC (2007l); (15) van der Brug (1984a); (16) SOPAC (2007c); (17) Rofe, Kennard & Lapworth (1996). Note – likely to underestimate surface water resources; (18) SOPAC (2007h); (19) Government of Samoa (2010); (20) SOPAC (2007m); (21) Estimated based on Furness and Gingerich (1993); (22) Average of Nukualofa, Ha'apai, Vava'u, Niuatoputapu and Niuafo'ou data from Tonga Meteorological Service (2011); (23) White (2005); (24) SOPAC (2007b); (25) Taulima (2002); (26) Based on KOWACO (1997); (27) Average of Sola, Pekoa, Lamap, Bauerfied, Nambatu, Whitegrass and Analgauhatsites in SOPAC (2007n).

Typically, the Pacific high volcanic islands receive high rainfall, which generates high runoff, in turn leading to rapid responses in steep valleys, and flash flooding on fringing coastal plains. The limestone and coral islands and atolls generally have limited or no surface water and are reliant on a combination of rainwater and limited groundwater lenses, supplemented by desalination on some islands to meet water resource needs. Exceptions to this include the drier Port Moresby area in Papua New Guinea and the large groundwater lens under Niue.

Much of the Pacific household water and irrigation is reliant on rainfall. The abundant rainfall in many areas, combined with the lack of surface water resources and, on some islands, limited or no potable groundwater resources and low investment in water infrastructure in other areas mean that many communities and even countries are highly vulnerable to rainfall variability, with many countries experiencing frequent droughts (Falkland 2002).

The amount of water available in thin groundwater lenses in atolls and limestone islands is a complex balance between recharge, exchanges with seawater and extraction for use (Section 2.2.1). Often the limited availability of freshwater will lead to potable use of brackish groundwater, such as the high chloride water used for a potable source in Kiribati (Kingston 2004). Many of these lenses are very sensitive to rainfall variability, shrinking during low rainfall periods, and are also particularly vulnerable to salinisation as a result of overpumping (Falkland 1993).

The highly porous nature of the sandy, calcareous and volcanic soils commonly found on Pacific islands leads to high groundwater recharge rates, but also makes many groundwater resources vulnerable to pollution from sanitation systems and agricultural activities. Nationally significant aquifers in Majuro (Marshall Islands) and Tarawa (Kiribati) have been compromised by septic tank seepage from densely populated urban areas overlying shallow aquifers (Falkland 2002).

As well as compromising shallow aquifers, faecal waste from humans and animals (mostly pigs and cattle) cause pollution of surface waters and water supplies in nearly all Pacific island countries. Eutrophication[7] of waters from these sources and agricultural chemicals has been identified as the major environmental threat to Pacific aquatic ecosystems (COS 2009).

Photos credit: David Duncan

Regionally, agricultural chemicals, mining discharges and industrial wastewater are also significant pollution sources. Agricultural chemical use increased significantly from the mid 1990s in the Pacific region and continues to be a threat to water supplies and ecosystem health (McIntyre 2005). Sediment loads arising from deforestation, mining and agricultural activities are also a significant threat to ecosystems and potentially compromise water treatment capacity in water supplies.

Mining is a significant source of income in Papua New Guinea and Nauru; however, impacts of mining waste are potentially catastrophic. The Ok Tedi Mine, located in the central Papua New Guinea highlands has severely impacted the Fly River for hundreds of kilometres downstream by discharging tonnes of mine waste and tailings into the river system daily for decades, and discharges remain at about 160 000 tonnes per day (Lottermoser 2010).

There is inadequate knowledge of water resources to inform decision making in most Pacific countries, and communication across sectors and between communities and government is often disjointed (Falkland 2002). Water governance is often centralised, focussed in a few government agencies, with little communication and coordination between agencies, communities and the private sector, with limited policy or legislated framework (SOPAC 2007e). Governance is further complicated by insufficient political and public awareness of the critical role of water in supporting sustainable development and the inadequate financing of water and sanitation provision due to poor cost recovery and a lack of 'economies of scale' (SOPAC 2007e). Nevertheless, recent initiatives to improve awareness and governance are starting to improve this position, evidenced by the establishment of national inter-sectoral coordination bodies in several countries and interim bodies in the remainder, together with the development and/or review of draft water resources policies and strategies underway in nearly all countries, supported by the GEF Pacific and EU IWRM Projects as executed by SOPAC.

7 Eutrophication is the increase in nutrients in a water body, increasing the plant and algal growth, which may upset ecosystem balance.

Table 2.5: State of water resources management of Pacific countries (updated from SOPAC 2007d).

Country	Inter-sectoral water coordination body	National water resources policy	Water resources legislation	IWRM Plan/ Strategy	Water Use Efficiency Plan
Cook Islands	Draft/interim	Draft/interim	Draft/interim	Not existing	Not existing
Federated States of Micronesia	Formally adopted, fully inter-sectoral and active	Not existing	Not existing	Not existing	Not existing
Fiji	Draft/interim	Draft/interim	Draft/interim	Draft/interim	Not existing
Kiribati	Draft/interim	Draft/interim	Draft/interim	Draft/interim	Not existing
Marshall Islands	Formally adopted, fully inter-sectoral and active	Draft/interim	Not existing	Draft/interim	Not existing
Nauru	Draft/interim	Not existing	Not existing	Not existing	Not existing
Niue	Draft/interim	Draft/interim	Draft/interim	Not existing	Not existing
Palau	Formally adopted, fully inter-sectoral and active	Not existing	Not existing	Not existing	Not existing
Papua New Guinea	Draft/interim	Draft/interim	Draft/interim	Not existing	Not existing
Samoa	Draft/interim	Formally adopted, fully inter-sectoral and active	Draft/interim	Draft/interim	Not existing
Solomon Islands	Draft/interim	Draft/interim	Draft/interim	Not existing	Not existing
Tonga	Draft/interim	Not existing	Draft/interim	Not existing	Not existing
Tuvalu	Draft/interim	Not existing	Not existing	Draft/interim	Not existing
Vanuatu	Draft/interim	Draft/interim	Formally adopted, fully inter-sectoral and active	Draft/interim	Not existing

Draft/interim   Not existing   Formally adopted, fully inter-sectoral and active

Water use efficiency in the Pacific islands varies depending upon the specific context of the island hydrology and supply system. Typically leakage losses within water supply systems are as high as 50% (Falkland 2002), and potentially limit development opportunities in countries with supply systems reaching their capacity due to leakage losses (Dawe 2001).

Pacific island water resources are highly vulnerable to the impacts of climate variability and change, in particular increases in the rainfall variability and the frequency of storms and sea-level rise.

Currently Pacific islands have a strong reliance on seasonal rainfall, in particular countries such as Tuvalu and Kiribati, which are heavily reliant on rainfall for drinking water resources. Increased variability in rainfall patterns, particularly increases in drought periods, significantly increases the freshwater vulnerability of islands relying predominantly on short-term rainfall for the majority of water resources.

Rainfall across the southern Pacific islands is strongly influenced by the El Niño Southern Oscillation (ENSO)[8] phenomena, influencing wet and dry cycles. An El Niño event typically increases rainfall and storm activity for central Pacific islands including Tuvalu, Samoa and western Kiribati, whilst coinciding with drought resulting in water shortages and drought in American Samoa, Fiji, Kiribati, Marshall Islands, Federated States of Micronesia, Papua New Guinea, Samoa and Tonga, with corresponding threats to food security and serious impacts on economies in these countries (UNESCAP 2007). A La Niña event; however, brings increased rainfall to the central Pacific islands and wetter conditions to much of Melanesia.

The low water extraction from many of the large island systems and the limited numbers of dams and gravel mining generally means that river flows are not significantly altered. Exceptions to this include areas of significant land clearance, such as the Nadi River basin in Fiji (Lal et al. 2009); however, as hydropower is being developed regionally, flow regimes will be changed significantly to accommodate the year-round supply demands. Similarly, low flows may suffer in small high volcanic islands, such as Rarotonga (Cook Islands) where a high proportion of the low flows are being redirected to water supplies. Little assessment has been undertaken on the ecological impacts of these altered flow regimes.

[8] The ENSO phenomenon refers to climatic and oceanic cycles of warming and cooling in the eastern Pacific Ocean. El Niño events are associated with warming and La Niña with cooling.

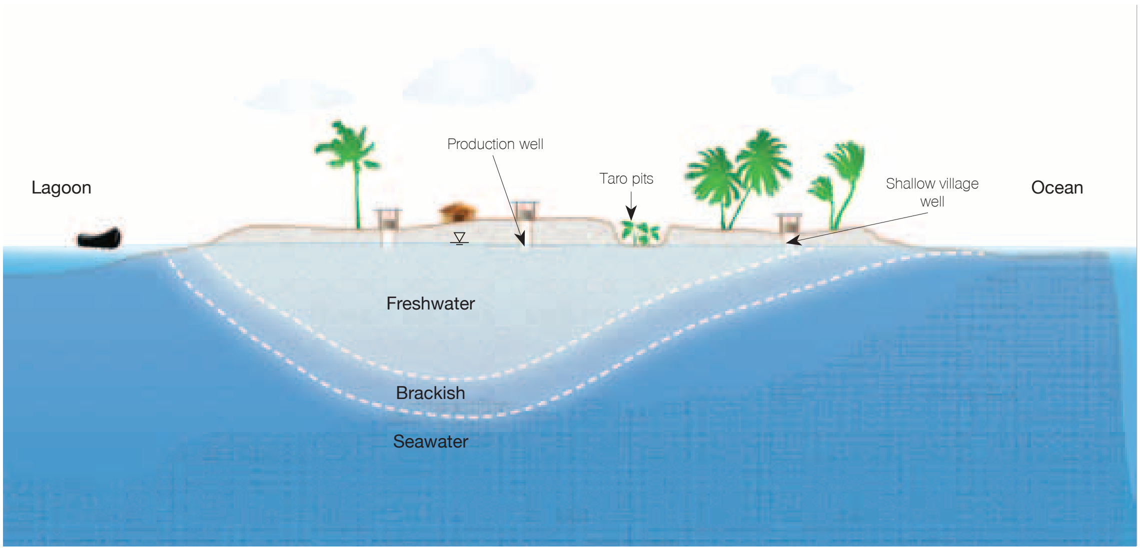
2.2.1 Atolls and Coral and Limestone Island Freshwater Resources

Water resources on atolls and coral and limestone islands are generally limited to groundwater, which is often very limited on low coral islands and atolls. Rainwater collection augmented by groundwater and desalination, generally provide the main water resources on these islands.

Surface water is not common on these islands due to the high transmissivity of the soils, and limited extent of the islands, limiting runoff and drainage. Where they do occur, lakes and other surface bodies are commonly brackish; however freshwater lakes do occur, such as Vai Lahi on Niuafo'ou, Tonga and rare occurrences on coral islands include Teraina, Kiribati, maintained by very high local rainfall (Falkland 2002).

Fresh groundwater on atolls, coral and limestone islands is often a delicate balance between rainfall, evapotranspiration, groundwater extraction and mixing with surrounding saline groundwater. On low-lying islands, this balance can be further complicated by storm surges, during which saline water mixes with fresh groundwater. The fresh groundwater typically occurs in lenses, floating on saline groundwater with a large brackish transition zone, where larger leeward islands are normally able to sustain much larger lenses than smaller windward islands (Bailey et al. 2009). Many of these lenses are highly sensitive to short-term rainfall variability, with reductions in the available resources by over 50% in some aquifers and complete depletion in others (Bailey et al. 2009).

Figure 2.5: Concept model of atoll groundwater.



The lack of fresh surface waters and reliable fresh groundwater resources has resulted in many small islands relying on rainwater for primary supplies. Tuvalu for example is almost entirely dependent upon rainwater, supported by small desalination plants. This reliance on rainfall makes many small islands, and Tuvalu particularly, highly vulnerable to rainfall variability and associated drought. Several countries, including Nauru and Kiribati rely on a combination of desalination and rainfall harvesting; however, costs of generating power and maintaining systems in such remote locations mean that water is expensive to generate, typically over US$4/KL (Freshwater and Talagi 2010; SOPAC 2007a). Even more extreme measures have been employed during drought, with water imported to Nauru in 2002 to resolve shortages, estimated at $58/KL (SOPAC 2007a). As a response to the 2011 Tuvalu State of Emergency, water was again imported into Tuvalu to alleviate drought conditions.

