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Vulnerability and adaptation (V&A) assessment for the water sector in Majuro, Republic of the Marshall Islands

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Vulnerability and adaptation (V&A) assessment for the water sector in Majuro, Republic of the Marshall Islands

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This report is an output of the Marshall Islands PACC Project. The assessment was carried out and the report was written by Mark Stege, with guidance from the PACC Project Management Unit. Technical assistance from the Majuro Water and Sewage Company, Marshalls Energy Company, and the PACC Programme Team, most notably Joseph Cain, Taito Nakalevu, Espen Ronneberg and Anne Moorhead, strengthened the report significantly.

The report was reviewed by a team that included Netatua Pelesikoti and Peniamina Leavai (SPREP), Ilisapeci Masivesi (Australian Department of Foreign Affairs and Trade), Gabor Vereczi and Marta Moneo (UNDP), and the coordinators of the PACC water projects.

EXECUTIVE SUMMARY

The Pacific Adaptation to Climate Change (PACC) project in the Republic of the Marshall Islands (RMI) is focusing on water resources management on the main atoll of Majuro. This vulnerability and adaptation (V&A) assessment was carried out to help identify and prioritise adaptation options for investment under the PACC project. It provides a detailed assessment of the Majuro water sector and the vulnerability of the sector to current and projected climate change impacts, and recommends some adaptation responses.

The main source of freshwater for Majuro is the airport catchment, which collects rainwater that is then transferred to reservoirs. However, during times of drought it is necessary to pump water from the underground water lens in Laura to supply the reservoirs. The aim of the PACC project is to build resilience to drought, and reduce reliance on the underground water lens. A 2011 assessment of the water sector in the RMI identified improvement of the airport catchment as a key way to do this. This V&A builds on these findings, and includes recommendations for redesigning and retrofitting the existing water infrastructure so as to better prepare for current climate variability and future climate change risks.

The V&A focuses on four critical water infrastructures located in and around the Majuro airport and the communities of Djarrot, Uliga, Delap (D.U.D.) and Rairok:

1. The airport water catchment and drainage system;
2. The reservoirs and Water Treatment Plant C;
3. The distribution lines from Plant C to Rairok and D.U.D.; and
4. Household rainwater harvesting systems in Rairok and D.U.D.

All four water infrastructures were found to be very highly vulnerable or highly vulnerable to tropical cyclones, storm surges and extreme high tides. The airport catchment area, having low elevation and high exposure, is particularly vulnerable along the length of the runway on both the ocean and lagoon side. The reservoirs were found to be most vulnerable at the pump station and water treatment facilities. Distribution lines were found to be highly vulnerable due to erosion and rising sea level. Household water systems are very highly vulnerable to damage or destruction of roof tops and gutter systems from strong winds during storms.

Based on key selection criteria, stakeholder priorities and expert opinion, the following adaptation responses are proposed:

Option 1: Install liners in reservoirs;

Option 2: Install evaporation covers on the reservoirs;

Option 3: Repair pipes in main and distribution lines;

Option 4: Improve runway air vents efficiency;

Option 5: Expand airport rainwater harvesting;

Option 6: Expand household rainwater harvesting;

Option 7: Expand community rainwater harvesting.

ABBREVIATIONS

AKIA	Amata Kabua International Airport
CSIRO	Commonwealth Scientific and Industrial Research Organisation
D.U.D.	Djarrot, Uliga, and Delap
ENSO	El Niño-Southern Oscillation
ITCZ	Inter Tropical Convergence Zone
JNAP	Joint Disaster Risk Management and Climate Change National Action Plan
MIPA	Marshall Islands Ports Authority
MWSC	Majuro Water and Sewage Company
NCCPF	National Climate Change Framework Policy
OEPPC	Office of Environmental Planning and Policy Coordination
PCCSP	Pacific Climate Change Science Programme
RMI	Republic of the Marshall Islands
V&A	Vulnerability and adaptation [assessment]

1. INTRODUCTION

The PACC programme is the largest climate change adaptation initiative in the Pacific region, with activities in 14 countries and territories. PACC is building a coordinated and integrated approach to the climate change challenge through three main areas of activity: practical demonstrations of adaptation measures; driving the mainstreaming of climate risks into national development planning and activities; and sharing knowledge in order to build adaptive capacity. The goal of the programme is to reduce vulnerability and to increase adaptive capacity to the adverse effects of climate change in three key climate-sensitive development sectors: coastal zone management, food security and food production, and water resources management. The programme began in 2009 and is scheduled to end in December 2014.

The PACC demonstration project in the Republic of the Marshall Islands (RMI) is focusing on water resources management on the main atoll of Majuro (Figure 1). The main source of freshwater for Majuro is the airport catchment, which collects rainwater that is then transferred to reservoirs. During long periods of drought, it is necessary to pump water from the underground water lens in Laura to supply the reservoirs. Over-reliance on the underwater lens can lead to problems such as depletion and saltwater intrusion. The aim of the PACC project is to build resilience to drought, and reduce reliance on the underground water lens.

The vulnerability and adaptation (V&A) assessment was carried out to identify and prioritise options for investment under the PACC project, to achieve the aim of resilience to drought. Building on the results of an earlier V&A assessment (Office of Environmental Planning and Policy Coordination (OEPPC), 2011), this report provides a detailed assessment of the Majuro water sector, and the vulnerability of four critical water infrastructures to projected climate change impacts. This report also provides recommendations for redesigning and retrofitting the existing water infrastructure so as to better prepare for current climate variability and future climate change risks.

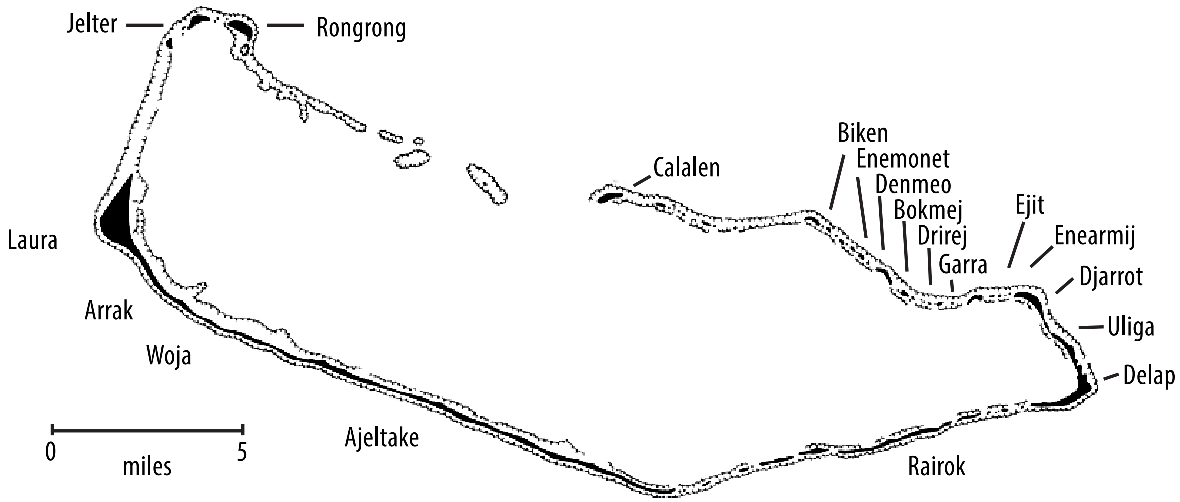


Figure 1. Map of Majuro Atoll (Office of Planning and Statistics, 1989).

The four critical water infrastructures assessed are located in and around the Majuro airport and the communities of Djarrot, Uliga, Delap (D.U.D.) and Rairok, and include:

(1) The airport water catchment and drainage system;

(2) The reservoirs and Water Treatment Plant C;

(3) The distribution lines from Plant C to Rairok and D.U.D.;

(4) Household rainwater harvesting systems in Rairok and D.U.D.

1.1. Methodology

The methodology was adapted from a previous V&A study conducted in 2011 by an eight-member expert team that included the author of this report (OEPPC, 2011). The methodology has three basic elements: an initial baseline assessment, a vulnerability assessment, and identifying adaptation response options.

The initial baseline assessment was done by reviewing available research and data on the water sector in Majuro, from the perspective of social, natural, and built systems components. The baseline assessment also provides an extensive analysis of past climatic data and extreme climate events in Majuro, including climate trends over time and climate drivers, as well as a synopsis of the most recent climate projections available for the Marshall Islands.

The vulnerability assessment included the following:

- Identification of projected climate change threats, as informed by the baseline assessment.
- Field research (including a community vulnerability survey and site visits, with a specific focus on the status of household water infrastructure) and applied expert judgment to assess exposure and sensitivity, and determination of impact of the climate threats, using the matrix shown in Figure 2.
- Assessment of adaptive capacity to these impacts and determination of vulnerability, using the matrix shown in Figure 3. Adaptive capacity includes the range of available adaptation technologies, availability and distribution of financial resources, skills and knowledge, management and response systems, and political will.

Based on this approach, a vulnerability matrix was developed for this V&A report (Appendix 1).

After determining the level of vulnerability for each of the four target water infrastructures to the various climate change threats, the outcomes of the vulnerability assessment are used to draw up a general discussion of adaptation options which were then subject to more detailed cost–benefit analysis (PACC, 2013).

		Exposure of system to climate threat				
		Very Low	Low	Medium	High	Very High
Sensitivity of system to climate threat	Very High	Medium	Medium	High	Very High	Very High
	High	Low	Medium	Medium	High	Very High
	Medium	Low	Medium	Medium	High	Very High
	Low	Low	Low	Medium	Medium	High
	Very Low	Very Low	Low	Low	Medium	High

Figure 2. Matrix used to determine impact (from OEPPC, 2011).

Adaptive Capacity	Impact: **Very Low** Inconvenience (days)	**Low** Short disruption to system function (weeks)	**Medium** Medium term disruption to system function (months)	**High** Long term damage to system property or function (years)	**Very High** Loss of life, livelihood or system integrity
Very Low Very limited institutional capacity and no access to technical or financial resources	Medium	Medium	High	Very High	Very High
Low Limited institutional capacity and limited access to technical and financial resources	Low	Medium	Medium	High	Very High
Medium Growing institutional capacity and access to technical or financial resources	Low	Medium	Medium	High	Very High
High Sound institutional capacity and good access to technical and financial resources	Low	Low	Medium	Medium	High
Very High Exceptional institutional capacity and abundant access to technical and financial resources	Very Low	Low	Low	Medium	High

Figure 3. Matrix for determining vulnerability (from OEPPC, 2011).

