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WATER CHALLANGES IN THE MARSHALL ISLANDS

Managing drought in a high rainfall Atoll country

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ABSTRACT

This paper addresses water security for the Republic of the Marshall Islands (RMI), a remote island country in the North Pacific. The paper looks at the range of conditions across the country, including population distribution, rainfall variability, water resources and community attitudes. The paper concludes that high rainfall alone does not mean security of water supply and discusses key factors to ensure the impacts of future droughts are minimised.

INTRODUCTION

It is hard to believe that when a community receives in excess of 3000mm/year of rain (almost five times Melbourne's average annual rainfall) that water could be so precious. It is in the Marshall Islands.

The Republic of the Marshall Islands (RMI) comprises a series of 29 coral atolls and five islands in the Pacific just north of the equator *(CIA, 2017)*. Go to Google Earth and zoom. Zoom again and a lot of tiny dots will appear. This is RMI (Figures 1 and 2), a rectangular area extending 1150 km north south and 1300 km east-west, about 4100 km from Sydney and 3200 km from Honolulu.

The 1225 islands of the Marshall Islands have a combined land area of 181 km2 scattered over an area of almost 2000 km2. Twenty-four of the 34 coral islands and atolls are inhabited.

This tiny republic of some 53,000 inhabitants has major water supply challenges, particularly on the two main islands, Majuro (28,000 people in 970 ha at 6.8 people per household) and Ebeye, (10,000 people in 40 ha at 8.4 people per household).

Rainfall varies from as much as 4000 mm per year in the south to less than 1200 mm per year in the north.

WATER RESOURCES AND SUPPLY ACROSS THE MARSHALL ISLANDS

Water resources and supply vary widely across the Marshall Islands. The discussion has been broken into three groups:

- Majuro – country capital, highly urbanised, approximately 28,000 people
- Ebeye – highly urbanised, approximately 10,000 people
- Outer Islands – traditional living, populations from a few hundred to 1800 across 22 atolls

The discussion in this paper will focus primarily on drought management for Majuro, with brief discussions on Ebeye and the outer islands to demonstrate the diversity of approaches.

MAJURO

A location plan for Majuro is presented in Figure 3. The several islands from Laura to Darrit (Rita) that form Majuro island have been interconnected by causeways to form a continuous land mass. Total length from Laura to Rita is approximately 50 km. Approximately 24,000 of the total Majuro population of 28,000 live in the area from the airport to Darrit (Rita).

Majuro's average annual rainfall is 3237 mm, distributed monthly as shown in Figure 4. Although rainfall is relatively high each month, there is a distinctly drier period from January to March. This pattern is more pronounced when extreme dry conditions prevail and the dry extends through April as shown in Figure 5 for the most severe droughts on record.

Majuro Water and Sewer Company (MWSC) is the State-Owned Enterprise (SOE) with responsibility for water supply to Majuro island.

Figures 1 and 2. Locality Plan and Atoll Plan, Republic of Marshall Islands

The water supply system is relatively complex, with multiple sources and treatment plants. A schematic of the water supply system is presented in Figure 6.

Majuro's water supply comprises three sources for public purposes, along with individual household rainwater harvesting. These sources are:

Airport System – 30 Ha airport catchment discharging to seven above ground reservoirs of 130 ML storage volume, providing non-potable water from the airport to the Darrit (Rita) end of the island. Water is pumped to customers for four hours five days per week (supply was as little as two days per week prior to 2016). The airport reservoirs are shown in Figure 7.

Laura groundwater lens - servicing the Laura end of the island with non-potable water via six wells and with a connection to the airport reservoirs to supplement the airport system as needed. Water is pumped for eight hours five days per week. The lens has a safe yield in the order of 400 ML/year.

Hospital System - Roof runoff from the hospital and capital building complex, along with extraction from the Delap groundwater lens, discharging to Water Treatment Plant A (WTP A). WTP A is small, with a capacity in the order of 150,000 Lpd and is dedicated to potable water supply to the hospital and the capital building complex.

Only about 25 percent of residential properties are connected to MWSC's piped water supply system, primarily because of a low level of service and affordability of MWSC water, along with the prevalence of household rainwater harvesting.