The water resources and supplies on small low-lying islands heavily reliant on rainfall and fragile groundwater lenses are therefore amongst the most vulnerable in the world to failure.

Case Study: Migration impacts on freshwater vulnerability

Funafuti, the main urban area of Tuvalu, located on Fongafale Islet demonstrates the impacts of significant migration on the limited fragile water resources of an atoll island. From an estimated early 1900s population of 275 (David 1913), slow growth through the early and mid-1900s, the move to independence in the 1970s and injection of foreign development funding into Funafuti drove significant migration from the outer islands to Funafuti through the latter 1900s, facilitated by the introduction of affordable travel between the atolls (Figure 2.6 – Gemmene and Shen 2009). Traditionally, the Funafuti islanders harvested small amounts of rainwater and relied on the groundwater resource in periods of drought::

"In the olden days, where there were very limited or few water storage catchments, people depended mostly on groundwater wells for drinking and cooking. Rainwater from thatched roof catchments and coconut tree trunks was used mainly for washing, bathing and other use… During a dry spell on an island, where green coconuts become unavailable for consumption, groundwater wells begin to dry up, the people depend mainly on the water drawn from holes dug in a Pulaka pit (traditional plant). These practices were later changed by the arrival of western missionaries when churches were constructed together with their water storage catchments…the local people who later adopted and relayed them from generation to generation" (Taulima 1994).

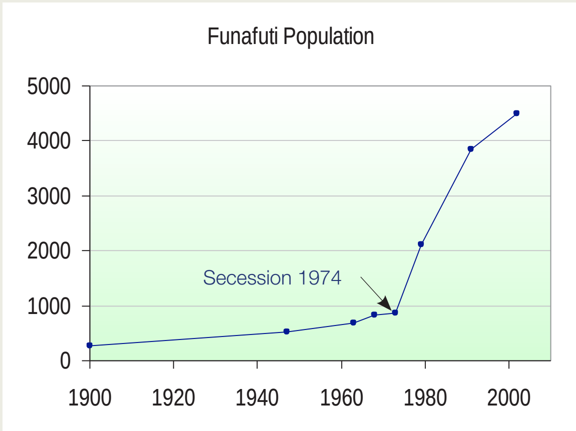


Figure 2.6: Funafuti Population 1900–2002 (Gemenne and Shen (2009) and David (1913).

The changes associated with this migration, combined with major landscape changes driven by the migration and development of the island as a World War II air base (Figure 2.7) have significantly altered the available water resources and the demands on them.

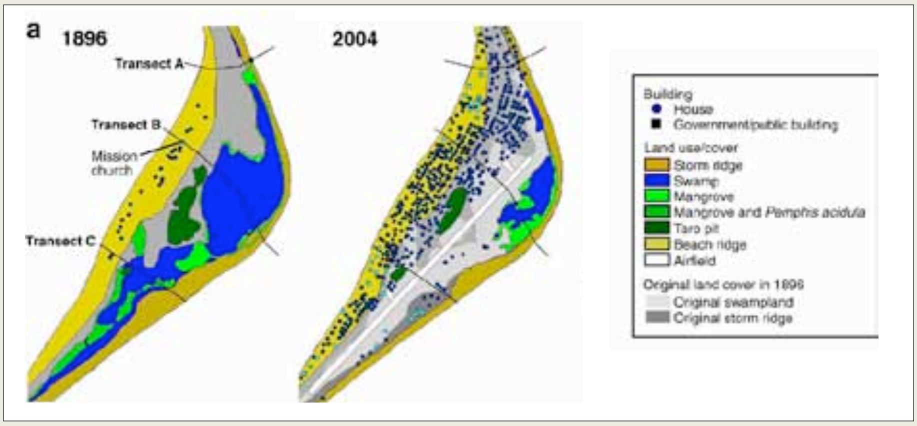


Figure 2.7: Change in Funafuti Landscape 1896-2004 (Yamano, H. et al 2007).

It is likely that the original freshwater lens was fragile due to the coarse sands and gravels that form the island and the aquifer. The borrow pits (Figure 2.8) and other island infrastructure development have altered the groundwater hydrology,

which combined with pressures from a small sea-level rise (approximately 100 mm) and increased demands on the aquifer have salinised the freshwater lens, which is no longer useable as a drinking water resource and even marginal for taro cropping (Webb 2007). Funafuti is now reliant on rainwater and limited output from a desalination plant. As a result of the changes to freshwater resources, Funafuti is increasingly vulnerable to drought, a major factor in the State of Emergency declared in September 2011.

Figure 2.8: Tidal brackish groundwater in borrow pit.

Photos credit: David Duncan

2.2.2 High Volcanic Island Freshwater Resources

Surface water in high volcanic islands is generally abundant, with high rainfall over central highlands and high runoff rates due to steep slopes and shallow base rock. Groundwater resources are typically not well developed, largely due to the availability of surface water resources, with a few notable exceptions, including the Port Vila water supply in Vanuatu. Other water sources such as desalination tend to be used only to address local conditions and lack of supply infrastructure (e.g. Denarau Island, Fiji and Rarotonga, Cook Islands).

The high rainfalls experienced in the large islands, with extremes over 10 m in central Papua New Guinea (McAlpine et al. 1983), and runoff coefficients of over 75% (Hall 1984), provide these islands with abundant water resources. The high flows are often accompanied by high sediment loads, exacerbated by land clearance and mining. The Fly River alone discharges over 100 Mt of naturally- and mine waste-derived sediment per year in approximately 190 billion cubic metres of water (Markham and Day 1994).

Many small high volcanic islands also have springs and perennial surface water resources, with discharges onto coastal plains, an example being Rarotonga (Cook Islands, Figure 2.2).

Photos credits: Tiy Chung, Tiy Chung and SOPAC

2.3 Climate Variability and Change

Pacific island freshwater resources are highly vulnerable to many of the impacts of climate variability and change, in particular increases in rainfall variability, sea-level rise and the frequency of tropical storms.

The IPPC 2007 report identified that under most climate change scenarios (Table 2.6), there is a very high level of confidence that water resources in small islands will be seriously compromised (IPCC, 2007). In the Pacific, a 10% reduction in average rainfall would reduce the freshwater lens on Tarawa (Kiribati) by 20%, and that this would be further compounded by sea-level rise potentially reducing the lens a further 29% (IPCC 2007).

The strong reliance of many atolls and coral islands on thin groundwater lenses makes them particularly vulnerable to sea level rise (SPREP 1999). Impacts on atolls in Kiribati and Tuvalu are likely to include increased reduced long-term freshwater lens capacity and potential increases in salinisation from storm surges (SPREP 1999).

Table 2.6: Climatic changes predicted by the IPCC and effects on water availability, accessibility and use (adapted for Pacific Islands from IPCC 2007).

Predicted change	Confidence	Impact on water security
More frequent or intense floods	Very likely	Damage to water storage infrastructure Increased water pollution Potential relief of water scarcity in some areas Higher operating costs for water systems Saltwater intrusion in coastal areas
Increase in area affected by drought	Likely	Reduced water availability Reduced groundwater resources Compromised water quality Increased risk of water-borne disease Increased demand for irrigation
More frequent or intense tropical cyclones	Likely	Damage to water storage/supply system Power outages causing disruption to public water supply Increased water pollution Increased risk of water-borne disease
High sea-level rise	Likely	Damage to water storage/supply system Saltwater intrusion in coastal areas Salinisation of groundwater and estuaries
Higher water temperatures	High	Increased water pollution Water quality problems, such as algal blooms and reduced dissolved oxygen content Higher operating costs for water systems
Changes in river flow and discharge	Likely	Changes in seasonal water availability Increased risk of flash floods Impacts on groundwater recharge Changes in water availability for hydropower generation
Increased rainfall variability	Very likely	Changes in seasonal water availability Changes in water storage Increased demand for irrigation water

There is considerable uncertainty about the effects of climate variability and change on the ENSO cycle, with responses differing from model to model; however, the majority of the models suggest a subtle shift to increasing El Niño-type activity, (IPCC 2007) with more frequent droughts and floods anticipated.

3.

Methodology



Photos credits: Amelia Krales.

3.1 Approach

This chapter outlines the method for this vulnerability assessment, based on a modified form of the Methodologies Guidelines (UNEP 2009). It also outlines the base assumptions; the modifications required to reflect the differences between freshwater resource vulnerability in a river basin environment and Pacific islands; and the application of the method.

The UNEP (2009) vulnerability assessment methodology assumes that vulnerability of a system is dependent upon three aspects: stress, adaptation and cooperation. It is assumed that these aspects operate across four core components, namely:

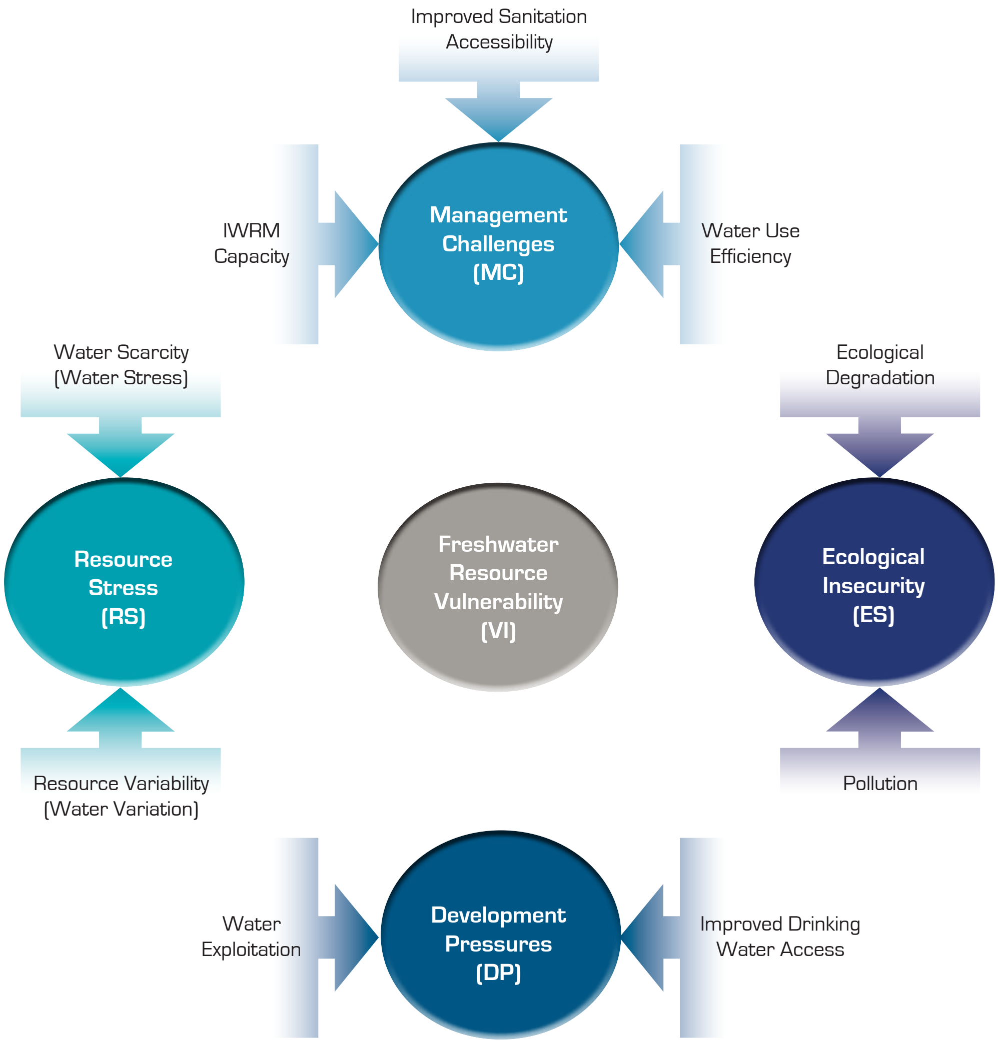
1. Total water resource: Analysis of the hydrologic balance before considering any water resource development and use, thus being the water resource formulation from a natural hydrologic process, and its relationship with global climate change and local biophysical conditions. Total water resource pressures are addressed under the Resource Stress components of this assessment.
2. Water resource development and use: Analysis of water resources supply and need balance, being mainly the water resources development capacity via an engineering approach, and its relation to water resource use, including domestic water use and development trends associated with urbanisation and modernisation, as well as water resources support to the economic development. Water resource development and use pressures are addressed under the Development Pressures components of this assessment.
3. Ecological health: Analysis of water resources after their development and use for domestic and economic use, for maintaining ecological health of the island, and its supply and demand relations, as well as key issues in the process. At the same time, the analysis will need to be conducted on water quality, as a consequence of water resources development and use (pollution), and its further influence to water resources budgeting on an island. Ecological health pressures are addressed under the Ecological Insecurity components of this assessment.
4. Management and governance: The above three components focused on the natural process, or natural adaptation, of freshwater resources development and use. The natural process, however, is usually heavily influenced by the social adaptation capacity to freshwater resources (i.e., the management capacity of freshwater resources plays an important role in enhancing a healthy freshwater resources development and use system). Thus, the assessment should be further conducted on the management capacity to evaluate the state and trends of institutional arrangement and other management factors in freshwater resources management. Management and governance challenges are addressed under the Management Challenges components of this assessment.