2. BASELINE ASSESSMENT

2.1. The Majuro water sector

The Majuro water sector can be considered as a complex of social, natural, and built system components.

2.1.1. Social system

The population of Majuro Atoll, the capitol of the Republic of the Marshall Islands, has increased sevenfold in the last half-century, so that now D.U.D. and to a lesser extent Rairok are densely populated. The combined population currently stands at 27,797, and internal migration trends point towards a continuing increase in the coming years (2011 Census).

The average household size is 7.0 people (2011 Census). According to the Census in 2011, 46.5% of households earn less than $10,000 per year, indicating a lack of financial resources at the household level to cope with the impacts of climate change.

Traditional landowners, local government representatives, school administrators, and church leaders all play a leadership role in the community. Traditional landowners are a particularly important group given that the majority of Majuro's population resides on land under informal tenure arrangements with landowners. Other key issues and trends for social systems related to the water sector include:

- increasing use of household water tanks/catchments as the primary source of drinking water;
- increasing state of disrepair of household water catchment systems; and
- increased water storage capacity in churches and schools.

2.1.2. Natural system

Majuro Atoll is comprised of a ring-shaped reef enclosing a shallow lagoon. The atoll is 40 km long (east–west) and 9.7 km wide (north–south) (Figure 1). The lagoon area is approximately 324 km^2 with an average depth of 45 m. For the most part the land is generally flat, rarely reaching over 3 m in elevation. The beach berms (ridges) composed of storm-deposited reef materials form the highest point in the land mass (Holthus et al., 1992).

In the mid-1940s, all lagoon openings along D.U.D., Rairok, and the current airport location were reclaimed to form the single 50 km strip of land towards Laura that today makes up Majuro island (Figure 4). Further contributing to the island's growth, seawalls have been constructed along over 30% of the Majuro shoreline (McKenzie, 2006). Seawall construction was typically done to extend living space, but today is mostly driven by coastal reclamation projects. One estimate placed the value in loss of use of land due to erosion and coastal reclamations above US$400 million over the past 25 years in Majuro (RMI EPA, 2008).

Figure 4. Lagoon openings in D.U.D. and Rairok were closed in 1944, followed by rapid development. (Photos courtesy of the Marshall Islands Visitors Authority.)

Overall, the eastern half of Majuro – comprising D.U.D and Rairok areas including the airport – has grown by nearly 70 hectares or 40% since 1967 (Table 1). The largest increase in land mass occurred at the airport, allowing development of the runway water catchment.

Table 1. Changes in the shoreline of eastern Majuro between 1967 and 2004 (modified from Ford, 2011).

	Growth (hectares)	Growth (%)
Airport	22.26	67.49
Rairok	19.27	19.79
Delap, Uliga	24.85	72.27
Djarrot (Rita)	1.46	2.91
Total	67.84	40.62

Human activities along the eastern Majuro coastline have disrupted the calcifying organisms that are responsible for Majuro's landmass – corals and foraminifera as well as calcareous algae, molluscs, echinoderms, and others – and shifted the geo-morphological zonation of the entire eastern half of Majuro, so that natural sediment production, transport, and build up along the coastline have been reduced (Sato and Yokoki, 2009; Fujita et al., 2009). Majuro's natural systems have been further stressed by human pollution and coral diseases (Pinca, 2005; Jacobson, 2011), beach mining (McKenzie, 2006), and 'ultra-urbanisation' where trees are cut down to allow for more homes and concrete (RMI Ministry of Resources and Development, 2010).

Human impacts mean that natural marine and terrestrial resources are unable to provide adequate sustenance and food security for communities in these areas. Urbanisation in the D.U.D. and Rairok areas is also leading to high groundwater extraction rates, though exact amounts are unknown, and there have also been instances of surface contamination from private septic tank seepage in Delap (MWSC, 2009).

2.1.3. Built system

RUNWAY CATCHMENT AND DRAINS

Assuming Majuro's average annual rainfall of 130 inches or 3300 mm, the runway has a potential yield of 170 million gallons or 650,000 m^3 (Beca, 2003). It is the largest single freshwater source in the Marshall Islands, supplying over 75% of the water utility's production (Figure 5).

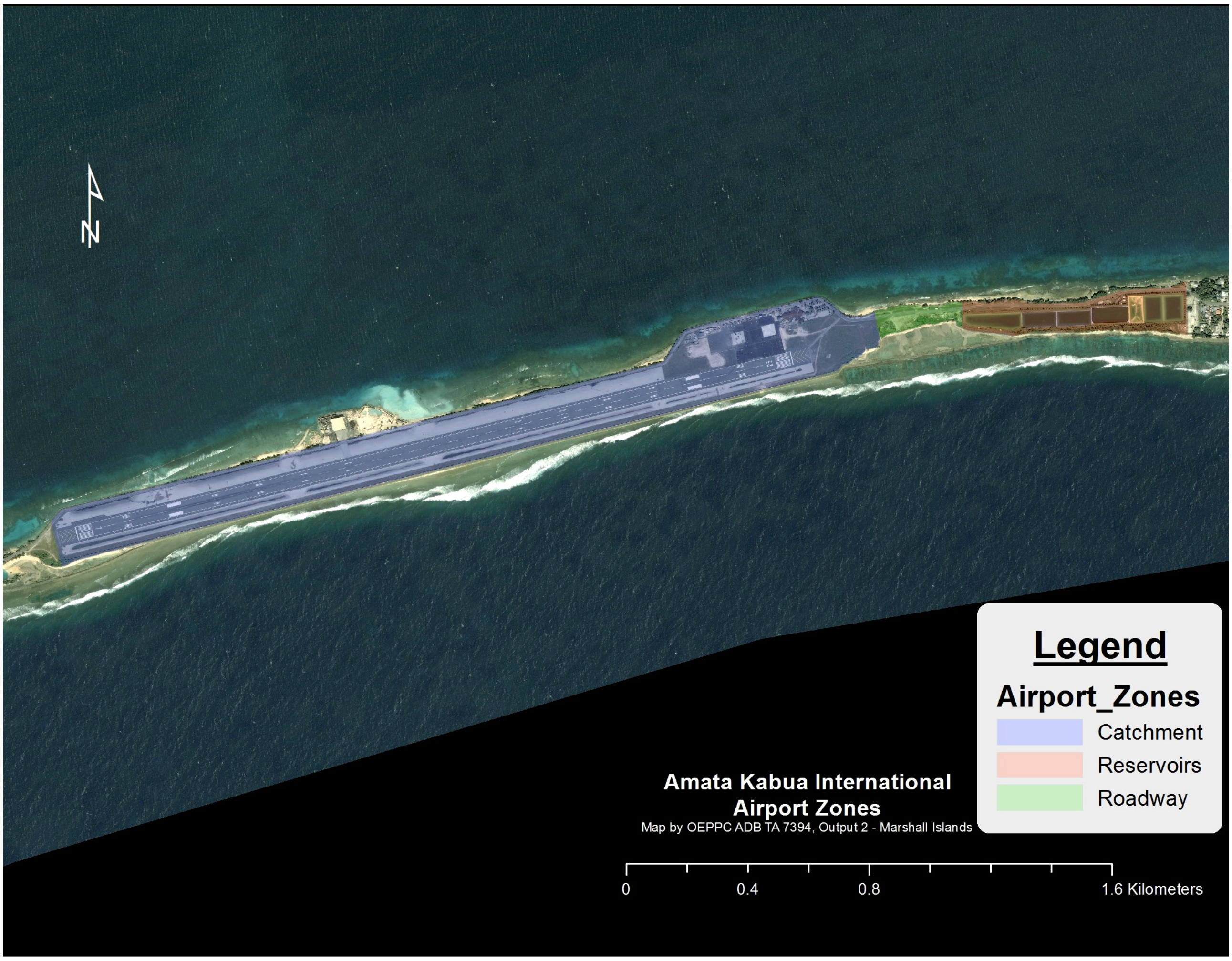


Figure 5. Majuro airport water harvesting and storage system (from OEPPC, 2011).

The airport was constructed in the early 1970s by connecting a number of islets together and filling in reef channels. The runway catchment was built on an exposed reef shelf along the south-facing rim of Majuro atoll. It is constructed of concrete pavement 2,407 m by 106 m. The runway catchment was originally designed at a higher elevation grade and with greater water catchment area, but due to cost considerations it was built at the current levels and surface area. The centre line of the runway is the highest point and sits about 3 m above mean sea level (MSL), from which the runway is grooved laterally for rainwater to drain towards nine depressed zones located along the runway shoulders about 2 m above MSL at the lowest point.

The catchment design includes air vents (Figure 6) along both shoulders of the runway, which allow hydrostatic pressure, generated underneath the airport pavement during high tides, to escape. Recent site observations conducted by Majuro Water and Sewage Company (MWSC) and Amata Kabua International Airport (AKIA) indicate that most air vents are currently operating, though more regular maintenance needs to be prioritised.

There are rainwater collection depressions along the length of both shoulders of the runway. Each depression has a screen-topped sump (Figure 7) and reticulated piping that directs water eastwards under gravity to the next

Figure 6. Air vent.

Figure 7. Screen-topped sump.

sump in the next downstream zone. At each zone the pipe diameter increases from 20 cm to 40 cm to allow for the increased volume of water. Rainwater from the runway catchment moves eastwards to the wet well underneath Pump Station 4.

Pump Station 4 is located on the eastern end of the runway approximately 15 m from the lagoon shore. It comprises four submersible pumps in a concrete building. A wet well is located beneath the pump station. There is a 24 cm cast iron dump line immediately outside the pump station, which during excessive water flows discharges directly into the adjacent lagoon. Otherwise, the water is transported 0.8 km east to the reservoirs.

The water collection system was upgraded in 1997 when four 1,000 gpm pumps were installed. At the time of the assessment there were only two pumps running in the pump station due to mechanical and electrical failure. MWSC in collaboration with Marshall Islands Ports Authority (MIPA) will soon install four new pumps so that larger volumes of water can be transferred during heavy rain. MWSC is also currently instituting a maintenance programme for the water catchment and transmission system.

The runway catchment is protected by armor rock across both ocean and lagoon coastlines. The ocean side is protected by a 20 cm thick, 1.5 m high concrete wall (Figure 8) that was constructed after a 1992 typhoon. After its construction, a 15 m section of the wall was damaged in 1995 due to heavy seas, and subsequently repaired. There is also a 1 m security wall with fencing buffering the catchment on the lagoon side (Figure 9).