The water discharged from WTP C is potable with chlorine residual as high as 4 mg/L. Because of intermittent supply, poor pipeline condition and lack of chlorine booster stations along the 15 km distribution mains the chlorine residual is quickly depleted and the water is not suitable for drinking. EPA conducts regular bacteriological and Free Available Chlorine (FAC) tests at eight sites along the mains. The normal failure rate is in the order of 40% of samples.

Figure 3. Majuro Location Plan

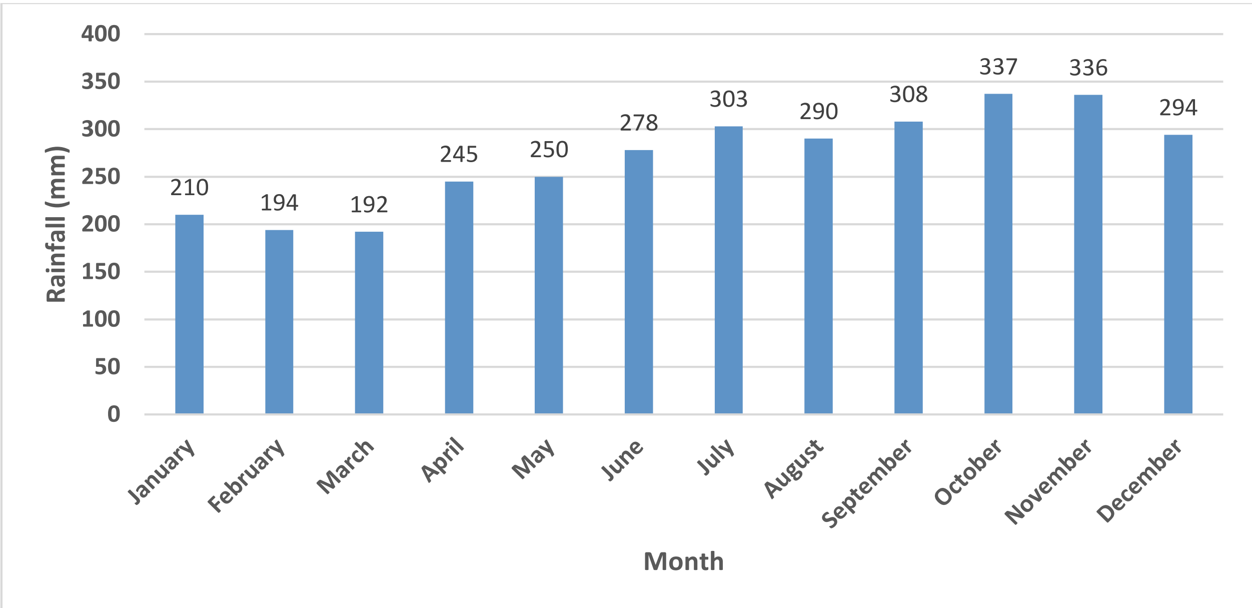


Figure 4. Majuro Average Monthly Rainfall

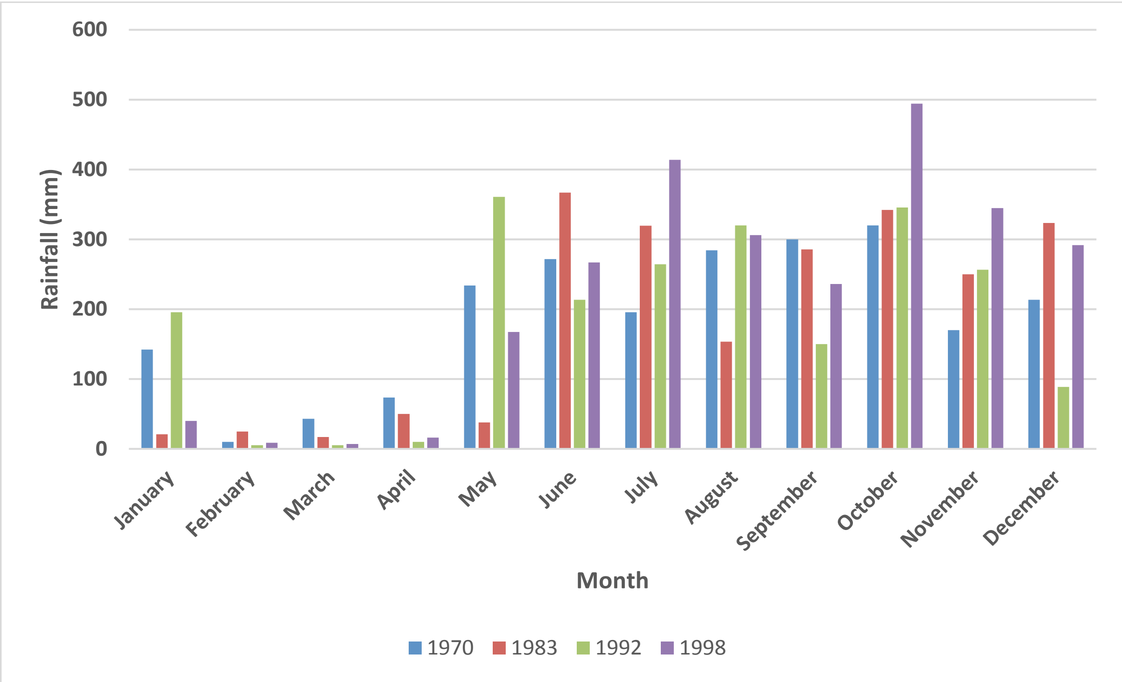


Figure 5. Rainfall Pattern in Extreme Dry Years

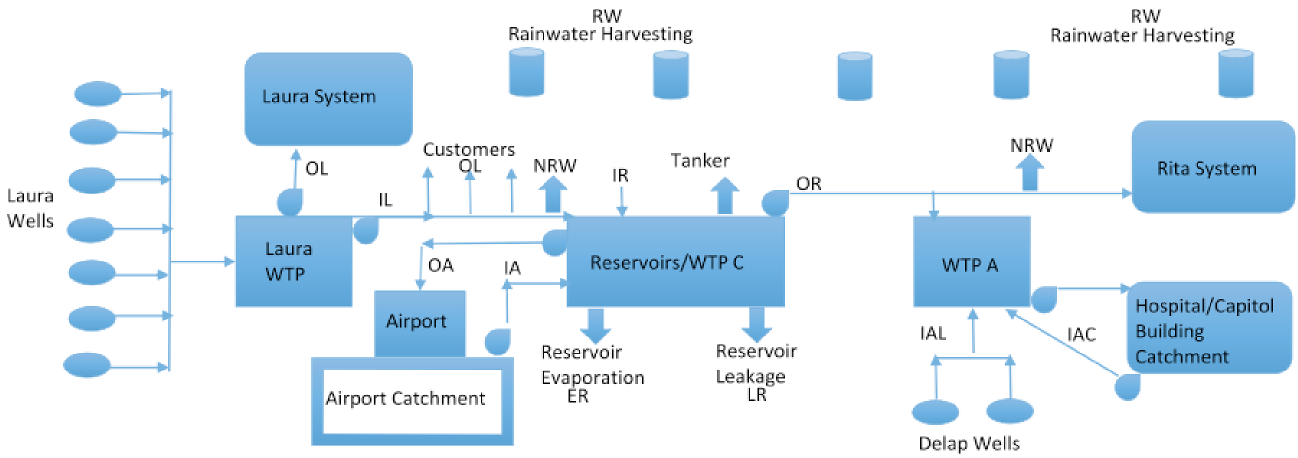


Figure 6. Schematic Majuro Water Supply

The water discharged from WTP C is potable with chlorine residual as high as 4 mg/L. Because of intermittent supply, poor pipeline condition and lack of chlorine booster stations along the 15 km distribution mains the chlorine residual is quickly depleted and the water is not suitable for drinking. EPA conducts regular bacteriological and Free Available Chlorine (FAC) tests at eight sites along the mains.

The normal failure rate is in the order of 40% of samples. MWSC regularly advises customers not to drink the water. A community survey undertaken by MWSC in 2016 (MWSC, 2016) found that 52% of residents use their own or neighbor's rainwater catchment for drinking water and 39% purchase bottle water for drinking water. There are at least eight commercial drinking water suppliers providing bottled drinking water.

Figure 7. MWSC Airport Reservoirs

THE IMPORTANCE OF RAINWATER HARVESTING

The primary source of raw water is the 30 ha airport runway and taxiways, producing an average 700 ML per year of runoff that is stored in six reservoirs of 130 ML capacity. The other important source is the Laura groundwater lens, which is capable of a safe yield of 400 ML per year, although normally withdrawal is far less.