This broad approach recognises that mitigation of freshwater resource vulnerability can be best achieved through an integrated water resource management (IWRM) framework. This assessment seeks to provide an analysis of the stress, adaptation and cooperation across the above four components in a consolidated manner. Through this approach it is possible to incorporate influences of drivers such as socio-economic development and climate variability and change implicitly into this assessment.

Figure 3.1 presents the assessment components and indicators adapted from the UNEP (2009) methodology.

Photos credits: Pisi Seleganui

Figure 3.1: Assessment components and indicatc



3.2 Vulnerability Index and Parameterisation

As outlined earlier, the assessment is based on an analysis of driving forces, pressures, environmental status, impacts and responses (DPSIR[9]) of water resource issues, undertaken within the context of system stress, natural and anthropogenic adaptation and cooperation. The following outlines the methodology adapted from UNEP to assess freshwater resource vulnerability.

The vulnerability of an island's water resources can be assessed from two perspectives: (a) the main threats on water resources and its development and utilisation dynamics; and (b) the island's challenges in coping with these threats. Following the same DPSIR framework analysis, the threats can be assessed, again, from three different components of water resource and use (i.e. resource stresses; development and use conflicts; ecological security), while challenges to coping capacity can be measured within the context of the region's water resource management capacity.

Thus, the vulnerability of an island's freshwater resources can be expressed as a vulnerability index [VI], which is a function of the resource stress [RS], development pressures [DP], ecological insecurity [ES] and management challenges [MC]:

$$VI \quad f(RS, DP, ES, MC)$$

[9] A DPSIR framework assumes links between the socio-economic drivers (D) (e.g. economic development) and the pressures (P) (e.g. pollution) on socio-economic-environmental systems; which in turn affect the state (S) of the environment (e.g. moderately healthy) through impacts (I) (e.g. reducing biodiversity). The management and governance responses (R) to this (e.g. regulations) in turn influence the first four components (D, P, S and I).

High vulnerability is linked to higher resource stresses, development pressures and ecological insecurity, as well as severe management challenges. In order to quantify the vulnerability index, the indicators for each variable should be determined and quantified. The principles for this selection and quantification include the following:

(1) Policy relevance, with specific consideration of the Millennium Development Goals (MDGs).

(2) Scientific credibility.

(3) There should not be too many parameters, but the selected ones must be representative.

(4) The selected parameters are measurable, and easily expressed as simple formulae with available supporting data.

(5) All parameters should be normalised to the range of 0 to 1, with 1 being the most vulnerable and 0 being completely secure.

(6) The contribution of each parameter to the vulnerability index should be weighted according to its importance.

(7) The value of the vulnerability index should range from 0 to 1, with 1 being the most vulnerable, and 0 being completely secure.

3.2.1 Parameterisation

1) Resource Stress (RS)

The general influence of water resources to vulnerability will be the quantity and quality of water resources, with the pressures from them being expressed as the "stress" and "variation" of water resources.

(i) Water Stress Parameter [RS_S]: The richness of water resources will decide to what extent they can meet the water demands of the population. The total water resources of a region [R_t] consist of the groundwater resources [R_{gw}] ($m^3.annum^{-1}.person^{-1}$) and surface water resources [R_{sw}] ($m^3.annum^{-1}.person^{-1}$). The per capita water resources [R] ($m^3.annum^{-1}.person^{-1}$) of an island with a population [P] can therefore be described as:

$$R = \frac{R_{sw} + R_{gw}}{P}$$

Thus, the water resources stresses (RS_s) can be expressed as the per capita water resources of a region, compared to a benchmark acceptable level of water resource. In river basin reporting, the generally agreed minimum level of per capita water resources (1 700 $m^3.annum^{-1}.person^{-1}$) [Falkenmark and Widstrand (1992)], has been used as follows:

$$\begin{cases} RS_s = \dfrac{1700 - R}{1700} (R \leq 1700) \\ RS_s = 0 \; (R > 1700) \end{cases}$$

On Pacific islands, there is generally a much stronger reliance on direct rainwater harvesting than in river basins. This is a result of a combination of factors, from the complete lack of alternative water resources available on some atoll islands, to the abundance of rainfall on some larger volcanic islands. Other influences include local capacity for investment in infrastructure; development of crops based on climatic cycles and river hydrology.

The Falkenmark and Widstrand (1992) benchmark (1 700 $m^3.annum^{-1}.person^{-1}$), based on northern hemisphere developed countries, could be seen to oversimplify the complexities of water use across the range of hydrological, geographical, social, economic and cultural environments in Pacific islands. Setting the benchmark higher would not reflect well the high dependence upon rainwater use and harvesting compared with other countries (see later discussion on water use efficiency), which might suggest a lower benchmark. Nevertheless, setting the benchmark lower would appear contrary to the frequent water shortages evident in Rarotonga, Cook Islands (SOPAC 2007g) and Upolu, Samoa (SOPAC 2007h), despite these countries having resources well above this benchmark. Further, the capacity to consider the strong temporal association with ENSO events would mean that a simple benchmark might not adequately reflect the water resource needs of any island.

The polarised nature of resource availability, typically abundant on volcanic islands, and scarce on low-lying atolls, means that adopting a different benchmark to the Falkenmark and Widstrand (1992) value would not significantly change the interpretation of the stress (or the resulting numerical indicators for Pacific islands). To provide some level of consistency with other freshwater vulnerability assessments, this value has therefore been adopted for this assessment.

(ii) Water Variation Parameter [RS_v]: The variation of the water resources can be expressed by the coefficient of variation [CV] of precipitation over the last 50 years. When data for the whole island is not available, one or several typical meteorological station data can be used for the calculation. An upper ceiling of 0.3 (30%) is set for the CV, reflecting a point above which rainfall variation critically impacts on security of water resources (UNEP 2009). Therefore:

$$\begin{cases} RS_v = \dfrac{CV}{0.3} (CV < 0.3) \\ RS_v = 1 \, (CV \geq 0.3) \end{cases}$$

The coefficient of variation is defined by normal statistical terms, where pi is the precipitation of the i^{th} year (mm):

$$CV = \frac{s}{\beta}$$

$$\beta = \frac{\sum_{i=1}^{n} p_i}{n}$$

$$s = \frac{\sqrt{\sum_{i=1}^{n} (p_i - \beta)^2}}{n-1}$$

Water availability varies both temporally and spatially across Pacific Island countries (see Table 2.4). At an island level, spatial variability is unlikely to be significant across small islands; however, there is significant variability across larger islands. Rainfall across New Guinea (the main island of Papua New Guinea) ranged from 1 000 mm a year in Port Moresby to 10 000 mm a year in the Star Mountain area (Lovai 2007).

Temporal variability in drier areas (such as Port Moresby) or islands with minimal storage capacity is a significant stress on managing water resources, with islands with no surface or groundwater storages vulnerable to monthly fluctuations and islands with groundwater resources sensitive to seasonal to annual variability (Falkland 1999). Whilst this parameter refers to annual variability, a timescale much larger than the sensitivity of many islands to drought conditions, it does generally reflect the regional driving ENSO phenomena, which in turn influences variability at much smaller timescales.

(2) Development Pressures (DP)

(i) Water Exploitation Parameter [DP_s]: Freshwater resources are recharged through a natural hydrological process. Over-exploitation of water resources will disrupt the normal hydrologic process, ultimately causing difficulties for the recharge of the water resource base. Thus, the water resources development rate (i.e., the proportion of the resource extracted for use), defined as the proportion of the total water resource [R_t] extracted for use [WR_s]), can be used to demonstrate the capacity of an island water cycle for a healthy renewable process. Thus:

$$DP_s = \frac{WR_s}{R_t}$$

Data on water use is limited for many of the Pacific island countries. Generally the figures presented rely on water extracted from constructed storages or off-takes, or from well-fields. Whilst numerous farming practices across the region access water directly from watercourses (including for example taro patches), traditional rain-fed agriculture dominates farming practice (FAO 2011). It is therefore considered likely that any under-estimation based on current patterns will not significantly affect this parameter.

(ii) Improved Drinking Water Access Parameter [DP_d]: The water stress parameter indicates the capacity of natural resources to meet society's needs on an island, whereas the improved drinking water access parameter is designed to describe how well society on the island has adapted the available freshwater for use (i.e., how well an island society is able to develop the freshwater resources to address the population's fundamental livelihood needs). This is an integrated parameter that reflects a comprehensive impact of the capacity of all stakeholders, from community to the government, to cope, as well as the availability of technologies and other adaptation strategies. Thus, the proportion of the population with/without access to improved water sources is an indication of the degree of increased stress associated with ongoing immediate water demands.

According to the UN MDG monitoring indicators and method [UN (2003)], the improved drinking water sources/supply include piped water; public taps; boreholes or pumps; protected wells; and protected springs or rainwater. Thus, the contribution of the improved drinking water access parameter (DP_d) is calculated as the proportion of the population [P] without access to improved drinking water [P_d] with the following equation:

$$DP_d = \frac{P_d}{P}$$

(3) Ecological Insecurity (ES)

The ecological health of an island can be measured with two parameters; namely, the water quality/water pollution parameter and the ecosystem deterioration parameter.

(i) Water Pollution Parameter [ES_p]: In addition to their influence on the hydrologic process, water development and use activities will produce wastes, polluting the water resources base. Thus, another very important factor influencing the vulnerability of water resources is the total wastewater produced on an island. The contribution of water pollution to water resources vulnerability, therefore, can be represented by the ratio between the total untreated wastewater discharge [WW] and the total water resources of an island [Rt]. A dilution factor of 7 to 10 for raw wastewater has been adopted for other regions in assessing the ecosystem impacts of wastewater on receiving ecosystems [UNEP (2008a & 2008b)].

It is recognised that the actual impacts associated with pollution will depend directly on the nature of the pollutants (including toxicity, persistence, mobility, bioaccumulation, as well as complex impacts such as endocrine disruption[10] and carcinogenicity[11]); environmental transport; the sensitivity of the receiving environment; and the exposure to the pollution. That said, the broad-scale volume and impact of urban and domestic wastewater pollution led to the focus on this pollution in the initial methodology [UNEP (2008a & 2008b)]. Whilst typically, even at the dilution factor of 7 to 10, wastewater pollution is likely to significantly compromise receiving ecosystems over a large scale, these dilution rates provide a point of reference for ecosystem impact assessment. Additionally, the processes associated with ammonia and nitrogen cycling will vary significantly at a very local scale and significantly between groundwater and river receiving systems. Accordingly, a dilution target of 10:1 of freshwater resource to wastewater has been adopted.

$$\begin{cases} ES_p = \dfrac{\left(\dfrac{WW}{R_t}\right)}{0.1} (WW < 0.1 \times R) \\ ES_p = 1\,(WW \geq 0.1 \times Rt) \end{cases}$$

(ii) Ecological Deterioration Parameter [ES_e]: As a result of the population expansion, the natural landscape was modified by the consequent urbanisation and other socio-economic development activities. Removing vegetation from landscapes changes the hydrological properties of the land surface, and can cause severe problems in supporting the function of ecosystems. These effects include flow modification and increasing vulnerability of the region's water resources to pollution and flow variation. Thus, the ratio of land without forest, wetland or native vegetation cover [A_d] (km^2) of the total island area [A] (km^2) can be used to represent the contribution of ecosystem water resources, expressed as:

$$ES_e = \frac{A_d}{A}$$

[10] Endocrine disruption is the interference with the endocrine (or hormonal) system in animals, potentially causing significant impacts on health and reproduction.