Figure 8. Ocean-side concrete wall and armor rock.

Figure 9. Lagoon-side wall on the right. White air vents are also seen to the left.

RESERVOIRS AND WATER TREATMENT PLANT C

When the rainwater reaches Pump Station 4, it is then pumped to a series of six raw water reservoirs with an aggregate storage of 33 million gallons (Figure 10). The water is filtered by two 5.5 m diameter gravity sand filters, injected with chlorine, transferred to a 1,800 gallon capacity clear water vault, and then pumped and stored in a seventh water reservoir with 3.5 million capacity (US Army Corps of Engineers, 2011).

The water reservoirs are constructed of 4 m high earthen berms that are rubber lined and capped with a concrete wall at the top for a total elevation of about 7.5 m above MSL. Armor rock revetment and dense vegetation stabilise the ocean shoreline and act as buffers to minimise salt spray to the water reservoirs.

Four submersible pumps pressurise the reticulation system described below. The pumps, associated electrical circuits and underground vault are housed within a concrete building located approximately 12 m within the lagoon. A saltwater pump house for the sewage system is located immediately on the lagoon foreshore area.

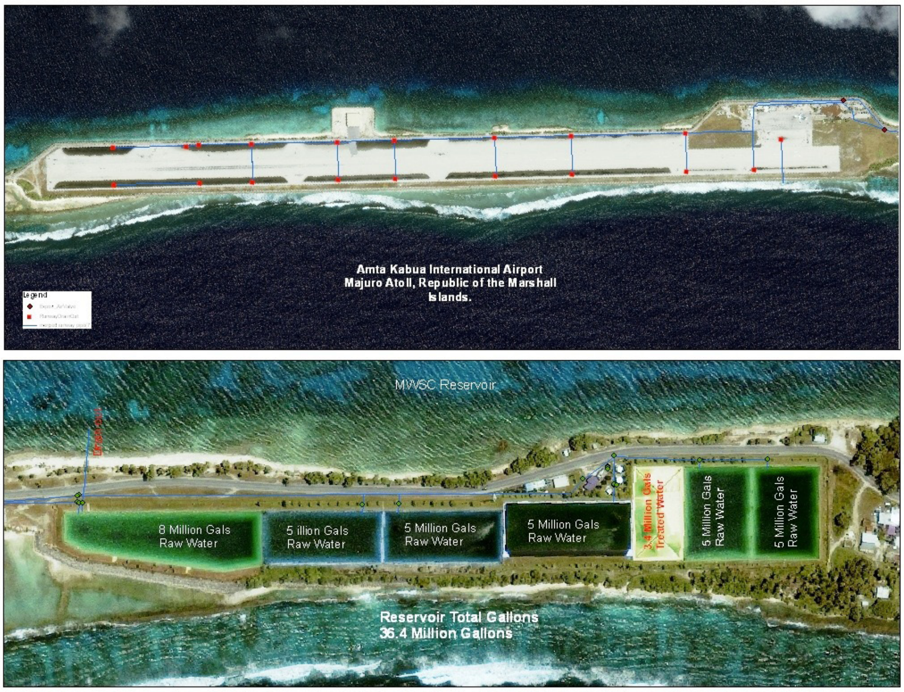


Figure 10. Water Reservoirs and Water Treatment Plant C (photo courtesy of Marshalls Energy Company, MEC).

DISTRIBUTION LINES

The airport reservoirs feed a reticulated distribution system that supplies chlorinated water to residential and commercial subscribers along the eastern half of Majuro (Figure 11). MWSC maintains a limited water supply regime of 1–2.5 days per week, depending on water levels. Water is pumped from the airport reservoirs to eastern Majuro along two underground pipelines, one 25 cm and made of cast iron and the other 30 cm PVC. The first distributes water to households along the eastern half of Majuro including airport facilities, while the second line runs parallel to the main distribution line and can transmit water at five different interconnecting cross valves including the furthest point in Rita where water pressure is weakest. These interconnecting cross valves are contained within 2 m deep chambers that are prone to flooding during heavy rain (ADB, 2004). MWSC has only recently begun installing bulk meters to help detect leaks, but anecdotal evidence suggests as much as a 50% loss (OEPPC, 2011).

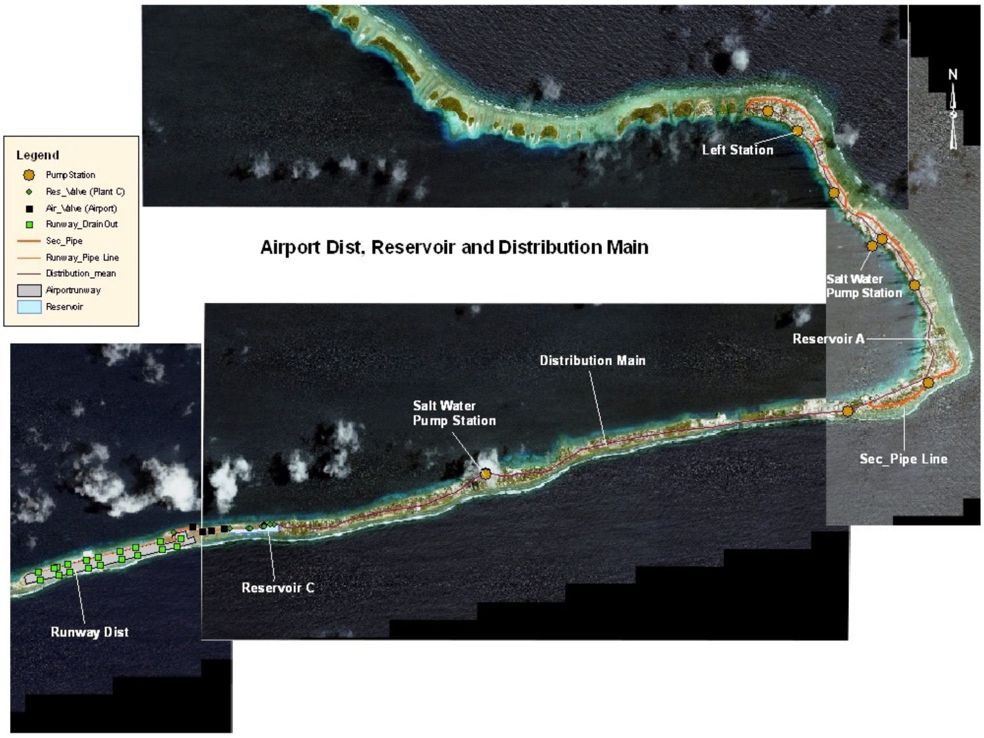


Figure 11. Eastern Majuro public water system (photo courtesy of MEC).

HOUSEHOLD WATER TANKS AND ROOFTOP CATCHMENTS

Nearly 70% of households in D.U.D. and Rairok owned water catchment systems in 2009 (EPPSO, 2009), and this increased to about 80% in 2011 (OEPPC, 2011). The majority of households use their own water tanks and roof catchment systems as the main source of drinking water (EPPSO, 2009). Maintaining these systems is thus of great importance to mitigating the impacts of drought.

Plastic/polyethylene water tanks are the most common type of water tank at 55.1%, followed by concrete tanks at 26.7%, and aluminium and fibreglass accounting for the remaining 18.2%. Whereas only 6.3% of all tanks on Majuro needed repair or replacement in 2009, in 2011 this grew to over 15% (Table 2).

Table 2. Condition of water tanks in Rita (EPPSO, 2009; OEPPC, 2011).

Condition of water tanks	2009 Majuro survey	2011 Rita survey
Working	93.70%	77.98%
Needs repair	4.39%	15.48%
Needs replacing	1.91%	0%
Unknown	0%	6.55%

The 2011 survey, focusing on Rita Village, also found that a growing number of household roofing, gutter, and other system components needed repair or replacement. Specifically, 20% of roofs needed repair and 24% needed replacing (OEPPC, 2011). Assuming 3,000 households in D.U.D. and Rairok altogether, this equates to 600 and 720 households, respectively. Roofing material is predominantly of aluminium sheeting overlaid onto a gable or hip frame. In terms of guttering systems, 25% of households needed repair and 14% replacement, or 750 and 420, respectively (OEPPC, 2011). The vast majority of guttering material is plastic using a half pipe guttering style (OEPPC, 2011).

Some community institutions (i.e. churches and schools) in D.U.D. have large water storage facilities, amounting to an estimated 500,000 gallons. For instance, the Salvation Army facility in Djarrot and Assumption School in Uliga can store 60,000 gallons and 150,000 gallons, respectively. These relatively large water supplies provide important relief to these communities during drought periods (OEPPC, 2011).

Table 3. Church and school water storage capacity in 2011 (OEPPC, 2011).

District	Gallons
Djarrot	155,800
Uliga	224,700
Delap	92,600
Rairok	15,000
TOTAL	488,100

2.2. Climate drivers, past climate, and past extreme events

2.2.1. Climate drivers

The RMI is located just north of the equator in the central Pacific Ocean. Rainfall on the islands mostly reflects seasonal variability of the northeast trade winds. Weaker trades from April to October coincide with greater rainfall in those months, while stronger trade winds from November to March coincide with decreasing rainfall.

Other significant climate drivers affecting the Marshall Islands are the El Niño-Southern Oscillation (ENSO), the Inter Tropical Convergence Zone (ITCZ), trade wind trough, Madden-Julian Oscillation (MJO), the Tropical Upper Tropospheric Trough, and the North Pacific Subtropical High. These features influence rainfall, winds, tropical cyclone or typhoon activity, temperature ranges, ocean currents, sea level and other aspects of Marshall Islands climate (Jacklick et al., 2011).

One recent example of the major influence that these natural climate drivers exert on short-term variations in sea level occurred in September 2011, when a La Niña event coupled with wind-driven sea surface displacement (Merrifeld, 2011) resulted in 10–20 cm higher sea levels than expected on Majuro (M. Ford, personal communication, 2011).

2.2.2. Past climate

PRECIPITATION

A nearly 60-year time series of atmospheric data is available from Majuro Weather Service Office, which shows a 15% decrease in rainfall over the last several decades, from 140 inches to about 130 inches per year (Figure 12). This historic downward trend goes against a number of future climate models for the Pacific region, discussed in the next section.