Household rainwater harvesting is a major component of Majuro's water supply system. Under normal circumstances the individual property tanks are regularly recharged by the high rainfall, and supply from MWSC is not essential.

Household rainwater harvesting systems are in poor condition and less than 50 percent of the roof area has effective guttering and/or downpipes. Consequently, the maximum yield under average rainfall is only about 175 ML per year compared with a potential 800 ML per year for a fully maintained and efficiently operated system.

Thus, optimised rainwater harvesting has the potential to supply as much water as the airport source and to be a much more significant source of supply than at present.

A community-wide survey in 2009 (*EPPSO, 2010*) found that 64 percent of households had rainwater tanks, with 51 percent of 3800L capacity (considered the minimum effective capacity). A significant effort was made to provide more rainwater tanks; the 2011 census for RMI (*EPPSO, 2012)* found that households with rainwater tanks had increased to 77 percent. MWSC's 2016 community survey found that the percentage had increased to 92 percent, with 61 percent of 1900 to 5700L capacity and only 6 percent less than 1900L. it should be noted that the MWSC survey covered only 10 percent of the residences and so there is a higher degree of error than the 2009 and 2011 surveys.

The surveys demonstrate the high dependence of the Majuro community on rainwater harvesting, albeit that a high proportion of tanks are too small to provide adequate storage. For example, for the average household population of 6.8 and each consuming only 40L of water per day, a 3800L tank will empty in two weeks. Those connected to MWSC system commonly have a float valve in their tanks and they are automatically topped up from the piped water supply to get through dry periods.

Those not connected to MWSC's system suffer rapid (two to four weeks) emptying of the tanks in low rainfall periods, resulting in drought conditions in a very short time.

Table 1: Drought Years Rainfall Pattern

Year	Rainfall (mm)			
	Period January - April		Annual	
	Rainfall	Percentage of Average	Rainfall	Percentage of Average
1970	270	32%	2258	70%
1983 (1)	113	13%	2192	68%
1992	216	26%	2215	68%
1998	72	8.6%	2606	80%
2016	184	22%	2600	80%

(1) The longest duration drought on record occurred in 1983. The low rainfall period extended from December 1982 until May 1983, with 231 mm over that six-month period

DROUGHT IN MAJURO

As noted above, water shortages in Majuro can occur with just a few weeks of low rainfall. A severe drought is typified by three months of low rainfall. Typical dry years are presented in Figure 5 above. Rainfall from January to April for historical "drought" years are presented in Table 1.

These data demonstrate that even in severe drought years the annual rainfall is still relatively high, with rainfall patterns recovering quickly in the period from May-June. National Oceanic and Atmospheric Administration (NOAA) rainfall statistics since 1973 also show that:

- there have not been consecutive years of extremely low rainfall from January to April
- even though there are low rainfall months, there has never been a month of no rainfall
- low water conditions have been replenished in the period after May

MANAGEMENT OF 2016 DROUGHT IN MAJURO

The Marshall Islands experienced an extreme dry at the start of 2016. An El Nino condition resulted in very low rainfall from December 2015. Majuro's rainfall for 2016 is presented in Figure 8 and comparisons with other drought years are presented in Table 1. The pattern is very similar to historical drought years, with recovery in May and with annual rainfall 80 percent of average.

Predictions by NOAA were for Majuro to suffer "the most severe drought on record", projected to last through June 2016 *(NOAA, 2015)*. There was considerable community concern about availability of drinking water and the demands on commercial drinking water suppliers were extreme. In mid-January after several weeks of essentially no rainfall there were queues at outlets and "crowd control" was implemented by some suppliers to enable all customers to get adequate supplies.

MWSC worked with the commercial drinking water suppliers to ensure there was no shortage of drinking water. Suppliers indicated a potential capacity of 300,000 Lpd, with a reliable capacity of 200,000 Lpd. In addition, the College of Marshall Islands' (CMI) Saltwater Reverse Osmosis (SWRO) plant could provide an additional 80,000 Lpd reliable capacity. The reliable supply equates to 7.5-10.4 Lpcd, which is ample for drinking water purposes. However, many in the community either were not conveniently close to the commercial suppliers or did not have the resources to pay for the water.