[11] Carcinogenicity is the capacity to cause cancer.

(4) Management Capacity (MC)

This component will assess the vulnerability of freshwater by evaluation of the current management capacity to cope with three types of critical issues, including: (i) efficiency of water resources use; (ii) human health condition closely dependent on, and heavily influenced by, accessibility to improved sanitation; and (iii) overall capacity in dealing with management of the island's water resources in an integrated manner. Thus, the management capacity will be measured with three parameters representing the above three key management issues; namely the (i) water use efficiency parameter [MC_e]; (ii) improved sanitation accessibility parameter [MC_s]; and (iii) integrated water resources management capacity parameter [MC_i].

(i) Water Use Efficiency Parameter [MCe]: The integrated capacity of water use policy and technology innovation will impact general water use efficiency. Thus, the inefficiency of the water resources management systems of Pacific islands can be demonstrated by examining the gap between water use efficiency [WE] ($.m^{-3}) and the average water use efficiency for developed island countries [WE_m] ($.m^{-3}). Water use efficiency [WE] is derived by dividing the GDP generated from an island [GDP] by the total annual rainfall [R_f], representing the total available water resource:

$$WE = \frac{GDP}{R_f}$$

The water use efficiency parameter [MC_e] can be represented by the GDP value of 1 m^3 of water, compared to the average water use efficiency, calculated in a similar fashion, for selected developed island countries – Japan, Hong Kong, Ireland, Singapore and the United Kingdom – all island nations in the top 25 countries based on GDP per capita (IMF 2011), as follows:

$$\begin{cases} MC_e = \dfrac{WE_m - WE}{WE_m} (WE < WE_m) \\ MC_e = 0 \ (WE \geq WE_m) \end{cases}$$

The choice of island nations with the strongest economies provides a benchmark for the productivity that can be achieved on the basis of limited water availability. In assessing the productive capacity of small island states, it is important to recognise that much of the GDP is supported by Overseas Development Assistance (ODA) investment (particularly in Nauru, Solomon Islands and Niue), which in turn increases the capacity of these countries to efficiently use water for productive use. Whilst it is not possible to segregate this influence in such a high-level assessment, this influence is considered in the interpretation of the water use efficiency parameter in Section 5.

(ii) Improved Sanitation Accessibility Parameter [MC_s]: Sanitation access is often dependent on the availability of freshwater resources. One of the crucial aims of sound freshwater management is to make water sources accessible by communities (rural and urban) to support their basic livelihoods. This is reflected in the inclusion of access to improved sanitation within the Millennium Development Goals. Thus, the management system should make efforts to achieve this goal, increasing the availability of water sources to communities to meet their basic livelihood needs.

Accessibility to improved sanitation, therefore, is used as a typical parameter to measure the capacity of a management system to deal with livelihood improvement matters. Similar to the accessibility to improved drinking water sources, the United Nations MDG monitoring indicators and method should be followed for this specific parameter calculation (i.e., improved sanitation should be defined as facilities that hygienically separate human excreta from human, animal and insect contact [including sewers, septic tanks, pour-flush latrines, composting toilets and pits with slabs]) (WHO and UNICEF 2010). The improved sanitation accessibility parameter [MC_s] will be the proportion of total population [P] without access to improved sanitation facilities [P_s], as follows:

$$MC_s = \frac{P_s}{P}$$

(iii) Integrated Water Resources Management (IWRM) Capacity Parameter [MC_i]: This is a parameter that demonstrates the capacity of the island water management system to manage the island's resources in an integrated manner across catchment boundaries, sectors and a governance framework that engages stakeholders from community to cabinet. A good management system can be assessed by its effectiveness in institutional arrangements, policy formulation, stakeholder engagement, financial stability, knowledge development and human resource capacity. Thus, the IWRM capacity can be assessed utilising the matrix in Table 3.1, which combines both governance and management aspects. The final score of the IWRM capacity parameter (MC_i) can be determined by an expert consultation based on the scoring criteria. The scoring in this report has been agreed on the basis of a regional technical advisory group and comments sought from relevant countries.

Table 3.1: Integrated Water Resources Management Capacity Criteria.

Grade	Low (1)	Moderately Low (0.75)	Moderate (0.5)	Moderately High (0.25)	High (0)
Institutional / Policy Arrangements	❐ No water policy ❐ No water resource legislation ❐ No formal communication or coordination between government agencies	❐ Draft water policy ❐ Draft water resource legislation ❐ Institutional meetings but no formal arrangements	❐ Water resource policy implemented ❐ Water resource legislation implemented ❐ Formal institutional arrangements, but regulation limited	❐ Participatory processes with cross-sectoral and cross-community representatives ❐ Regulation established ❐ Information on governance decisions open and accessible to all	❐ Participatory water resources policy framework with open community engagement ❐ Institutional framework, communication and operational linkages ❐ Regulation open with transparent auditing
System Knowledge	❐ No/limited awareness of role of water in economic development, health and environmental protection ❐ Insufficient knowledge to complete national and international reporting requirements	❐ Limited data collected for some water resource components ❐ National and international reporting completed with limited data gaps	❐ Basic system data collected (e.g. supply, demand, rainfall, yields, consumption, etc.) and basic understanding of system resources, stressors and linkages ❐ National and international reporting completed with no data gaps	❐ High level of system understanding, supported by resource modelling ❐ Monitoring processes established and benefits demonstrated to deliver ongoing funding	❐ Understanding of system resources and stressors and linkages, integrated in planning processes, monitoring and evaluation strategies with feedback ❐ Transparent and open access to water resource data and academic debate on water resources
Stakeholder Engagement	❐ Isolated initiatives with no stakeholder engagement in governance ❐ No formal engagement and responses are reactive	❐ Formal engagement with all stakeholders without engagement in governance ❐ Stakeholder communication strategy developed and implemented	❐ Participation limited to directed delivery of solutions ❐ Stakeholder capacity building strategy developed and implemented	❐ Policy and strategy frameworks incorporate representative stakeholder engagement in governance ❐ Formal and informal capacity sharing and exchange with all stakeholder sectors	❐ Implementation of strategy for consultation/engagement of stakeholders from all levels and sectors ❐ Formal participative water resources governance processes with open community participation
Financial Stability	❐ Inadequate financing of capital and ongoing management	❐ Adequate funding available for capital works but insufficient funding for ongoing maintenance and operation	❐ Financial water resource planning undertaken and worked into national budgets	❐ Fee for service charges regulated, but often not covering costs	❐ Sustainable, accountability transparent financial planning established
Human Resource Capacity	❐ No or extremely limited expertise across sectors ❐ No or extremely limited capacity across stakeholders	❐ Professionals in limited key positions ❐ Mechanisms in place to provide capacity access to stakeholders	❐ Capacity base not wide and low capacity for higher level needs (e.g. monitoring, modelling and planning) ❐ Stakeholder capacity building strategy developed and implemented	❐ Core professional for water resource management – consultants only engaged for strategic specialist work ❐ Formal and informal capacity sharing and exchange with all stakeholder sectors	❐ Specialist knowledge available, either directly or through institutional arrangements ❐ Stakeholder led dialogues and initiatives

High vulnerability is linked to higher resource stresses, development pressures and ecological insecurity, as well as severe management challenges. In order to quantify the vulnerability index, the indicators for each variable should be determined and quantified. The principles for this selection and quantification include the following:

(1) Policy relevance, with specific consideration of the Millennium Development Goals (MDG_s).

(2) Scientific credibility.

(3) There should not be too many parameters, but the selected ones must be representative.

(4) The selected parameters are measurable, and easily expressed as simple formulae with available supporting data.

(5) All parameters should be normalised to the range of 0 to 1, with 1 being the most vulnerable and 0 being completely secure.

(6) The contribution of each parameter to the vulnerability index should be weighted according to its importance.

(7) The value of the vulnerability index should range from 0 to 1, with 1 being the most vulnerable, and 0 being completely secure.

3.2.2 Weighting

The vulnerability index is a composite index, based on the combination of the preceding parameters, weighted based on expert consultation to reflect relative contributions of each component to overall vulnerability. The vulnerability index [VI] can be calculated as:

$$VI = \sum_{i=1}^{n} \left[\left(\sum_{j=1}^{m_i} x_{ij} \times w_{ij} \right) \times w_i \right]$$

Where n = number of parameter categories (four in this assessment); m_i = number of parameters in i^{th} category; x_{ij} = value of j^{th} parameter in i^{th} category; w_{ij} = weight given to j^{th} parameter in i^{th} category; and W_i = weight given to i^{th} category.

To ensure that the final VI value is in the range from 0 to 1, the following restrictions apply to the relative weights:

(1) the total of weights given to all parameters in each category should be equal to 1; and

(2) the total of weights given to all categories should be equal to 1.

Because the process of determining relative weights can be biased, making the final results difficult to be compared to each other, equal weightings have been adopted.

Photos credits: SOPAC

3.3 Interpreting the Results to Inform Policy Recommendations

The vulnerability index is a tool to inform management decisions including policy recommendations. Generally speaking, a 2-step assessment process should be applied to link the VI result with policy recommendations. Firstly, general conclusions can be made on the vulnerability of the island's freshwater resources based on the overall VI score. As a guide to this analysis, Table 3.2 provides broad direction on vulnerability classification. Secondly, policy recommendations can then be made after further review of the parameter results in the four sections (i.e., resource stress; development pressure; ecological security; management capacity), and specific policy interventions can then be made accordingly.

Table 3.2: Guidance on island freshwater vulnerability.

Vulnerability Index	Interpretation
Low (0.0 – 0.2)	This indicates an island water system in terms of resource richness, development practices, ecological state, and management capacity. No serious policy change is likely to be needed. It is possible that moderate problems may exist on the island in some aspects of the assessed components, and policy adjustments should be considered after examining the VI structure.
Moderate (0.2 – 0.4)	This indicates island sustainable water resources management are generally in a good condition. There may still be major challenges, however, in either technical support or management capacity-building. Water policy design should focus on the main challenges identified after examining the VI structure, and strong policy interventions should be designed to overcome any key constraints identified.
High (0.4 – 0.7)	This indicates the island is experiencing high water resource stresses, and policy should be focused to provide technical support and policy backup to mitigate the pressures. A longer-term and appropriate strategic development plan should be made, with a focus on rebuilding management capacity to deal with the main threatening factors.
Severe (0.7 – 1.0)	This indicates the island's water resources are highly vulnerable with a poor management structure. Restoration of the island's water resources management will require major commitment from both government and general public. Restoration is likely to be a long process, and an integrated plan should be made at the island level, with involvement from international, national and local level agencies.

Photos credits: David Duncan

4.

Diagnosis of Issues



Photos credits: SOPAC.

4.1 Driver, Pressure, State, Impact and Response Assessment of Water Resources

The analytical framework, known as Drivers, Pressures, State, Impacts and Responses (DPSIR) framework, used by the UNEP Global Environment Outlook (GEO) process and others, was used to provide perspective for the vulnerability assessment. It integrates anthropogenic as well as environmental change (caused by human activities and natural processes) factors with social, economic, institutional and ecosystem pressures to provide a simple analysis framework.

The DPSIR analysis will be completed for each identified issue. Because the scale of the problem for each issue may vary, related to other issues, the drivers and pressures may be analysed at different scales.