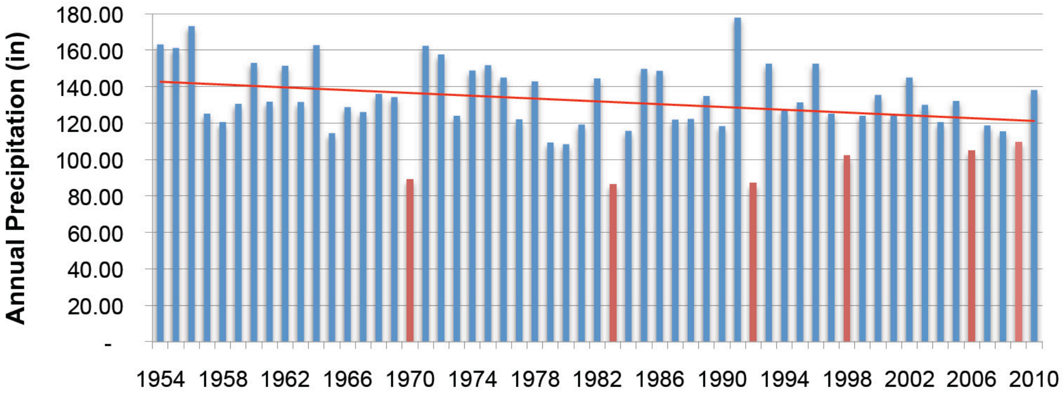


Figure 12. Majuro precipitation record, El Niño years shown in red (Majuro WSO).

El Niño events appear to be increasing in frequency since 1975 (NOAA, 2009), characterised in the Marshall Islands by prolonged drought periods. Droughts are well known on Majuro and recently occurred in 1970, 1982, 1992, 1998, 2006, and 2009[1]. During the drought from late 1997 to early 1998, Majuro received less than 2 inches or 50 mm of rain for four consecutive months. Monthly pumpage from the Laura lens reached a maximum of about 286,000 gallons per day during this period (MWSC, 2005), nearly three times its normal rate. Sanitation efforts were restricted without adequate water, and a number of communities around the Marshall Islands experienced increases in skin diseases (bacterial and fungal/yeast infections) and diarrhoeal diseases during this time (OEPPC, 2011).

In March 1998 the US government declared a severe drought disaster in the Marshall Islands (FEMA, 1998), and Majuro's reliance on the Laura water lens was augmented with reverse osmosis machines donated by Japan and the US. Three difficult months later the drought broke, and household and public reservoir levels returned to normal.

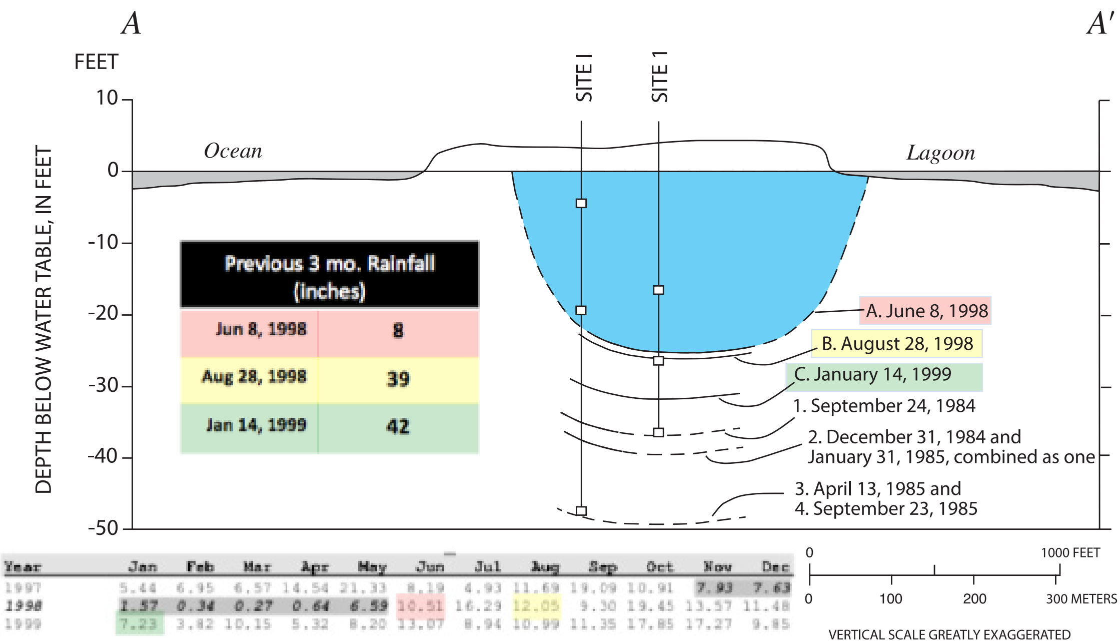


Figure 13. Effects of 1998 drought on Laura feshwater lens (modified from Presley, 2005).

Figure 13 provides time series depth measurements of the Laura lens, color-coded in red (June 1998), yellow (August 1998), and green (January 1999) for ease of reference to corresponding monthly precipitation data. It indicates the Laura water lens took 7 months of average rainfall to recover, i.e. to deepen by 3 meters, following the 1997–1998 drought. Data following an earlier drought in 1983–1984 show a deeper overall status of the Laura freshwater lens and a faster lens recovery rate, consistent with a smaller Majuro population at that time.

1 Although data are only available for a single location on Majuro, this is treated here as an atoll-wide phenomenon.

TEMPERATURE

Temperature data from the Majuro Weather Service Office over nearly 60 years show that inter-annual variability of temperature is quite small, as would be expected given the proximity to the equator (Figure 14). However, over the entire time series there is a noticeable upward trend.

Maximum temperatures have shown an accelerated pace of warming since 1973, and the linear trend since 1973 shows warming of around 1ºC in the 30-year period. The trend in minimum temperature, by contrast, has been increasing more slowly over the same period (Jacklick et al., 2011). Linear trends of +0.14ºC (maximum) and +0.12ºC (minimum) are shown in Figure 14.

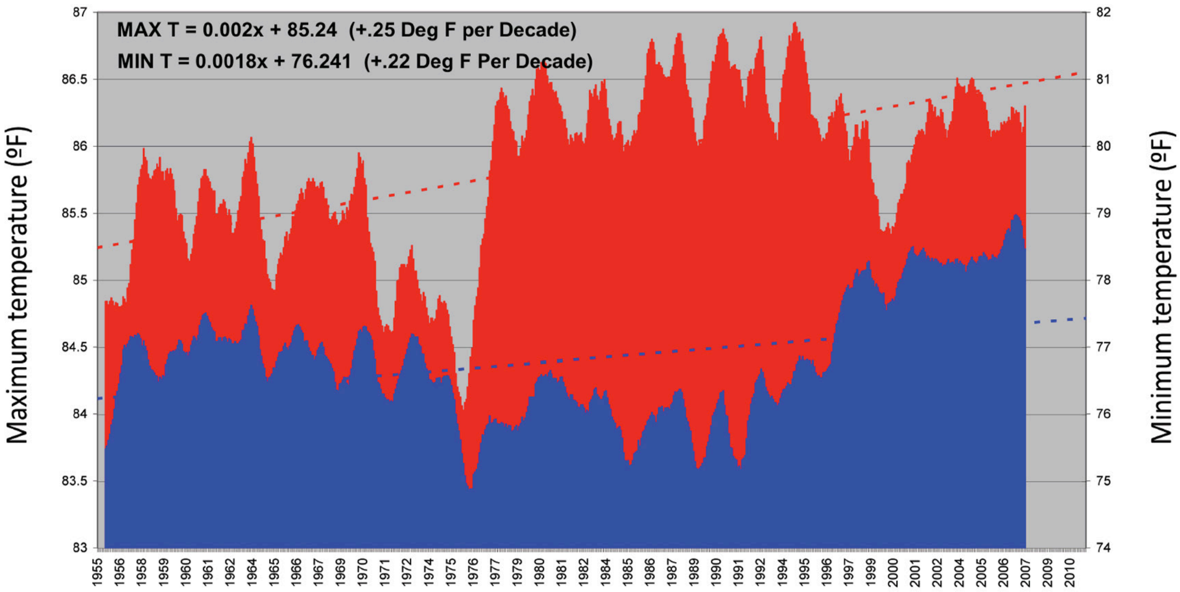
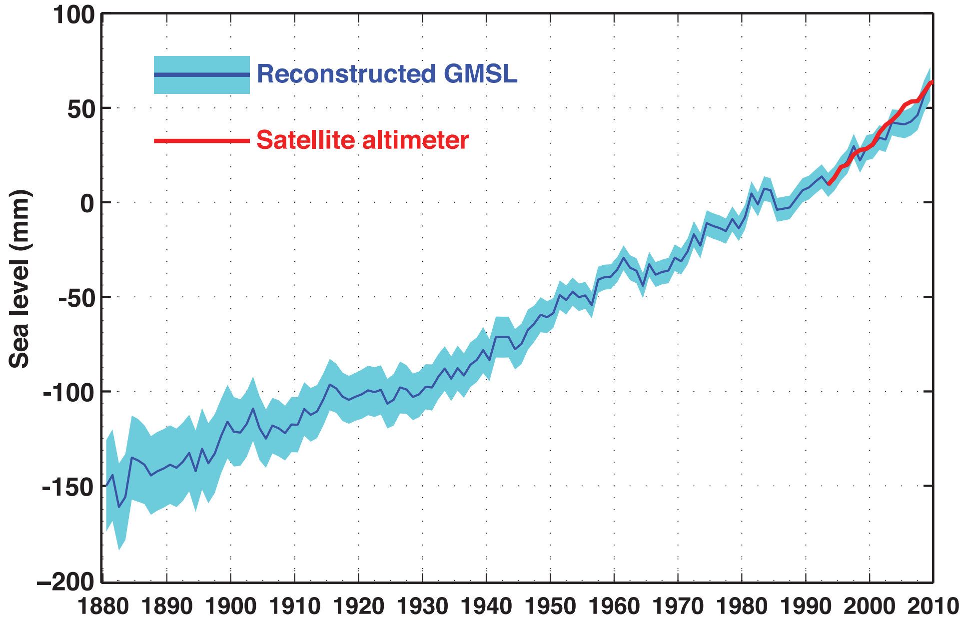


Figure 14. Maximum (red) and minimum (blue) temperature in Majuro 1955–2007 (Jacklick et al., 2011).