Water supply by trucking increased from the typical 1 ML per month to about 5 ML per month. MWSC was unable to keep up with trucking demand and worked with EPA to establish Emergency Water Transport Regulations to enable commercial operators to support MWSC in meeting the significantly higher demand.

The RMI government declared a State of National Emergency on 4 February 2016 and USA's President Obama declared a State of Disaster on 28 April 2016. These declarations enabled international support for the drought. For Majuro the primary support was for leasing of a 1 MLd SWRO plant and emergency water distribution outlets.

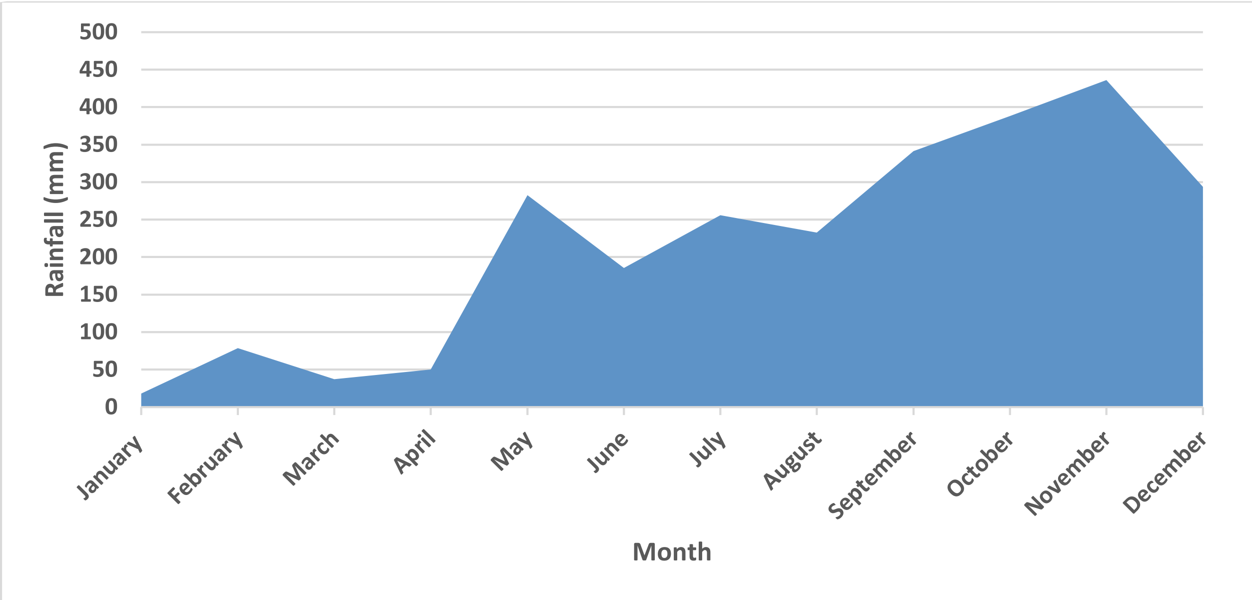


Figure 8. Majuro 2016 Rainfall

The primary author developed a model of Majuro's water supply system to enable reliable forward estimates of the water balance for Majuro to:

1. (a) Estimate the likely water in storage at the end of June when the drought was forecast to break
2. (b) Estimate the likelihood of having the storages at 115ML at the end of December to be prepared in the event of another low rainfall pattern in early 2017.

In addition, a drought management plan developed under an Asian Development Bank (ADB)-funded program (*MWSC, 2015*) was completed in December 2015. These were the primary drought management tools.

The drought management plan highlighted three important factors for drought management:

1. Ensure that the airport reservoirs contain at least 115 ML of water at the start of December
2. Maximise transfer of water from the Laura groundwater lens within the constraints of managing salinity in the lens
3. Supply to four zones on an individual basis to the Delap-Uliga-Darrit (DUD) area to optimise water supply efficiency to all sections of town. Without zoning and with high demands the community at the bottom end of the system would not get water under the intermittent (three days per week, four hours per day) normal operating regime.