Driving forces (D) represent major social, demographic and economic developments in societies, and the corresponding changes in lifestyles, and overall consumption and production patterns. Demographic development may be regarded as a primary driving force, whose effects are translated through related land use changes, urbanisation, and industrial and agriculture development.

The pressures (P) are produced as an effect of the driving forces. The pressures represent processes affecting the resource (water) by producing substances (e.g., emissions), physical and biological agents, etc. that consequently cause changes to the state (S) of water resources. Examples of pressure indicators include the emission of nutrients and pesticides by agriculture, effluent disposal in wastewater from sewage treatment, and flow regulation related to hydroelectric dams.

The state may be described by adequate structural (e.g., river morphology), physical (e.g., temperature), chemical (e.g., phosphorus and nitrogen concentrations) and biological (e.g., phytoplankton or fish abundance) indicators. Depending on the changes of state, society may suffer positive or negative consequences. These consequences are identified and evaluated to describe impacts (I) by means of evaluation indices.

Governance and management Responses (R) include governance (such as policies), commercial (e.g. market driven) and social (e.g. behavioural change) intended to mitigate impacts or adapt to them.

The following outlines a DPSIR assessment of the Pacific Islands water resource issues.

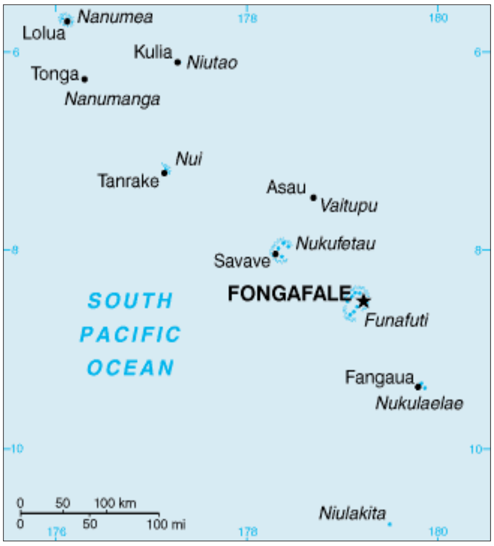
4.2 Assessed Countries

In undertaking an assessment of the freshwater vulnerability of Pacific island countries, it is important that the countries selected for assessment are broadly representative of the region. As discussed earlier, the single most important factor in determining the water availability in Pacific island countries is the geological nature of the islands. It is also important to recognise that water resources are almost entirely managed at an island level. Transfer of water resources between islands is generally not feasible, as islands within a country are commonly separated by many kilometres, and in some cases, thousands of kilometres of ocean. Accordingly, the approach adopted is to consider the most populated island within each of the countries assessed.

In reviewing a single island within a country, it is recognised that there will be significant differences in water resource vulnerability within a Pacific island country containing both large islands and atolls. Nevertheless, it is anticipated that combining different island forms across different countries will enable reliable conclusions to be drawn on regional freshwater vulnerability.

Accordingly, countries have been selected to cover a representative cross-section of the island formations. Fongafale Islet in Tuvalu and Majuro Atoll in the Marshall Islands are atolls in predominantly atoll groups; Nauru is an uplifted limestone island; Rarotonga in the Cook Islands and Upolu in Samoa are small volcanic islands and Viti Levu in Fiji and New Guinea in Papua New Guinea are predominantly large volcanic islands.

4.2.1 Fongafale Islet (Tuvalu)



Source: CIA World Factbook.

Productivity (GDP$.m^{-3} rain):	$0.24
Island population ('000s):	4.5[a]
Island Area km^2	1.4[b]
Island Population Density (cap.km^{-2}):	3 200
Cost recovery of supply:	Limited[c]
Proportion of population with mains supply:	0%[c]
Wastewater (Mm^3.yr^{-1}):	0.07[d]
Water Resources (m^3.capita^{-1}. yr^{-1}):	0[e]
Rainfall Coefficient of Variation:	22%[c]
Total Water Use (Mm^3.annum^{-1}):	0.09[c]
Vegetation cover:	10%[f]

a) SPC (2005); b) Webb (2006); c) SOPAC 2007b; d) assumes 80% of water use (SOPAC 2007b) is discharged as wastewater; e) SOPAC (2007b) reliant on rainwater (typically 18 m^3.capita^{-1}. yr^{-1}); f) Yamano et al 2007.

Tuvalu consists of nine low-lying atolls of limited land area, with high population densities on a land mass of about 26 km^2, spread across 1.2 million km^2 of ocean. The islands consist of coarse coral sands overlying limestone, with a maximum elevation of 5 m above sea level. The economy is heavily dependent upon foreign assistance and public sector expenditure, with the bulk of agriculture at the subsistence level (SOPAC 2007b). The climate is moist and tropical, with the country considered at high risk to cyclones and storm surges (SOPAC 2007b).

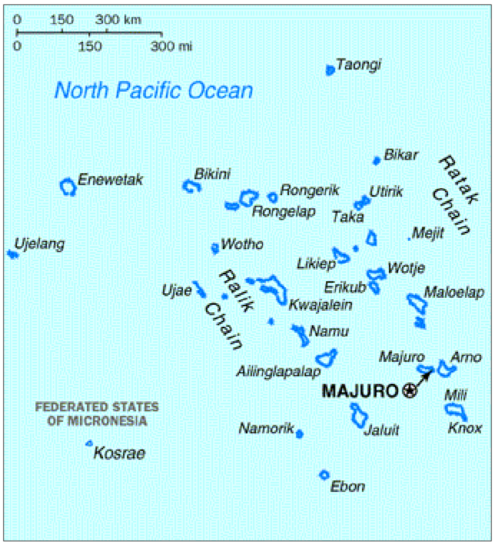
There is no surface water in Tuvalu, and the coarse sediments generally do not sustain fresh groundwater lenses to the extent of other atoll countries in the region (SOPAC 2007b). As a whole, the supply of natural freshwater is restricted to stored household and communal rainwater, supplemented by limited desalinated water. In the main population centre of Funafuti, septic systems have heavily polluted groundwater, which discharges into Fongafale lagoon and has contributed to the collapse of the near-shore reef systems. These coastal areas are a major source of livelihood and also contain marine biodiversity of conservation value (SOPAC 2007b). In response to the limited freshwater availability and impacts of the septic toilets on groundwater and the lagoon, Tuvalu has commenced a strategy to replace existing flush toilets with dry composting toilets.

Outer islands are generally reliant on rainwater with access to limited groundwater lenses. The majority of islands have wells; however these are generally not used for drinking due to pollution from sanitation and increasing salinity. The need to reduce demand and conserve water is also not widely appreciated, and complex cultural and land tenure conditions limit the opportunity for intervention by government (SOPAC 2007b). The extreme nature of the pressures of limited water resources was demonstrated by the national State of Emergency declared in October 2011 due to a lack of water in Nukulaelae and Funafuti, with uncertain reserves on many other islands.

The low-lying nature of the atoll islands and their limited groundwater resources make Tuvalu particularly vulnerable to sea-level rise. Combined with the high sensitivity of rainfall variability to ENSO cycles, Tuvalu's long-term freshwater resources are highly vulnerable.

Photos credits: SOPAC

4.2.2 Majuro Atoll (Marshall Islands)



Source: CIA World Factbook.

Productivity (GDP$.m^{-3} rain):	$0.24
Island population ('000s):	28[a]
Island Area km^2	9.7[b]
Island Population Density (cap.km^{-2}):	2 900
Cost recovery of supply:	Partial[b]
Proportion of population with mains supply:	30% (approx.)[b]
Wastewater (Mm^3.yr^{-1}):	0.84[d]
Water Resources (m^3.capita^{-1}.):	20[b]
Rainfall Coefficient of Variation:	16%[b]
Total Water Use (Mm^3.annum^{-1}):	1.7[b]
Vegetation cover:	15%[c]

a) RMI (2006); b) SOPAC (2007f); c) FAO (2010a); d) Estimated from SOPAC (2007f) assuming 80% of water use discharged as wastewater.

Marshall Islands consists of two chains of coral atolls and coral islands located in the mid-west of the Pacific Ocean. The land mass of about 180 km^2, is spread over about 2 million km^2 of ocean, with a population of about 63 000. The highest point in the country is only 10 m above sea level, and the average elevation is 2 m. The economy is heavily dependent on foreign assistance and public sector expenditures, with the bulk of agriculture at the subsistence level (SOPAC 2007f). The climate is moist and tropical, with the country considered at high risk to cyclones and storm surges (EPPSO 2006).

Other than temporary and localised ponding following heavy rain, there is no surface water in the Republic of Marshall Islands. As a whole, the supply of natural freshwater is restricted to rainfall captured and limited fresh groundwater lenses. The main groundwater lens used for freshwater supply is the Laura Lens, about 600 m wide, covering approximately 140 ha, located on Majuro Island (USGS 2005). The Laura groundwater wells produce approximately 380 000 L a day, which is supplemented by a desalination production of about 750 000 L a day during drought and 2 300 L a day rainwater harvesting from the airport (SOPAC, 2007f). The combination of rainwater, supplemented by desalinated mains water and limited groundwater is also the main source of water on Ebeye, the other main centre of population in Marshall Islands. On Ebeye, many households are reliant on desalinated water sourced from the US base at Kwajalein for drinking water (SOPAC 2007f).

Photos credits: SOPAC

The outer islands are largely dependent on rainwater and limited groundwater lenses, accessed by gallery wells (SOPAC 2007f); however, during severe droughts, people on the outer islands have relied on coconut water for their drinking water (SOPAC 2002).

Rapid population growth, urbanisation, and increasing private and public sector development are driving significantly increased freshwater demand (SOPAC 2007f). Currently supply is not meeting demand, with much of the country facing constant water rationing, with water available at most for several hours a day for several days a week (SOPAC 2007f). In drought years, typically every six to nine years and associated with ENSO events, restrictions are tightened. The 1998 drought resulted in rainfall of 8% of the average over January to March, resulting in the declaration of a national disaster (USGS 2005). These pressures are compounded by significant leakage and water theft, typically 25% (USGS 2005).

The development pressures are reflected in the low remnant vegetation coverage providing natural groundwater catchments. Groundwater contamination associated with septic tanks, agricultural practices and fuel storage have polluted the limited groundwater resources. Water quality testing indicates that most households are using contaminated water sources (SOPAC 2007f), consistent with high rates of water-borne disease.

Water supply from groundwater and desalination are further compromised by power outages, and a lack of water conservation and demand management strategies and land is almost entirely privately owned, restricting government infrastructure initiatives. The lack of water resource legislation and national policy and an information exchange system, together with minimal community engagement and integration across sectors have limited the Marshall Island's capacity to meet the challenges of such limited water resources (SOPAC 2007f).

The low-lying nature of the atoll islands and their groundwater lenses means that Marshall Islands is particularly vulnerable to sea-level rise. Combined with the high sensitivity of rainfall variability to ENSO cycles, the long-term Marshall Islands' freshwater resources are highly vulnerable.

4.2.3 Nauru

Source: CIA World Factbook.

Productivity (GDP$.m^{-3} rain):	$0.50
Island population ('000s):	10.0[a]
Island Area km^2	22[b]
Island Population Density (cap.km^{-2}):	455
Cost recovery of supply:	Limited[b]
Proportion of population with mains supply:	0%[b]
Wastewater (Mm^3.yr^{-1}):	0.37[c]
Water Resources (m^3.capita^{-1}. yr^{-1}):	0[d]
Rainfall Coefficient of Variation:	54%[d]
Total Water Use (Mm^3.annum^{-1}):	0.42[d]
Vegetation cover:	11%[e]

a) SPC (2010a); b) SOPAC 2007a; c) adapted from water use figures of Falkland (2010); d) Falkland (2010); e) Thaman et al (2009).

Nauru consists of a single raised limestone island of about 21 km^2, with a central raised plateau about 30 m above sea level surrounded by a narrow coastal plain. The depletion of significant mineral phosphate reserves has seen Nauru shift from one of the world's strongest economies in the 1960s to a position where the economy is now heavily dependent upon foreign assistance and public sector expenditure, with the bulk of agriculture at the subsistence level (SOPAC 2007a).

Gallery wells consist of shallow wells with horizontal collection tubes collecting water from shallow aquifers. Coconut water is the liquid (mostly water) inside a coconut.