SEA LEVEL

In terms of sea level, measurements at the Majuro project site indicate a sea-level rise of 4.0 mm/year since 1993 (SPSLCMP, 2010). This is an insufficient temporal sampling for some purposes but the data are consistent with regional rates of sea level rise (Figure 15, right) and reconstructed global data extending back to 1900, which indicate a sea-level rise of about 1.7 ± 0.2 mm/year (Figure 15, left). Satellite-based observations since 1993 closely mirror this upward trend (Church and White, 2011), also shown in Figure 15, next page.



Location	Lat/Long	Installation Date	Trend (mm/yr)	Change from previous month
Cook Is	21°12’17.1”S / 159º47’5.2”W	Feb 1993	+4.9	0.0
Tonga	21°8’12.5”S / 175°10’50.5”W	Jan 1993	+8.9	-0.1
Fiji	17°36’17.7”S / 177°26’17.7”E°°	Oct 1992	+5.1	-0.1
Vanuatu	17°45’19.2”S / 168°17’27.7”E	Jan 1993	+6.2	-0.1
Samoa	13°49’36.4”S / 171°45’40.7”W°	Feb 1993	+5.1	0.0
Tuvalu	08°30’8.9”S / 179°12’42.6”E	Mar 1993	+3.8	0.0
Kiribati	01°21’54.2”N / 172°55’58.8”E	Dec 1992	+3.2	-0.2
Nauru	0°31’45.9”S / 166°54’36.2”E°	Jul 1993	+4.0	-0.2
Solomon Is.	09°25’44.1”S / 159°57’19.3”E	Jul 1994	+5.9	0.0
PNG	02°02’34.5”S / 147°22’25.6”E	Sep 1994	+6.5	+0.1
FSM	06°58’49.9”N / 158°11’50.8”E	Dec 2001	+14.8	+0.7
Marshall Is.	07°06’21.7”N / 171°22’22.1”E°	May 1993	+4.0	+0.2

Figure 15. Top: global mean sea level and uncertainty 1880–2009 (Church and White, 2011). Bottom: Pacific island short-term sea level rise trends through September 2010 (SEAFRAME, 2010).

Meanwhile, between 1992 and 2001, global sea level rise has been observed to accelerate to about 2.8 mm/year (Church and White, 2006), part of which may be linked to an acceleration of ice sheet mass loss (Velicogna, 2009). If this currently observed acceleration continues, the contribution from polar ice sheets would grow from less than 1 mm/year in the period 2002–2006 to 17 mm/year by the end of the 21st century (Shaeffer and Hare, 2010).

2.2.3. Past extreme events

Extreme events described here include tropical cyclones, storm surges, drought, and extreme high tides. Each extreme event category is elaborated on below. Since 1963, almost 80% of all extreme events have taken place between the months of December and April (USAID, 2008).

TROPICAL CYCLONES

A tropical cyclone (also called a typhoon) is defined as a combination of intensive rainfall, storm surge, high winds and/or king tides that causes extensive flooding. During El Niño years, tropical cyclones have shown a propensity to form over Marshall Islands waters due to the warm water pool migrating into the area coupled with the monsoon surging overhead (Jacklick et al., 2011). Most tropical cyclones pass westward over Marshall Islands waters before increasing in intensity to pose a threat (Figure 16).

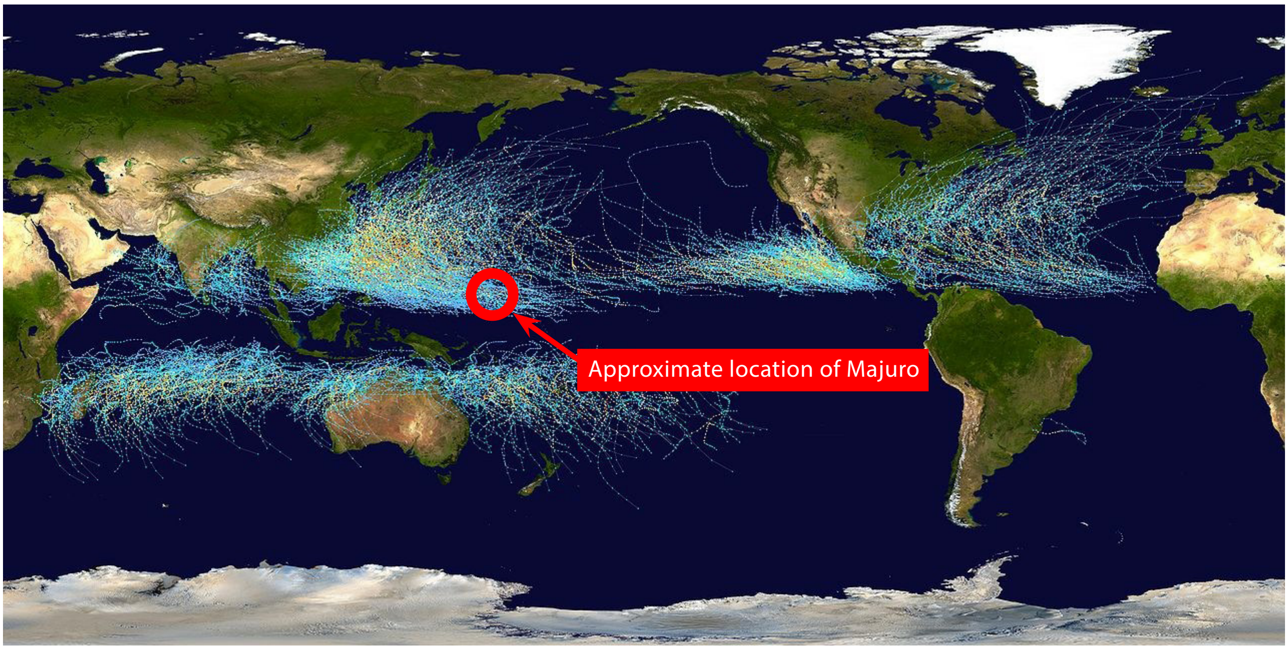


Figure 16. Global tropical cyclone tracks 1985–2005 (image courtesy of Wikipedia).

Two of the most destructive storms on record occurred in 1905 and 1918[2]. Until 1905 there had been a narrow but continuous land connection – like today – between eastern Majuro and western Majuro (Spennemann, 1998). The tropical cyclone of 1905 breached this in two places, and the 1918 tropical cyclone generated a storm surge that washed across the entire southern part of the atoll flooding an area over 32 km in length (Spennemann, 1998). The waves were strong enough to bombard these sections of the island with coral boulders torn loose from the reef's edge. Trees, small vegetation and houses were washed into the lagoon (Spennemann, 2002).

More recently, three tropical storms have passed within 150 nautical miles of Majuro (Holthus et al., 1992). The most recent was in January 1992, which developed and gained force as it approached from the southeast as shown in Figure 17. Lasting three days with peak wind speeds of 65 mph (105 km/h) during the height of the storm, what eventually became Typhoon Axel was significantly less severe than the 1905 and 1918 events, but it occurred recently enough to offer useful insights into future typhoon impact scenarios.

2 Severe storms have occurred in the Marshall Islands in 1905, 1918, 1957, 1979, 1982, and 1992, and less severe storms in 1899, 1988, 2006, and 2008 (Spennemann and Marschner, 1994; Samuel, 2011). Storms that generate south of Majuro have historically been the most destructive (E. Samuel, personal communication, 2011; M. Zedkaiah, personal communication, 2011).

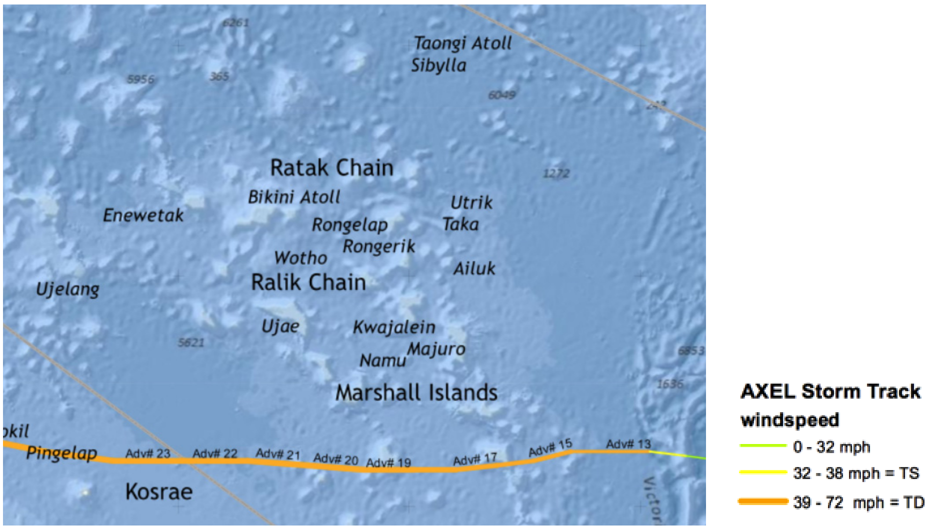


Figure 17. Typhoon Axel storm track (courtesy of Pacific Disaster Center).

All of Majuro was without power during the height of the January 1992 storm (Holthus et al., 1992). The most directly impacted south-facing ocean side, including the airport runway and rainwater catchment area, became inundated with seawater and littered with rocks and debris (R. Reimers, personal communication, 2011).

Because of the importance of the airport for both transport and water sectors, it was prioritised by the RMI government for emergency disaster response. Within three days, the airport runway and water catchment was cleared of debris, and damaged areas patched up. The gravity-fed airport water pump was used to flush accumulated seawater off the runway, thus making the airport water catchment system operational again.

Following the storm, a 1.5 m concrete wall was constructed with funding from the US Federal Aviation Administration along the entire southern side of the airport tarmac. The wall was tested soon after in 1995 when high waves again from the south damaged a 15 m section of the wall (C. Ostwaldt, personal communication, 2011). The wall was patched up soon afterwards and the water catchment system made operational again within a few days. Commercial areas impacted along the project site similarly returned to operating condition soon after the storm. Food trees such as breadfruit recovered more slowly from the high levels of salt spray (Spennemann, 1998) than the salt-tolerant pandanus.

STORM SURGE

Storm surge is defined as wave action that is often linked to high tides and wind-driven sea surface displacement causing flooding. In late November 1979[3] a subtropical high-pressure system formed some 2,000 miles east of the Marshall Islands, creating higher than normal sea level at its perimeter and a swell with a wave amplitude of over 20 feet that inundated large parts of eastern Majuro over several days (Spennemann, 2002).