A critical factor in the water balance was the safe yield from Laura lens. The safety of the lens was a highly public and political concern for sustainability and there was significant pressure on MWSC to limit withdrawal, even though previous scientific reports had indicated a safe yield as high as 1.5 MLd. RMI EPA suggested a limit of 200,000 Lpd to MWSC in December 2015. As a consequence, RMI EPA and MWSC worked together to have a confirmatory review of yield undertaken by the Secretariat of the Pacific Community (SPC) in March 2016 (*SPC, 2016).*

The SPC report concluded "*This report conservatively estimates that on average 350 thousand gallons per day (1.3 MLd) is achievable and will not result in any long term impacts"*, while cautioning to cease withdrawal from a well if the conductivity exceeded 1,000µS/cm.

With this confirmation MWSC was able to safely abstract from Laura lens at up to 750,000 Lpd or 24 ML/month.

The output from the water balance model is presented in Figure 8. The model was used to predict the volume in the airport reservoirs at the end of each month based on the inflows and outflows shown in Figure 6. The predicted volumes were based on the 1983 rainfall pattern, which was considered representative of the potential rainfall pattern for 2016.

Based on NOAA's forecast of the drought lasting though to the end of June, in February the model predicted that the reservoirs would be effectively empty by early May and there was a high probability of Majuro being without water for up to two months. Thus, in February, the RMI government committed to a maximum six-month lease of a containerised 1 MLd SWRO plant. At that stage the safe yield for the Laura lens had not been established so an assumed conservative allowance of 17 ML/month was used in the model. In the meantime, MWSC closely monitored the salinity of the abstracted groundwater.

Tenders were called for the SWRO lease and GE Power Water and Process Technologies, operating from Australia, were awarded the contract in early March, with delivery to site scheduled for early May. In the meantime, the actual volume in the reservoirs was tracked on a daily basis.

The model predicted reasonably accurately the future position and enabled regular updates to MWSC Board, the Minister for Public Works and the government. The actual storage beyond February was higher than predicted due to a higher than forecast rainfall in February and increased withdrawals from the Laura lens based on the confirmatory findings of SPC.

As a consequence, the model was modified to predict month end storages based on the actual rather than the predicted storage for the previous month.