Freshwater resources in Nauru are limited to a small brackish lake and a small groundwater lens thought to be transient. Whilst Nauru has moderate rainfall, it is strongly impacted by La Niña events, with annual rainfalls during these periods as low as 20% of the long-term average (Falkland 2002a).The main water supply for the country is provided by desalination of seawater, supplemented by rainwater. The available freshwater for the country during a drought is limited to the 12 litres per capita per day provided by the desalination plant. This compares poorly with the World Health Organization recommendation of 15–20 litres per person per day for emergency water supplies for refugees (WHO 2003).

Household water supplies are supplemented in about 38% of houses by brackish groundwater use for toilet flushing and washing (Bouchet and Sinclair 2010). Sanitation is generally managed at a household level, with septic tanks and cesspits, causing widespread contamination of the aquifers recorded in a 2010 survey (Bouchet and Sinclair 2010). The exception to this is the Location area, where there is direct discharge of primary sewage onto the western beaches.

Photos credits: David Duncan

The extremely limited freshwater resources of the island and the heavy reliance on desalination to meet basic human needs make Nauru particularly vulnerable to climate variability and change. Combined with the high sensitivity of rainfall variability to ENSO cycles, Nauru's long-term freshwater resources are highly vulnerable.

4.2.4 Rarotonga (Cook Islands)

Source: CIA World Factbook.

Productivity (GDP$.m^{-3} rain):	$0.02
Island population ('000s):	13.9[a]
Island Area km^2	67[a]
Island Population Density (cap.km^{-2}):	207
Cost recovery of supply:	No[b]
Proportion of population with mains supply:	96%[c]
Wastewater (Mm^3.yr^{-1}):	1.4[f]
Water Resources (m^3.capita^{-1}. yr^{-1}):	3 900[d]
Rainfall Coefficient of Variation:	19%[e]
Total Water Use (Mm^3.annum-^{1}):	4.4[f]
Vegetation cover:	61%[g]

a) Cook Islands Statistics Office (2010); b) SOPAC (2007a); c) WHO / SOPAC (2008); d) estimated on current population and resources from Clement and Bouget (1992); e) Carter and Steen (1984); f) Brockman Tym International (2000); g) Cook Islands Government (2010).

The Cook Islands consists of 15 islands with a land mass of 237 km^2 spread across 1.8 million km^2 of ocean. These islands include high volcanic and raised limestone islands and atolls. The capital city, Avarua, is located on Rarotonga, the largest and most heavily populated island. The Cook Islands are heavily dependent upon tourism and have the highest per capita GDP of the Pacific Island Countries ($10 875).

Water resources of the southern islands are largely surface water dependent, with some significant groundwater lenses on the larger islands. The smaller northern group of islands are largely dependent upon rainwater harvesting and groundwater.

Water use on Rarotonga is very high, with estimates as high as 1200 litres per person per day; however, it is recognised that systemic and household leakage represents a very large component of this (SOPAC 2007g). It is anticipated that the ongoing distribution system upgrade will address many of the leakage issues. Currently, even though rainfall across Rarotonga is high, typically over 2 metres annually and higher across the central mountains, the water supply system struggles to meet demands, with parts of the island commonly losing water supply during dry years. The supply draws on surface water off-takes supplemented by groundwater abstraction.

Wastewater management on Rarotonga is largely based on septic tanks, with centralised sludge management, although a small sewer system is operational. Wastewater pollution of groundwater and livestock pollution of surface waters are increasing coastal eutrophication potentially compromising the tourism on which the island relies (SOPAC 2007g).

The largest challenge to sustaining water resources in the Cook Islands is disaster resilience. The country is particularly prone to cyclones, with five hitting the islands in five weeks in 2005 (four of which were category 5). Sustaining water supplies in this environment requires the capacity to plan well and respond rapidly with emergency supplies, particularly on outer islands reliant on rainwater tanks and groundwater lenses vulnerable to storm surges.

Photos credits: David Duncan

4.2.5 Upolu (Samoa)

Source: CIA World Factbook.

Productivity (GDP$.m^{-3} rain):	$0.16
Island population ('000s):	136[a]
Island Area km^2	1 115[b]
Island Population Density (cap.km^{-2}):	124
Cost recovery of supply:	Low[b]
Proportion of population with mains supply:	94%[a]
Wastewater (Mm^3.yr^{-1}):	15[c]
Water Resources (m^3.capita^{-1}. yr^{-1}):	3 500[d]
Rainfall Coefficient of Variation:	20%[e]
Total Water Use (Mm^3.annum-^{1}):	42.5[f]
Vegetation cover:	52%[g]

a) Government of Samoa (2007); b) SOPAC (2007h); c) Estimate based on population from domestic wastewater (ADB 2008) and industrial wastewater (UNEP 2000) estimates; d) Rofe et al (1996) underestimates groundwater; e) Government of Samoa (2006); f) Government of Samoa (2010); g) FAO (2010b).

Samoa consists of two main volcanic islands, Upolu and Savai'i, and seven smaller islands, islets and rocks, with a total area of about 2 820 km^2. The capital Apia is located on Upolu, the most populated island. The economy is heavily dependent on foreign assistance and overseas remittances, with the bulk of agriculture at the subsistence level (SOPAC 2007h).

Catchment sizes are small, and slope gradients steep, resulting in rapid responses to rainfall events, and low flows in dry periods. Flooding in Apia is common, with four major floods in the past century (SOPAC 2006). Water supply on Upolu is predominantly surface water sourced, supplemented by groundwater. Small hydropower plants also utilise these headwaters and typically meeting 40% of national energy demand (SOPAC 2007h).

Development pressures and land clearance around the major watersheds are starting to threaten the protected nature of these upper catchments; however, system cost recovery is not sufficient to fund supply or protective measures (SOPAC 2007h). Samoa has reached its sanitation MDG early, with near total access; however despite initiatives to improve water supply and water use efficiency, the country is not on track to achieve the drinking water MDG (WHO/SOPAC 2008).

Samoa is the only Pacific nation that has implemented a national water resource management policy. The high rate of land held within complex customary land ownership has led to development of participatory approaches for water resources management; however, land access remains a challenge for managing water resources (SOPAC 2007h).

The single greatest challenge to Samoa's water resources management is potentially the high vulnerability to natural disasters (cyclones, floods and tsunami). The estimated cost of natural disasters is 46% of GDP in years of major disasters (about one in seven years); however, significant costs have been averted by mitigation strategies (World Bank 2006).

Photos credits: SOPAC

4.2.6 Viti Levu (Fiji Islands)

Source: CIA World Factbook.

Productivity (GDP$.m^{-3} rain):	$0.07
Island population ('000s):	662[a]
Island Area km^2	10 429[a]
Island Population Density (cap.km^{-2}):	63
Cost recovery of supply:	Partial[b]
Proportion of population with mains supply:	19%[c]
Wastewater (Mm^3.yr^{-1}):	56[d]
Water Resources (m^3.capita^{-1}. yr^{-1}):	43 800[e]
Rainfall Coefficient of Variation:	26%[f]
Total Water Use (Mm^3.annum-^{1}):	67[e]
Vegetation cover:	51%[g]

a) Fiji Islands Bureau of Statistics (2008); b) SOPAC (2007i); c) WHO/UNICEF (2010); d) estimated on current population and estimated discharge adapted to include industrial load (Burke 2000) and less population serviced by coastal WWTPs (Government of Fiji 2006); e) FAO (2011c); f) adapted from ICGI (2000); g) Government of Fiji (2007).

Fiji consists of about 322 islands with a land mass of about 18 333 km^2, that includes large volcanic islands, raised coral islands and low-lying atolls and coral islands. Viti Levu is the largest and most populated island and contains Suva, the capital city. Over a third of the country's GDP can be attributed to natural resource-related activities such as agriculture, forestry, fisheries, tourism, and mining, with tourism the fastest growing sector (ADB 2005).

The abundant rainfall across most of the larger islands means that adequate water is generally available to meet most water demands. Nevertheless, the reliance on consistent rainfall and limited infrastructure to secure supply means that Viti Levu is vulnerable to drought periods, generally consistent with El Niño events (SOPAC 2007i). Viti Levu and other Fijian volcanic islands with high rainfall and steep valleys are susceptible to flooding.

Water supply systems service the largest towns and cities; however several of these, including the tourism hub of Nadi, are reaching their capacity.

Natural disasters significantly impact on water resources management, particularly on smaller islands, where sources may be limited to rainwater harvesting and shallow groundwater lenses; and vulnerable to increased salinisation during storm surges. Nationally, costs of years with significant natural disasters (typically one in three years) are about 8% of GDP (World Bank 2006).

Improved water resources governance has been identified as critical to long-term sustainable management in Fiji, including development of an enabling framework, together with increased national and community awareness and technical capacity (SOPAC 2007i).

Photos credits: Tiy Chung

4.2.7 New Guinea (Papua New Guinea)

Source: CIA World Factbook.

Productivity (GDP$.m^{-3} rain):	$0.004
Island population ('000s):	5 800[a]
Island Area km^2	405 340[b]
Island Population Density (cap.km^{-2}):	12
Cost recovery of supply:	Yes[c]
Proportion of population with mains supply:	10%[d]
Wastewater (Mm^3.yr^{-1}):	186 400[e]
Water Resources (m^3.capita^{-1}. yr^{-1}):	120 000[f]
Rainfall Coefficient of Variation:	15%[g]
Total Water Use (Mm^3.annum-^{1}):	277[h]
Vegetation cover:	65%[i]

a) Based on estimated growth (SPC, 2010a) and 200 Census data (NSO, 2002); b) NSO (2002); c) PNG DEC (2007); d) WHO/UNICEF (2010); e) including Porgera Mine (Bunn et al 2006), Ok Tedi mine (Lottermoser (2010) and domestic and industrial (UNEP 2000); f) based on national average FAO (2011a); g) Hall (1984); h) FAO (2011b); i) FAO (2010c).

Papua New Guinea is the largest (462 840 km^2) and most populous Pacific island country (5.8 million people), consisting of the eastern half of the island of New Guinea, several large high volcanic islands and numerous high volcanic islands and coral atolls. Its diverse geography gives rise to an equally diverse range of ecosystems which accommodate a wide variety of flora and fauna making up 5% of the world's biodiversity (Berdac and Mandeakali 2005).

Agriculture contributes about one third of GDP, but supports about 85% of the population, mainly at subsistence level (Berdac and Mandeakali 2005). Minerals and oil contribute a further third of the GDP. National development and freshwater management are complicated by the complex land tenure system, with only 3% owned by the state (SOPAC 2007j).

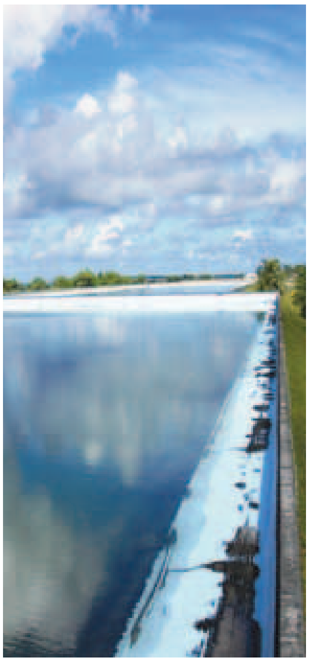
Papua New Guinea has abundant freshwater resources across the high volcanic islands; however the largest population centre, Port Moresby is located in the country's driest area. Significant hydropower and mining developments are large water users and most of the major urban areas have piped water supplies. Wastes from mining, in particular the Ok Tedi Mine in central Papua New Guinea, which discharges over 160 000 tonnes of waste rock and tailings daily (Lottermoser 2010) have resulted in significant environmental impact on the country's largest river (Sowei et al. 2002).

Only about 41% of the population have access to improved drinking water and 45% to improved sanitation; however, this is even lower in rural communities, at 33% and 41%, respectively (WHO/UNICEF 2010). Disturbingly, even though significantly more people have gained access to these facilities since 1990, the high population growth rates have resulted in these access rates falling over this 18-year period. Diarrhoea was attributed as the primary cause of 6% of deaths in Papua New Guinea (WHO 2009) and was likely to be a contributing factor to numerous other causes.