3 The weather system that generated this November 1979 wave surge was traced back to Typhoon Alice (January of that year), a storm that prompted US federal disaster relief assistance in eight Marshall Islands atolls not including Majuro.

Figure 18. Flooding in Majuro D.U.D. November 1979 (Spenneman, 2002).

In Rita, the wave surge inundated the coastline and entire northern end of the village but did not cross over the middle of the island like in other parts of D.U.D. (E. Samuel, personal communication, 2011; R. Reimers, personal communication, 2011). The depth of flooding or run up onto the island was highest during a number of afternoon high tides (M. Ford, personal communication, 2011; R. Reimers, personal communication, 2011) and the most consistently affected areas of D.U.D. were those that had the least land mass, i.e. parts of Jenrok and Uliga and all former lagoon openings now barred by causeways. Figure 18 is a photo of one such area in D.U.D. These areas were completely inundated from ocean to lagoon, with some cars and houses carried away during the heaviest surges.

Due to the northerly direction of the waves, Majuro airport and other areas on the southern and western parts of the atoll were relatively protected. Those who could find transport were evacuated to these locations. There were reports of minor injuries, but no deaths resulted from the waves (R. Reimers, personal communication, 2011). Property damage on the other hand was significant, with damages to homes resulting in 5,000 people being left homeless (Spennemann, 2002).

Less damaging than the 1979 event, another high wave event occurred in December 2008 due to swells generated in the north Pacific. This particular storm was an unusual low-pressure system that approached the northern Marshall Islands from the west, producing the last storm of a relatively wet and stormy La Niña year. Gale force winds pushed up large swells that, when combined with higher tides typically associated with a La Niña year, caused various points along Majuro Atoll and other islands in Micronesia to be inundated with seawater (Ward, 2009).

About 700 people in Majuro and Arno atolls were displaced from their homes. In Rita, 47 houses of wooden and cement construction suffered structural damage. The airport reservoir system experienced overtopping which disrupted MWSC service for several hours (RMI Ministry of Public Works, 2008). The damage to homes and infrastructure was estimated at US$1.5 million (USAID, 2009).

SEA LEVEL RISE AND EXTREME HIGH TIDES (KING TIDES)

Neither the 1979 or 2008 northerly storms nor the 1992 southerly tropical cyclone coincided with high tidal periods, suggesting that the impact on this densely populated community and the entire island of Majuro could have been more severe if tidal conditions had been different.

In February 2011, Majuro experienced a tidal event during which there were two days of sea levels 6 cm higher than any prior records, and extensive flooding throughout Majuro. This period of higher sea level was partially a result of La Niña overlying a 3–4 mm/year long-term trend of sea level rise (M. Ford, personal communication, 2011). Flooding at the airport was particularly alarming. Seawater breached the newly constructed revetment protecting the Airport Rescue and Fire Facility (ARFF) as shown in Figure 19, ran up onto the adjacent roadway about 3 inches (6 cm) in depth, and backed up the nearby storm drain. The surrounding areas of the runway water catchment surface became contaminated, and other areas along the western half of the 1 m wall buffering the tarmac from the roadway were littered with debris and rocks thrown up by crashing waves.

The raised sea level generated hydrostatic pressure beyond what the runway air vents designed in 1979 were able to accommodate. The resulting damage to the airport pavement surface, shown in Figure 20, has prompted discussion among airport officials about boring for sediment samples of the ruptured areas for the purposes of further study.

During and after the king tides, clean-up crews were prompt and effective in response, notably those from the RMI Airport Authority. The RMI Ministry of Public Works also conducted an assessment of damage caused by the king tide to the airport runway and catchment areas and recommended local patching (R. Sunga, personal communication, 2011). No repairs had been carried out at the time of the assessment, but from the perspective of the transport sector, airport officials were beginning to discuss ways to reduce airport vulnerability to sea level rise exacerbated by storm surge (Lyon Associates, 2011; Chong Gum, 2011).

Figure 19. Flooding airport road, February 2011 (photo courtesy RMIPA).

Figure 20. Hydrostatic pressure damage to the Majuro airport catchment, caused by upwelling during the February 2011 king tide (photo courtesy RMIPA).

2.3. Climate projections

This section draws on analyses conducted for the southern half of the Marshall Islands – which includes Majuro – by the Pacific Climate Change Science Programme (PCCSP)[4] using 18 selected climate models. Using these models, PCCSP has developed climate projections for 2030, 2055, and 2090 time periods under low (B1), medium (A1B), and high (A2) emission scenarios. This baseline report emphasises the A2 emission scenario where applicable, and in line with the PCCSP method calculates these projections of future climate relative to a 1981–2000 baseline.

2.3.1. Precipitation and temperature

The PCCSP projections draw an association between warming air temperatures and higher rates of rainfall for the remainder of the 21st century. In summary, all climate models predict warming temperatures and increasing rainfall but disagree in terms of magnitude. The multi-model mean is shown in Figure 21.

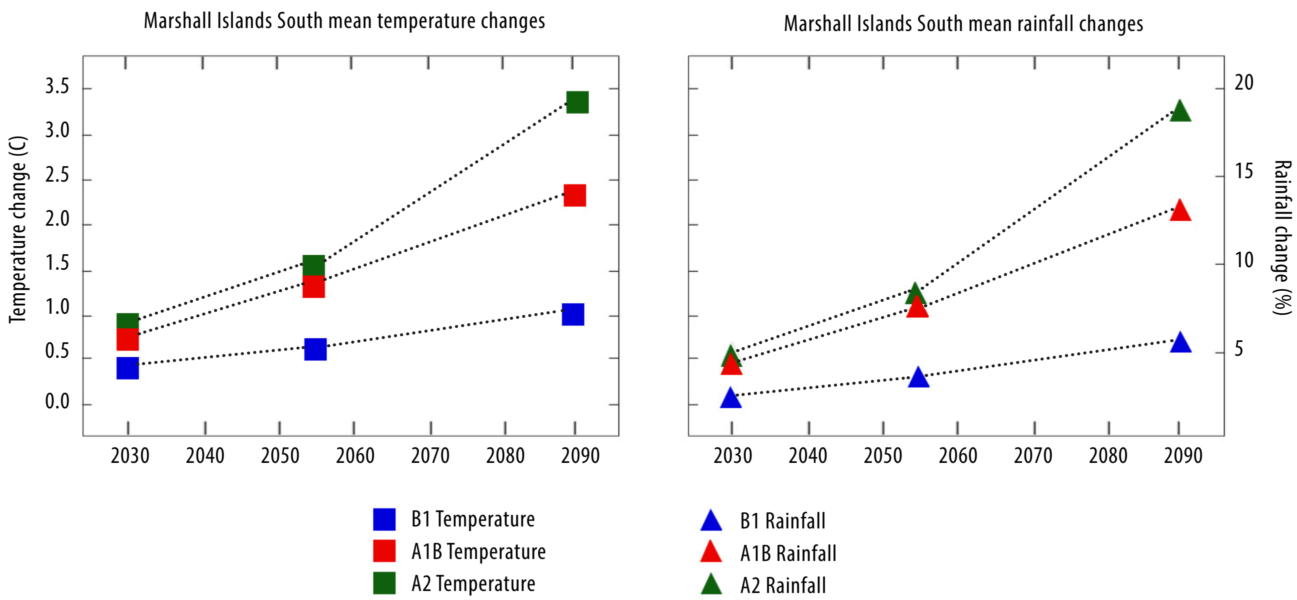


Figure 21. Mean (18 model) temperature and rainfall changes relative to 1981–2000 (PCCSP, 2011).

In terms of temperature increases, the Marshall Islands worst case scenario is 1.2°C by 2030, 2.2°C by 2055, and 4.9°C by 2090 (Table 4). Note the projected ranges and standard deviation from mean, indicating increasing uncertainty as the calculations advance in timescale. Rainfall calculations have a similar upward trend moving towards later timescales, with an annual mean change of 4.8%, 8.3%, and 18.8% by 2030, 2055, and 2090, respectively (Table 5).

Table 4. Projected annual temperature changes (PCCSP, 2011).

Date	Range	Mean	St. Dev
2030	0.6–1.2	0.8	0.2
2055	1.1–2.2	1.5	0.3
2090	2.5–4.9	3.4	0.6

4 http://www.pacificclimatechangescience.org/

Table 5. Projected annual changes in rainfall (PCCSP, 2011).

Date	Increase in rainfall
2030	4.8%
2055	8.3%
2090	18.8%

Most of the 18 PCCSP climate models calculate 'wetter to much wetter' conditions by 2090, with only one of the models projecting 'much wetter' conditions as early as 2030. Interestingly, none of the models projects drier conditions, contrary to historic 50-year trends which indicate a 1% annual mean decrease in rainfall (Jacklick et al., 2011). This could be due to anomalous trends in historic rainfall for Majuro (NOAA, 2011) or unknown drivers missing within the PCCSP calculations. The PCCSP projections do not include projections of drought, though projections of extreme events in general indicate increasing extreme event intensity, which would include increasingly intensive (i.e. prolonged) drought periods.

2.3.2. Sea level rise

Sea level rise is expected with 'very high confidence' to cause the low-lying ecosystems and the communities who rely on them to increasingly experience adverse impacts such as submergence, coastal flooding, and coastal erosion throughout the 21st century and beyond (IPCC, 2014). The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has developed sea level projections for the Marshall Islands as part of the PCCSP work for country reports. The projections for the Marshall Islands are for 2030, 2055 and 2090 under the B1, A1B and A2 emission scenarios. Projections are 3–16 cm by 2030, 11–30 cm by 2055, and 22–62 cm by 2090 (Australian Bureau of Meteorology, 2011).

The most recent estimates for total *global* sea level rise show an expected rise of about 10 mm/year by 2050 and 2100 (Jevrejeva et al., 2010; Vermeer and Rahmstorf, 2009). For the Vermer and Rahmstorf projections, the average rate over the 21st century is in the range of 8–18 mm/year, with higher rates in the latter half of the century. If the currently observed acceleration continues, the contribution from polar ice sheets would grow from less than 1 mm/year in the period 2002–2006, to 17 mm/year by the end of the 21st century (Shaeffer and Hare, 2010).