The drought broke in early May, with 95 mm of rain

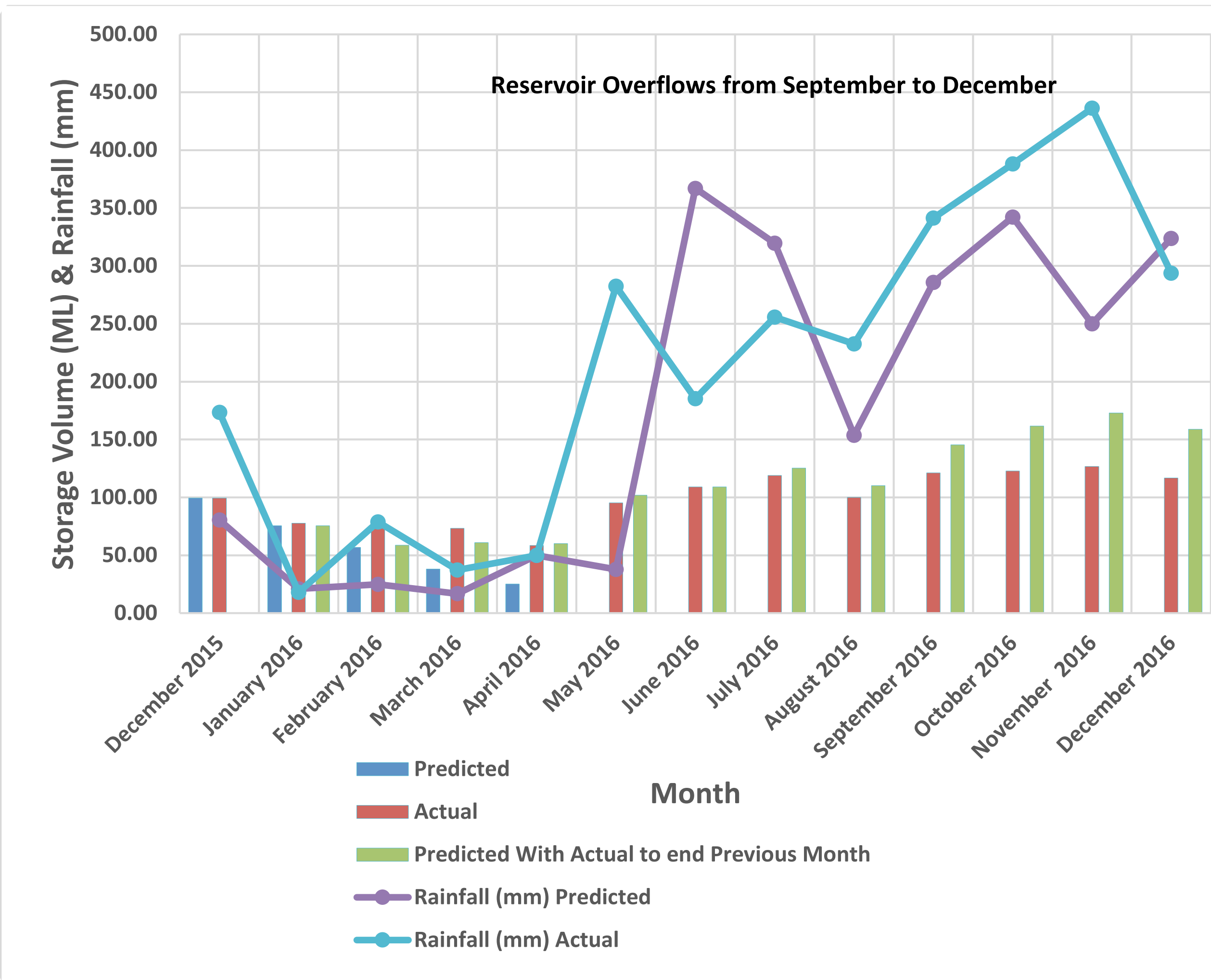
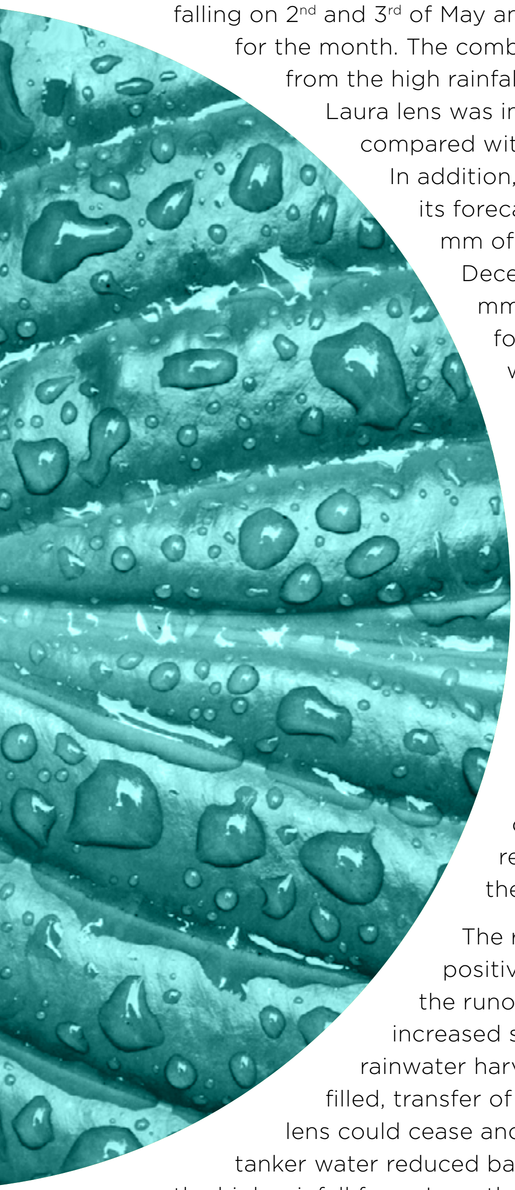


Figure 9. Majuro Water Balance Model for 2016



falling on 2nd and 3rd of May and a total of 282 mm for the month. The combined inflow for May from the high rainfall and transfer from Laura lens was in the order of 65 ML compared with demand of 22 ML. In addition, NOAA had changed its forecast, predicting 1930 mm of rain from June to December, including 190 mm in June (actual rainfall for June to December was 2130 mm). Based on these forecasts and the volume in the reservoir storage, GE was advised on 19th May not to proceed with commissioning the emergency SWRO, which arrived in Majuro on 24th May 2016, due to shipping delays. The SWRO containers remained on the dock and were returned to Australia on the next available ship.