Photos credits: SOPAC

5.

Vulnerability Assessment



Photos credits: SOPAC, SOPAC and David Duncan.

In order to better manage the challenges on the Pacific islands' water resources, it is important to understand the pressures arising from the regional drivers notably, rapid population growth, migration to urban areas, economic development and significant growth in tourism and mining, both water intensive sectors. Emigration of skilled workers from the region continues to stress regional capacity to respond to these challenges, so this assessment aims to identify the priority areas of freshwater vulnerability to focus investment and action.

5.1 Resource Stresses

The conditions of these islands are likely to be broadly consistent with that experienced on numerous small low-lying islands throughout the Pacific. The lack of water resources and high variability of rainfall contribute to the vulnerability of water resources, which can be expressed as "scarcity" and "variation" of the water resources. Water scarcity refers to the limited capacity of the water resources base to meet the demands of the island population. It is generally expressed as per capita water availability and compared with the generally accepted minimum level of per capita water requirement proposed by Falkenmark and Widstrand (1992) (1 700 $m^3.person^{-1}.year^{-1}$). The variation in the water resources is expressed by the coefficient of variation (CV) of precipitation. A threshold 30% is set for the CV, reflecting a point above which rainfall variation critically impacts on security (UNEP 2009).

Table 5.1: Resource stresses for selected Pacific islands.

Island	Indicators		Parameters		
	Available Water Resources $m^3.capita^{-1}$	Precipitation Coefficient of Variation	Water Stress RS_s	Water variation RS_v	Resource Stress R_S
Fongafale	0	22%	1.0	0.73	0.84
Majuro Atoll	20	16%	0.99	0.53	0.75
Nauru	0	54%	1.0	1.0	1.0
Rarotonga	3 900	19%	0	0.63	0.32
Upolu	3 500	20%	0	0.67	0.34
Viti Levu	43 800	26%	0	0.63	0.33
New Guinea	120 000	15%	0	0.5	0.25

The water resources available on Pacific islands are highly dependent upon the island form. Volcanic islands generally have an abundance of water resources, particularly larger high volcanic islands such as New Guinea and Viti Levu. The availability of water is such that flooding is an ongoing threat in low-land areas during the wet season. Importantly though, the temporal and spatial variation of rainfall, population density and landform mean that even on these large islands, drought conditions can be experienced during El Niño cycles.

The rainfall on smaller volcanic islands, such as Rarotonga and Upolu are also well above the 1 700 $m^3.capita^{-1}$ threshold; however, the smaller, steep catchments and flashy[14] nature of river and stream flows present challenges to water resources management. As development and population growth pressures increase, it is likely that both islands, and particularly Rarotonga, will experience increasing pressures on sustaining supplies. Further growth in the high water demand sectors of tourism and agriculture on Rarotonga may place critical pressure on an already stressed system. The rainfall variability on Rarotonga and Upolu are moderately high, meaning that, during dry years these stresses will be even higher. The implication is that water resources on small volcanic islands are already a critical development pressure and may become so on other islands.

Small Pacific islands are extremely vulnerable to water resource stresses. Nauru is subject to both a lack of significant resources, and high rainfall variability. Combined with the high population densities of these islands, the lack of freshwater resources at times presents a challenge to meeting basic human needs, and is likely to present a significant challenge to any major development on Nauru, Majuro Atoll and Fongafale. As a result

[14] Flash flooding and flows typically rise and fall very rapidly. This stresses both flood warning systems, with limited response times, and water harvesting, often restricting options to storage rather than harvesting water from steady-flow streams and rivers.

of the extremely limited water availability, and the exposure of these resources to threats from tropical storms and rainfall variability, these islands are particularly vulnerable to climate variability and change pressures. High rainfall variability is reflected in development of rainwater and desalination as the major water sources on Nauru, Majuro Atoll and Fongafale, as well as the move to innovative approaches, including developing storages for airport runway catchments.

5.2 Development Pressures

The water development pressures reflect the capacity of islands' water resources to meet the competing demands of the agricultural, industrial and commercial sectors as well as that of the community. The two factors considered in this assessment, the amount of water taken from the available resource and household access to drinking water, reflect these demands. Across the Pacific the stress on water resources due to consumptive and productive use was found to broadly reflect the availability of water. The capacity to meet human needs; however, was more likely to be associated with matching management and investment to human needs.

Table 5.2: Water development pressures for selected Pacific islands.

Island	Indicators			Parameters		
	Total water use $Mm^3.year^{-1}$	Total Water Resources $Mm^3.year^{-1}$	Access to Improved DW % population	Water exploitation pressure DP_e	Drinking water inaccessibility DP_d	Development Pressure DP
Fongafale	0.09	0	97	1.0	0.03	0.52
Majuro Atoll	1.7	1.4	94	1.0	0.06	0.53
Nauru	0.4	0	90	1.0	0.1	0.55
Rarotonga	6.7	55	96	0.12	0.02	0.07
Upolu	42.5	1 328	88	0.03	0.13	0.07
Viti Levu	70	28 600	47	0.0	0.53	0.27
New Guinea	71	801 000	40	0.0	0.60	0.30

Analysis of large volcanic islands such as Viti Levu and New Guinea identified systems with almost no impacts on flows and almost no associated stress. Whilst it is recognised that significant hydropower developments have the potential to alter this situation, the abundance of available water means that stresses associated with extractive demands are currently very low. Nevertheless, the large, predominantly rural populations across these large rugged islands are clearly stretching the capacity to deliver safe drinking water supplies, with very limited difference in access rates since 1990. Significant investment in these areas has seen a considerable increase in the number of people with access to drinking water; however, the population growth has matched this over the last 18-year period. It is anticipated that both Papua New Guinea and Fiji will fall significantly short of the MDG for improved drinking water access.

Smaller volcanic islands experience low to moderate stress on water resources associated with extractive use; however, seasonal variability in water resources on Upolu and Rarotonga means that rivers and streams can be significantly stressed over the dry season (SOPAC, 2007h & 2007g). Nevertheless, the low rate of exploitation indicates significantly more water is available. The challenge to water resource managers is to find mechanisms to access and harvest this resource to meet development and household supply needs. The relatively high level of access to improved drinking water indicates that this is generally occurring; however, given that Samoa is not on track to meet the improved drinking water access MDG, further work is required to develop the available water resources.

Small atoll and raised coral islands typically make maximum use of the limited resources available. The extreme stress on water resources means that resources outside the traditional surface water and groundwater resources have been developed, including a high dependence on rainwater harvesting and desalination. The small populations and targeted investment strategies have enabled these islands to achieve relatively high levels of access to drinking water supply, with most of these countries on track to meet the relevant MDG targets. Nevertheless, whilst access levels are high, the extended periods of minimal water access during periods of extended drought (often months) indicate significant scope for improvement.

5.3 Ecological Insecurities

Ecological health of freshwater systems is fundamental to both biodiversity protection and ecosystem services providing food, water and other resources. The factors that contribute to ecological vulnerability are depletion and modifications of flows, pollution loads discharged into waters and loss of habitat (both wetland habitat and habitat providing a buffer for waters). Vulnerabilities associated with resource depletion are addressed under resource stresses. Accordingly, the ecological vulnerability of freshwater systems has been assessed by consideration of pollution loads and loss of vegetation across the islands.

Table 5.3: Ecological health pressures for selected Pacific islands.

Island	Indicators			Parameters		
	Wastewater Volume million $m^3.year^{-1}$	Total Water Resources million $m^3.year^{-1}$	Vegetation Cover percent of island area	Water Pollution EH_p	Ecosystem Deterioration EH_e	Ecological Health Pressure EH
Fongafale	0.08	0.0	10	1.0	0.9	0.95
Majuro Atoll	1.85	1.4	10	1.0	0.85	0.93
Nauru	0.3	0.0	11	1.0	0.89	0.94
Rarotonga	1.4	55	61	0.02	0.39	0.21
Upolu	13.8	1 328	15	0.01	0.35	0.18
Viti Levu	28	28 600	50	0.0	0.49	0.25
New Guinea	186 400	801 000	71	0.32	0.35	0.34

The abundant water resources of the volcanic islands, combined with limited industrial sector development means that flows on volcanic islands are generally adequate to provide for mixing and dilution of currently discharged wastewaters. The key exception to this is the waste rock and tailings from Ok Tedi Mine, which has caused major degradation of the Fly River for hundreds of kilometres downstream from the mine site. At a local scale, toxic chemicals may accumulate within systems; however, the lack of significant inland industrial wastewater discharges means that this effect is generally limited to rivers downstream of mining developments. The undeveloped interiors of the large islands of Viti Levu and New Guinea have resulted in many of the catchment headwaters being protected and with low vulnerability. Notably, the Ok Tedi experience provides an indication of how this may change significantly in a period of a decade.

The smaller islands have seen development pressures expand across the catchment area for many of the surface water and groundwater resources, resulting in degraded vegetation cover. The most severe example is that of Nauru, where phosphate mining has denuded over 80% of the nation's vegetation. Atolls with high population densities have limited space available for expansion, resulting is minimal remnant vegetation. The removal of vegetation generally removes a protective barrier from both groundwater and surface water catchments, increasing freshwater vulnerability. An exception to this may be revegetation with non-native species, which may impact on water resources through processes such as high water uptake or high leaf shedding into catchments.

The magnitude and urgency of the challenge in managing water pollution of small islands are due to a combination of high population density rates, use of sanitation systems that discharge into freshwater resources (such as cesspits and septic tanks) and extremely limited freshwater resources for mixing. A recent survey of wells on Nauru identified that 70% of wells in the country are contaminated by faecal wastes (Bouchet and Sinclair 2010), reflecting this high vulnerability.

5.4 Management Challenges

Water resources management is measured in this study by assessing the efficiency of resource use, the capacity to supply household access to improved sanitation, in turn protecting receiving water resources, and through the application of IWRM management and governance.

Table 5.3: Ecological health pressures for selected Pacific islands.

Island	Indicators			Parameters		
	Rain-based Productivity $USD.m^{-3}	Sanitation percent of population	Water Use Efficiency MC_e	Improved Sanitation MC_s	IWRM Capacity MC_I	Management Challenges
Fongafale	1.96	84	0.05	0.16	0.9	0.37
Majuro Atoll	0.24	72	0.02	0.27	0.8	0.36
Nauru	0.50	50	0.00	0.50	0.9	0.47
Rarotonga	0.02	100	0.00	0.00	0.9	0.3
Upolu	0.16	100	0.40	0.00	0.5	0.3
Viti Levu	0.07	71	0.77	0.29	0.55	0.54
New Guinea	0.004	45	0.99	0.55	0.8	0.78

The efficiency of water resource use is assessed as the productivity against a basket group of islands and island nations located in the Pacific Ocean with high productivity (Japan, Singapore, Hong Kong and New Zealand). This basket group had a minimum productivity of US$0.47.m^{-3} rainwater, reflecting the rain-based agriculture that forms the mainstay of many Pacific island economies. Against this benchmark, only Fongafale and Nauru were able to match or better the productivity per unit of rainfall, reflecting the effective use of rainwater as a core resource on these islands. The productivity of all other islands was low, reflecting the minimal intensive agriculture and industry development in these countries.

Sanitation access is complete on both Rarotonga and Upolu, reflecting initiatives to meet MDGs in both Cook Islands and Samoa. New Guinea is struggling to make progress on improving sanitation access, with minimal change in coverage since 1990. The limited availability of water resources, combined with household level of wastewater management without central coordination in Nauru, with limited access to improved sanitation, are likely to be factors in the high diarrhoea rates in Nauru, which is also indicative of an island with stressed water resources. Whilst productivity associated with water resources is relatively high, this should be considered in the context of extremely high costs of generating much of the water using diesel-fuelled reverse osmosis, which exceed the rain-based productivity rate by over ten to one.

All Pacific islands are struggling with IWRM capacity. Of the seven islands represented, only Samoa has a national IWRM policy. The lack of key water professionals (such as hydrologists, hydrogeologists and planners) in many countries further restricts capacity to manage water resources; however, recent developments in IWRM planning and implementation through ongoing regional and national projects have the potential to rapidly improve this situation.