Sea level projections are not being developed for dates earlier than 2030, however earlier changes in sea level are critically relevant for adaptation planning in the Marshall Islands. A rise in sea level of even 0.1 m would threaten the suitability for human habitation and infrastructure in some near-shore areas at the project sites, especially in terms of land use and underground freshwater resources (RMI, 2011). It is clear that the Marshall Islands faces major impacts and that nearly all of the uncertainties operate towards higher rather than lower estimates (RMI, 2011; Steffen, 2009).

2.3.3. Extreme weather

There is presently no clear view on future extreme climate events for the Marshall Islands, such as tropical cyclones and storm surges. Some leading researchers in the region suggest fewer and more intense typhoons in the southern Pacific and fewer tropical cyclones of unknown intensity in the northern Pacific (CSIRO, 2011). Others predict greater intensity of tropical cyclones driven by rising ocean temperatures (Elsner et al., 2008). Whatever the case, it is reasonable to anticipate greater frequency of flooding during extreme weather events due to elevated sea levels.

3. VULNERABILITY ASSESSMENT

This section considers the vulnerability to future climate threats of the four key infrastructures, i.e. (1) the runway catchment and drains; (2) the reservoirs and water treatment plant; (3) the distribution lines; and (4) the household water tanks and catchments. The assessment includes consideration of exposure and sensitivity for each of the assets, and based on this, the level of impact was deduced through expert assessment. The rating of adaptive capacity of the assets is based on consultation and expert assessment. The results are given in the matrix in Appendix 1.

Considering climate drivers, past climate trends, past extreme events, and climate projections described in the baseline assessment, future climate threats of concern to the Majuro water sector may include: increased incidence of flooding due to tropical cyclones and storm surges; decreased incidence but greater intensity of drought; a progressive increase in temperature including sea surface temperature; and sea level rise.

Future threats should also take into consideration relevant non-climate factors, such as social and demographic trends. Some of these non-climate stressors, such as pollution and overpopulation, are likely to compound the climate-related threats.

3.1. Runway catchment and drains

The airport catchment area and subsurface water reticulation pipes were found to be very highly vulnerable to saltwater intrusion during tropical cyclones, and highly vulnerable to storm surges and extreme high tides. Saltwater intrusion may occur from waves overtopping the coastal reef zone which in turn generates salt spray from wave action affecting large areas of the water catchment. Saltwater is seen to also upwell from below the catchment surface. The most vulnerable areas were found to be along the length of the runway on both the ocean and lagoon side. Hydrostatic pressure generated underneath the airport pavement during high tides is designed to escape through air vents located along both shoulders of the runway; however some sections of the paved concrete surface have ruptured with water upwelling from below the surface during recent extreme high tides.

The airport catchment was also found to be highly vulnerable to potential degradation of the pavement from temperature increases, i.e. bitumen may leach into the surrounding environment. The lack of regular maintenance of the water supply and drainage systems increases the vulnerability of the airport catchment. The water authority with jurisdiction over the water catchment has limited access to the catchment due to airport safety regulations, and lacks resources, reducing the adaptive capacity of this asset.

Pump Station 4 was found to be very highly vulnerable to saltwater intrusion during northerly tropical cyclones, storm surges and extreme high tides. Specifically, the raw water-holding tank can become inundated with seawater seeping through the pump station entrance. There is also the potential for flooding of electrical boards which sit about 0.5 m above ground level.

The pump station transfers raw water from the catchment to the raw water reservoir. Excess flow of raw water from the catchment discharges directly into the nearby inner lagoon via a 25 cm cast iron pipe line (or dump line). The pump station is also vulnerable due to its location near the foreshore where, during periods of high tide and high waves, saltwater contamination of the holding tank can occur, especially when the dump line outfall backflows with saltwater. This occurs because of the low level of the dump line. The use of the dump pipe is restricted for several hours at a time when backflow occurs. This threat impacts on both the quality of the raw water (through saltwater contamination) in the holding tank and the raw water being transferred to the raw water reservoir (OEPPC, 2011).

3.2. Reservoirs and Water Treatment Plant C

Along both ocean- and lagoon-facing sides of the reservoirs, the elevation (about 7.5 m above MSL) and the surrounding vegetation protect this vital water structure from significant climate impact. The reservoirs may be more affected by rising evaporation rates as global atmospheric temperatures increase. The current evaporation rate estimates for Majuro vary between 12.5% and 20% (Beca, 2003; MWSC, 2011). However, evaporation losses are considered of lesser significance compared to other system losses, e.g. leakages in the water reticulation system (MWSC, 2011).

By comparison, the nearby pump station and water treatment facilities located at ground level face severe climate impacts. Similar to Pump Station 4, the pump and treatment facilities at Plant C were found to be very highly or highly vulnerable to saltwater intrusion during northerly tropical cyclones, storm surges and extreme high tides. Specifically, the 1,800 gallon capacity clear water vault can become inundated with seawater seeping through the pump station entrance. There is also the potential for flooding of electrical boards which sit about 0.5 m above ground level.

3.3. Distribution lines

The distribution lines from the airport catchment to Rairok and D.U.D. households were found to be highly vulnerable to tropical cyclones, storm surges and sea level rise. Despite low sensitivity to contact with water, salt or otherwise, scouring of the aboveground roadway and loss of landmass along the lagoon foreshore would expose the underground services lines (i.e. water, telecommunications, electricity) to potential disruption and damage. This has already occurred at one section of the Majuro roadway near the airport (Figure 22).

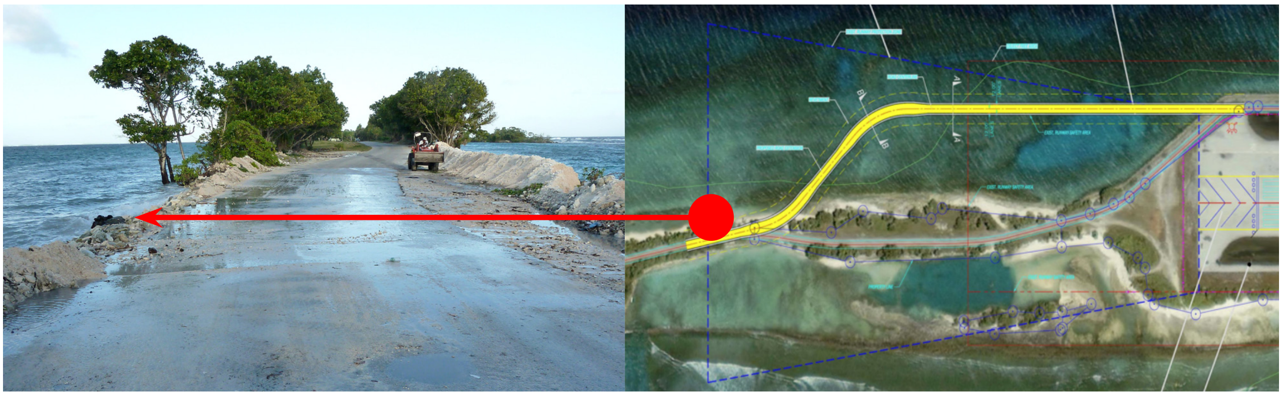


Figure 22. Erosion at airport road realignment project (images courtesy Murray Ford and MIPA).

System losses due to non-climate stressors such as leaks and theft are also serious concerns in that they are a significant constraint to the efficient operation of the water system during periods of drought. No direct impact from drought or temperature increase is perceived.

3.4. Household water tanks and rooftop catchments

Deteriorating conditions of household water catchment systems were highlighted in the 2011 Rita Community Vulnerability Survey (OEPPC, 2011), where it was found that a growing number of tanks and other water catchment system components needed repair or replacement relative to the 2009 Household Water Survey (EPPSO, 2009). Deteriorated conditions of tanks and roof catchments lower operational efficiencies of the rainwater harvesting systems and increase sensitivity of all communities on Majuro to drought.

Household water systems are very highly vulnerable to damage or destruction of roof tops and gutter systems from strong winds during storms. Tanks are likely to fill with water which will make them more stable, but there is potential for damage to the tank foundations from storm surge and high waves, especially for households within 30 m of lagoon-side and ocean-side shorelines. According to the 2011 Rita Community Vulnerability Survey, virtually every household on the ocean and lagoon sides that was affected by the 1979 and 2008 storm surges had their water supply adversely impacted (OEPPC, 2011).

In term of threats from sea level rise, tanks located in low elevation areas may experience destabilisation of foundations from seawater upwelling. Concrete exposed twice a day to salt water (i.e. by tides) will also gradually crack from progressive surface weathering, commonly known as salt attack. Overall vulnerability is considered to be high (OEPPC, 2011).

In terms of threats from drought, dry conditions may cause cracking of cement tanks and foundations, however vulnerability of the physical structure of household rainwater harvesting systems is considered to be low. Threats from increased temperature are also low, as the water tanks are mostly made from polyurethane rated UV-20, meaning they can withstand temperatures up to 65°C before deforming, well above the projected increase of 31–34°C for the Marshall Islands. Concrete tanks that are properly lined or sealed would also not be affected, and so vulnerability is again considered to be low (OEPPC, 2011).

4. ADAPTATION OPTIONS

After completing the vulnerability analysis, the next step is to develop adaptation responses. Opportunities for adaptation responses may exist in natural, built, social, economic, and sector-specific systems, for example:

- Engineering options (e.g. community and household water tanks, sea walls and drainage systems);
- Traditional local strategies (e.g. windward forests and selection of crops);
- Social responses (e.g. resettlement and migration);
- Land use planning (e.g. zoning and development controls);
- Economic instruments (e.g. subsidies and tax incentives);
- Natural systems management (e.g. rehabilitation, conservation, watershed management);
- Sector-specific adaptation practices (e.g. agriculture – salt-tolerant taro species, cropping patterns, etc.);
- Associated institutional options (e.g. institutional reform, administrative innovations and capacity building) which can further support these adaptation responses and ensure their success.

In identifying possible adaptation options, the following selection criteria were considered:

- Supported by government through government policy, i.e. the National Climate Change Framework Policy (NCCPF) and the emerging National Water and Sanitation Policy, or through Government strategies and plans, i.e. the emerging Joint Disaster Risk Management and Climate Change National Action Plan (JNAP);
- Effectiveness in addressing the impacts of climate change;
- Urgency of action in addressing the impact;
- Community support;
- Available resources for implementation; and
- Commitment or interest from Government and development partners.