5.5 Vulnerability Index

The overall Vulnerability Index (VI) is determined by giving equal weights to each of the four components of the index, resource stresses (RS), development pressures (DP), ecological health pressures (ES), and management challenges (MC). These components were determined by giving equal weights to each of the individual parameters. Individual components and the VI for each island were then broadly classified as 0 to 0.2 Good, 0.2 to 0.4 Moderate, 0.4 to 0.7 high and above 0.7 as severe.

Table 5.5: Vulnerability index for selected Pacific islands.

Island	RS	DP	EH	MC	VI
Fongafale	0.87	0.52	0.95	0.37	0.68
Majuro Atoll	0.75	0.53	0.93	0.36	0.64
Nauru	1.00	0.55	0.94	0.47	0.74
Rarotonga	0.32	0.07	0.21	0.30	0.23
Upolu	0.33	0.07	0.18	0.30	0.22
Viti Levu	0.43	0.27	0.25	0.54	0.37
New Guinea	0.25	0.30	0.34	0.78	0.42

Water resources management provide the greatest challenge regionally, across nearly all islands. The other significant challenge is the delivery of fundamental human needs, improved drinking water and sanitation. Collectively, the islands can be considered in three broad groups:

- Low-lying islands under severe resource and environmental stress, with significant development pressure and a need for improved water management and governance (Fongafale, Majuro Atoll and Nauru).
- Moderate-sized volcanic islands with adequate water resources, significant water management and governance challenges in managing the available resources, but a high-level of provision of improved drinking water and sanitation (Rarotonga and Upolu).

Larger volcanic islands with adequate water resources, but significant to severe water management and governance challenges in managing available resources, in particular provision of drinking water and sanitation (New Guinea and Viti Levu). The assessment highlights that the freshwater resources of the low-lying islands Majuro Atoll, Nauru and Fongafale, are highly to severely vulnerable. The underlying drivers behind this assessment are the extremely low availability of water resources, the high population density, management challenges and development pressures. All three islands share a lack of surface freshwater resources and very limited or no fresh groundwater resources. The pressure on the available resources is exacerbated by clearance of native vegetation for housing and mining (Nauru) and high septic density over the groundwater resources. Whilst these islands are augmenting supplies through household and airport runway rainwater harvesting (Fongafale and Majuro, respectively) and desalination, the lack of integration of water resources governance and management is further stressing their capacity to manage limited resources.

These three islands, which are likely to be representative of communities on small low-lying islands across the region, will be highly vulnerable to climate variability due to the small rainwater collection area available and the increasing island populations. Resource stresses and ecological health insecurity are severe on all three islands. The high population densities mean that protecting the underlying groundwater will be dependent upon improved wastewater and land management. The second group of moderately sized and populated volcanic islands, including Upolu and Rarotonga are generally at a point where natural water resources are likely to be adequate to meet demand needs into the future. Nevertheless, even on these islands, there are significant management challenges. Rainfall variation is relatively high on both islands, reflecting challenges to maintaining water supplies throughout the year; however, both islands have significant scope for water resources development.

The challenges to larger volcanic islands are typically more management than resource driven. Generally water resources are abundant; however, temporal and spatial variation can temporarily impose restrictions on major commercial centres. The struggle to increase access to improved water supply (combined with similar outcomes associated with access to improved sanitation) is indicative of the need to improve water resources management in Viti Levu and New Guinea, and more broadly of larger volcanic islands in the region. The abundance of rainfall has limited the need to explore irrigated agriculture; however, the periods of drought and water restrictions experienced in Nadi on Viti Levu and Port Moresby on New Guinea indicate a need for greater water demand management, infrastructure investment and water resources management.

6.

Conclusions and Recommendations

Photos credits: Tiy Chung, David Duncan and Nauru IWRM Project.

6.1 Conclusions

The vulnerability of water resources, and the associated socio-economic and environmental stresses in the Pacific are closely related to the availability of water. Factors that contribute to this include the total resource, demands on the resources and the spatial and temporal variability of the resource. The distance between most islands means that water resources are typically managed on an island basis, with some exceptions for connected islets along atolls. On larger islands there is the capacity to manage water resources collectively, not necessarily restricted to catchments; however, the rugged, often inaccessible nature of the interior of the larger islands present other challenges in terms of access to water resources, and supporting rural populations with safe drinking water supplies and sanitation.

All 14 of the Pacific island countries are recognised as small island developing states, acknowledging their specific social, economic and environmental vulnerabilities. The greatest vulnerability is reflected in the lack of water resources in low-lying islands. Six island countries, Nauru, Niue, Kiribati, Tonga, Tuvalu and the Republic of Marshall Islands, have no significant surface water resources and of these, only Tonga and Niue have significant groundwater resources. The almost total dependence upon rain-fed agriculture across all of the Pacific island nations means that their economies and peoples' livelihoods are particularly vulnerable to drought and rainfall variability and ultimately to climate variability and change pressures. At the other extreme, the intense rainfall and runoff experienced in several large volcanic islands cause flooding on the coastal plains. The rainfall variability (as high as 54% in Nauru) means that rain cannot be relied upon on several islands, who have adopted desalination to provide greater security, but at a very high operating cost, which are further impacted by the variability of electricity supply and global fuel costs. Climate variability and change will therefore become an increasingly important driver in water resource planning and decision-making.

The main islands in low-lying countries face a further problem of population migration, to the extent that many islands support populations well beyond those that could be supported by traditional water resources. The increasing urbanisation of islands such as Fongafale (Tuvalu), Tarawa (Kiribati) and Majuro and Ebeye (Marshall Islands) means that the integration of water resources management is becoming increasingly critical on islands already under severe water resource stress.

Whilst several of the countries most vulnerable to water resource stress have become efficient in meeting human needs and using limited resources, the economic vulnerabilities of New Guinea are reflected in productivity rates for available resources about 100 times lower than other Pacific island economies.

The poor progress regionally towards meeting basic human water needs is reflected in the access rates to improved sanitation and safe drinking water, regionally at 53% and 50% respectively, compared with global averages of 61% and 87%. Most importantly, these rates have not improved significantly in the Pacific since 1990.

Ecologically, the smaller islands are also under greatest stress, with 85% to 90% of vegetation cleared on Majuro Atoll, Nauru, Fongafale and Upolu, reflecting the high population densities of these islands, from 124 to 2 600 people.km^{-2}. These islands also have the smallest capacity to absorb the wastewater generated from the urban areas, polluting critical groundwater lenses. The lower population densities, high runoff and limited development of large islands have generally allowed them to provide a higher level of protection for vulnerable ecosystems. Impacts on these islands tend to be localised to areas of intense development such as mining, urban or tourism development. Nevertheless, the experiences of mining development in the Fly River of New Guinea indicate that these local impacts can be extreme.

Probably the greatest challenge facing Pacific island countries in water resource management is the limited technical and governance capacity. The remoteness of these islands and small populations may limit options to manage resource pressures. Combined with emigration of skilled professionals out of the region there is minimal capacity within regional countries to respond to the day-to-day vulnerability threats, let alone the frequent natural disasters experienced in some countries. Many countries have small administrations dealing with the varying complexities of main and outer island issues, without the access to economies of scale available to many larger countries tackling similar issues. The broad lack of enabling national policies and legislation, and the lack of capacity to implement existing strategies must be tackled to reduce regional, national and island freshwater vulnerability.

6.2 Recommendations

Several attempts have been made in the past to provide regional solutions to water resource management problems. Increasingly it is being recognised, as is highlighted by this assessment, the region consists of a myriad of islands and countries, each with a combination of water resource, ecological, development and management pressures. These are in turn overlaid by the range of interlinked cultural, geographical and climatic environments and associated stresses and vulnerabilities. From a resource management approach, the largest unit that practically is suited to a consistent approach is at country level, due in part to shared culture and consistent governance framework. It is recommended that a country-based approach be pursued in managing water resources, and in addressing water resource development. Whilst programmes and projects may necessarily operate regionally to provide critical mass on resourcing, individual strategies are required for each country, and commonly at an island or island group level, to support development of water resources and manage vulnerability.

Management continues to be one of the greatest challenges addressing regional water resource vulnerability. The isolation of many islands, combined with limited local resources means that islands and countries in the region struggle to develop and retain a sustainable level of technical and management capacity. Long-term strategies to address this weakness are fundamental to developing a sustainable management capacity in the region. Further, this must be supported by high level engagement to ensure political commitment to developing and implementing sustainable policies and legislation.

Improving water use efficiency is crucial to maintaining basic human needs on the most stressed islands and supporting sustainable development elsewhere. This area would benefit from the application of strategic cost-benefit analyses, to drive efficiency programmes, together with high-level political engagement.

Delivery of IWRM within a model adapted to the Pacific is critical to delivery of many of the recommendations discussed in this report. Ensuring communication and knowledge exchange across government agencies, the private sector and communities, together is critical in delivering strategies that require these stakeholders to work in an integrated manner. The delivery of IWRM into Pacific islands countries may also require varying degrees of institutional reform to optimise governance and management arrangements.

The low level of delivery of improved drinking water and sanitation into several countries, together with the water resource stress evident in low-lying countries supports investment in infrastructure. The type of investment is likely to be at a household or community level in low-lying islands, and probably a combination of household level and centralised infrastructure on larger islands. Utility reform associated with cost-recovery and improved efficiency and aligned with infrastructure investment, mainstreaming IWRM and infrastructure management and maintenance would enable countries to maximise development opportunities associated with water resources and better meet basic human rights.

Disaster risk management needs to be integrated into national planning and water resource management needs to be integrated into disaster risk management to provide Pacific island countries with resilience that reduces the costs significantly from as high as 46% of GDP. Again, communities need to be an integral component in the planning and delivery of disaster management plans to ensure that those same communities are protected.

Currently there is minimal feedback nationally and regionally on progress towards addressing major water resource issues. Indicator frameworks are required at national and regional levels to provide critical feedback to decision-makers on the success (or otherwise) of policy decisions and implementation. These frameworks need to be integrated to optimise the value obtained from the information transfer from the local to the global level.

Greater networking, information exchange and collaborative approaches at a sub-regional and regional level would enable progress to be built on the collective work of several countries addressing similar issues, such as sanitation and household drinking water safety planning. Whilst ad hoc initiatives are addressing these issues on an issue by issue basis, utilising the regional bodies to coordinate efforts offers a more efficient and cost-effective use of limited resources.

Whilst management of existing resources is fundamental to alleviating freshwater vulnerability in Pacific island countries, several key areas of research may offer opportunities for improving the regional status of water resources and management. These include improvements in rainwater harvesting and storage (considering both traditional and innovative options); management and appropriate technology options for the whole island water cycle, optimising use of rainwater, surface water, groundwater (including brackish resources) and wastewater; assessing the role of desalination in both everyday supply and emergency situations and developing governance and management frameworks that suit the technological solutions and the unique Pacific socio-economic environment.

Finally, the good initiatives originating in many countries need to be recognised and supported, both to build capacity and to develop the most appropriate solutions to many of the problems facing the region. Examples of this are numerous, but include the integration of rainwater, sanitation and groundwater resources management on Nauru and Fongafale to balance the critical freshwater resources, sanitation needs, alternative water sources and protecting vulnerable ecosystems.

Photos credits: Dean Sewell, Marc Overmars ans SOPAC.

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The 14 Pacific Island Countries (PICs) are home to over 9 million people, speaking about 1,200 languages, with the majority (80%) of Pacific islanders living in rural areas. These Pacific Island countries have about 1,000 islands covering a land area of just over half a million square kilometres, spread across 180 million square kilometres of ocean, containing three internationally recognised biodiversity hotspots.This Assessment argues that the greatest vulnerability is reflected in the lack of water resources in low-lying islands, exacerbated by limited human, financial and management resources, and increasing population densities. This new focused analysis for selected islands also concludes that the Pacific island nations' economies, fragile ecosystems and peoples' livelihoods are particularly vulnerable to climate variability and change pressures. Evidence based options are presented to address resource, development, environment and management pressures and to target the reduction of these vulnerabilities.

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