Guided by the selection criteria, key stakeholder priorities as expressed through the PACC Programme Management Unit (PMU), expert opinion including that of the PACC cost–benefit analysis (CBA) consultant and MWSC senior advisors and management, and additional guidance from SPREP Climate Change Division, the following adaptation responses are proposed:

Option 1: Install liners in reservoirs;

Option 2: Install evaporation covers on the reservoirs;

Option 3: Repair pipes in main and distribution lines;

Option 4: Improve runway air vents efficiency;

Option 5: Expand airport rainwater harvesting;

Option 6: Expand household rainwater harvesting;

Option 7: Expand community rainwater harvesting.

Each adaptation option aims to address operational inefficiencies in the present freshwater system to effect a reduction in reliance on the underground water lens in Laura during times of drought, thus benefiting all areas of Majuro and the water sector, directly and indirectly.

This V&A report has examined four key water infrastructure at the utilities and household levels, and recommended interventions that will increase the resilience of the Majuro water sector overall to climate impacts. The next stage is to assess the seven options using cost–benefit analysis to decide on which options to prioritise (PACC, 2013).

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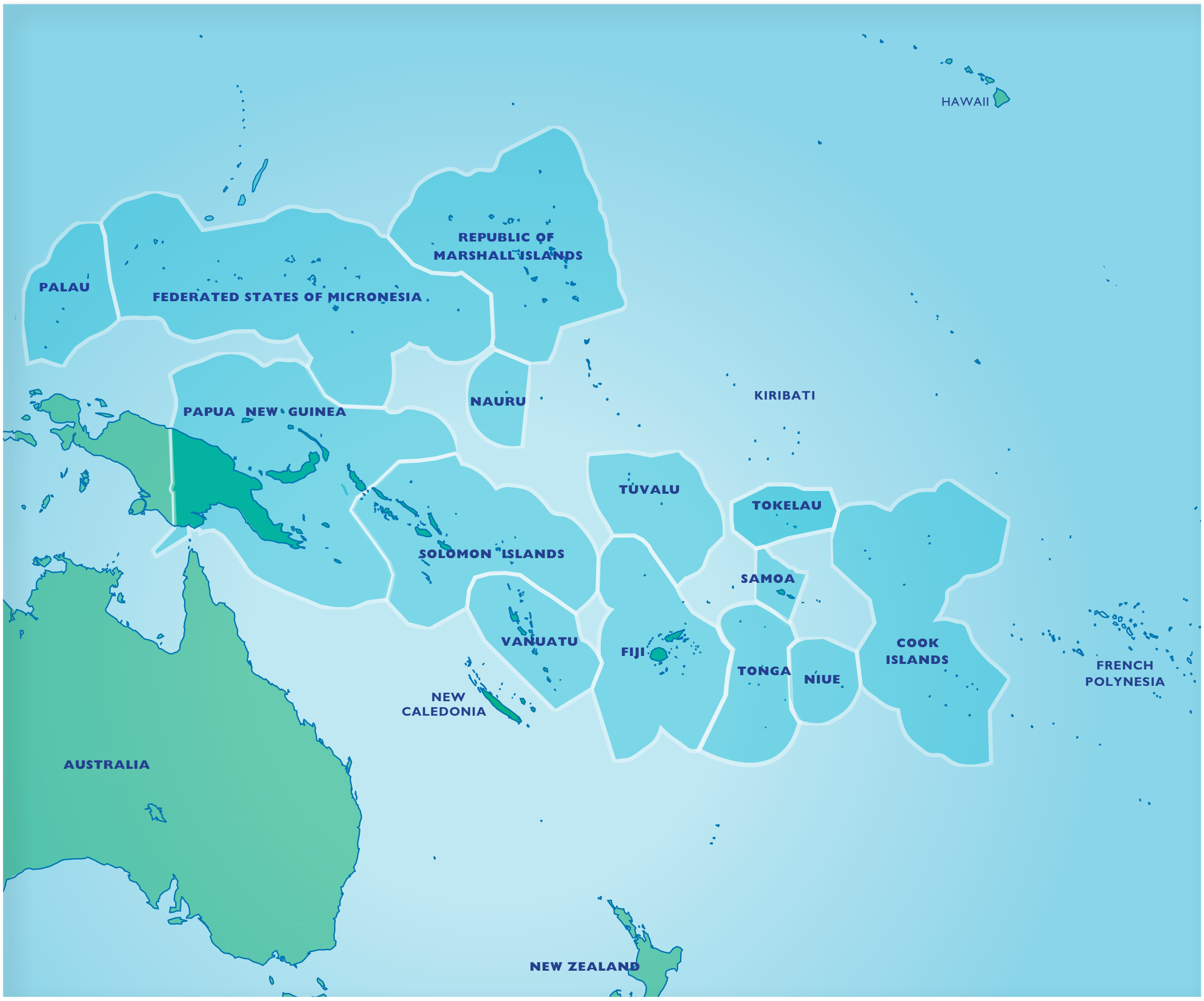
APPENDIX 1. VULNERABILITY MATRIX RESULTS

System Component or assets	Threat	Exposure	Sensitivity	Impact level (expert assessment of exposure and sensitivity)	Impact summary	Adaptive capacity (consultation/ expert assessment)	Vulnerability (impact and adaptive capacity)
Runway catchment and drains	Tropical cyclone	Very High	Very High	Very High	Water catchment not able to supply fresh water. Drainage system blocked by debris. Rupture and failure of the pavement. Overtopping contaminating water source.	Low (1)	Very High
	Storm surge (2008)	High	High	High	Drainage system blocked by debris. Rupture and failure of the pavement.	Medium	High
	Extreme drought	–	–	–	No significant impact	–	–
	Increased temperature	High	High	High	Potential for degradation of the pavement. Bitumen may leach into the water supply.	Medium	High
	Sea level rise (2030)	High	High	High	Saline water upwelling caused by high sea water levels will increase inundation of airport pavement both through the substrate and via the drainage system. This will also cause pavement rupture and flooding.	Low	High
Reservoirs and water treatment plant	Tropical cyclone	Very High	Very High (2)	Very High	Flooding of the pump station, inundation of pre-treatment chamber, potential for flooding electrical boards.	Low (3)	Very High
	Storm surge (2008)	High	High	High	Flooding of the pump station, inundation of pre-treatment chamber, potential for flooding electrical boards.	Low	High
	Extreme drought	High	High	High	Drought will not directly affect the pumps, but they will not be able to function if the reservoirs are empty	High (4)	High
	Increased temperature	Low	Low	Low	Potential for overheating of pumps and electrical equipment which could degrade them over time.	High	Low
	Sea level rise (2030)	Very High	High	Very High	During king tides, potential for flooding of the pump station, inundation of pre-treatment chamber. February 2011 king tide almost reached the plant.	Low	Very High

System Component or assets	Threat	Exposure	Sensitivity	Impact level (expert assessment of exposure and sensitivity)	Impact summary	Adaptive capacity (consultation/ expert assessment)	Vulnerability (impact and adaptive capacity)
Distribution lines from Plant C to households	Tropical cyclone	High	High (5)	High	Erosion of the coastline leading to less land to sustain the land area containing the distribution lines	Medium (6)	High
	Storm surge (2008)	High	High (5)	High	Already very thin strip of land. Northerly swells and king tides erode the coastline leading to even less land to sustain the distribution lines	Medium (6)	High
	Extreme drought	–	–	–	No significant impact	–	–
	Increased temperature	–	–	–	No significant impact	–	–
	Sea level rise (2030)	High	High (5)	High	Increased frequency of inundation of asset. Water upwelling caused by high sea water levels may cause loss of land area to sustain the asset.	Medium (8)	High
Household and community water tanks/roof catchments (7)	Tropical cyclone	Very High	Very High	Very High	Damage/destruction to roof tops and gutter systems. Tanks likely to fill with water which will make them more stable but there is very high potential for damage to the foundations.	Low	Very High
	Storm surge (2008)	Low	Medium	Medium	Tank foundations may be compromised by saltwater inundation. Rooftops and gutters out of harm's way.	Low	Medium
	Extreme drought	High	High	High	Dry conditions may cause cracking of cement tanks and foundations.	Low	High
	Increased temperature	Low	Low	Low	Plastic tanks would not be affected by 2–4 degrees increase in temperature. Concrete tanks that are properly lined or sealed would not be affected.	Low	Low
	Sea level rise (2030)	High	High (8)	High	Tank foundations may be compromised by saltwater inundation. Rooftops and gutters out of harm's way. Houses with sea walls not impacted. Concrete exposed to salt water will also gradually crack and leach cement.	Low	High

NOTES

1. FAA sees its function as a transport provider. The water authority is responsible for the water supply components of the airport. In practice this leads to uncertainty over who is responsible for maintenance and repair of the water catchment and drainage.
2. This assumes that the extreme event brings saltwater flooding into the pump station.
3. There is no emergency management plan for the water treatment system that is under use.
4. High assumes that the plant will be able to be operational quickly once the reservoirs are full again. Alternatively the function of the pump station will be inhibited if there is continual drought, this will only be overcome if there is more water in the reservoirs or losses are less.
5. Pipe material doesn't degrade when in contact with salt water, however loss of landmass can undermine structural integrity.
6. Medium based on demonstrated response capability of Ministry of Public Works at one section of the Majuro roadway near the airport which is already eroding.
7. Assume closed water tank system, not open.
8. High based on being within 30m of existing shoreline, with seawalls of variable height and structural integrity.



PACC – building adaptation capacity in 14 Pacific island countries and territories

PACIFIC ADAPTATION TO CLIMATE CHANGE (PACC) PROGRAMME

The PACC programme is the largest climate change adaptation initiative in the Pacific region, with activities in 14 countries and territories. PACC is building a coordinated and integrated approach to the climate change challenge through three main areas of activity: practical demonstrations of adaptation measures, driving the mainstreaming of climate risks into national development planning and activities, and sharing knowledge in order to build adaptive capacity. The goal of the programme is to reduce vulnerability and to increase adaptive capacity to the adverse effects of climate change in three key climate-sensitive development sectors: coastal zone management, food security and food production, and water resources management. PACC began in 2009 and is scheduled to end in December 2014.

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The PACC Technical Report series is a collection of the technical knowledge generated by the various PACC activities at both national and regional level. The reports are aimed at climate change adaptation practitioners in the Pacific region and beyond, with the intention of sharing experiences and lessons learned from the diverse components of the PACC programme. The technical knowledge is also feeding into and informing policy processes within the region.

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