The rain had multiple positive impacts in that the runoff to the reservoirs increased significantly, residential rainwater harvesting tanks were filled, transfer of water from the Laura lens could cease and the demand for tanker water reduced back to normal. With the high rainfall from June, the reservoirs started overflowing in September and continued intermittently for the remainder of 2016.

The model proved to be a valuable tool and it has been developed further, with a model for 2017 having been developed upon which actual monthly performance can be monitored, including predictions of quantum and timing of overflows.

LEARNINGS FOR THE 2016 MAJURO DROUGHT

There were several important learnings from the 2016 drought for MWSC:

- Water resource management is critical - the issue was primarily one of effective water resource management rather than a severe shortage of water
- A definitive plan is essential - an up to date drought management plan provides a clear plan on the various actions to be taken and when these actions should be implemented
- Data is knowledge – the uncertainty with safe yield from Laura lens meant that the quantum transferred initially was less than possible which meant the reservoir supply was under greater stress
- A predictive tool enables planning with some certainty – the supply-demand model enabled the potential risks to be better assessed and for changes in risks to be identified and managed more quickly
- Identify and manage risks - although the emergency SWRO eventually was not required, it was a vital risk mitigation tool. If NOAA's early forecasts had held there was a major risk that 28,000 people in Majuro would not have had water for up to two months, with significant public health issues
- Emergency water distribution systems could be improved - in future, if there is a need for drinking water to be made available to the wider community it may be better to optimise and subsidise the water available from commercial drinking water suppliers rather than setting up temporary water tank outlets with uncontrolled withdrawals of free water emptying the tanks very quickly
- Keep the community informed - a more extensive community engagement program commencing in late 2015 would have reduced the amount of community nervousness and angst. Advising the community that MWSC had a clear plan which it was implementing would have placated many of the concerns.

EBEYE

Ebeye's primary source of public water is desalination, which theoretically provides a drought-free supply. Rainwater harvesting is not as prevalent as in Majuro The challenge for Ebeye is to keep the existing 0.6 MLd and 75,000 Lpd SWRO units operating with limited operating and maintenance expertise and limited spare parts. A photo of the 0.6 MLd SWRO plant is presented in Figure 10.

Ebeye is in the process of procuring a 1.6 MLD SWRO facility, scheduled for commissioning in May 2017. This facility will enable all demands to be met without the current intermittent supply on a zonal basis.

Figure 10. Ebeye 0.6 MLd SWRO Plant

An important component will be long-term training of the water company's operators, covered under a two-year operating component of the contract being delivered by Australian company, Osmoflo.

Kwajalein Atoll Joint Utilities Resources (KAJUR), the operating company, suffered a major failure of the energy recovery unit on the 0.6 MLd SWRO plant on 25th May 2016, which was equivalent to a "drought" for Ebeye. A new unit had to be flown into Ebeye from the USA, which took two weeks, with the new energy recovery unit being installed on 9 June. Rationing was required during the downtime to enable the combination of product water in storage and daily production from the smaller SWRO plant to meet the basic needs of the community.

Important learnings from the Ebeye "drought" were:

- Preventative maintenance is vital when a community is so reliant on one source of water supply
- Spare parts, including an inventory of what is in store and regular replacements, particularly for vital components, are essential
- Keeping the large product water storage close to full is important to provide as much emergency storage as possible
- Two parallel SWRO trains as against one larger unit provides emergency capacity in the event of failure of one train (this arrangement is being used with the new Osmoflo plant)
- Established procurement and delivery arrangements with key suppliers enables replacement parts to be delivered to Ebeye more quickly
- A community engagement plan for situations such as experienced in Ebeye should be developed to enable prompt messages and to ease concerns from all sectors of stakeholders and the wider community

OUTER ISLANDS

Water supply in the outer islands is very rudimentary, with most of the small communities using rainwater harvesting and/or shallow wells. Water supply on outer islands is the responsibility of local governments, that generally lack appropriate skills or funding. Rainwater harvesting is of low standard and shallow wells quickly become saline during dry periods. A few islands have permanent saltwater or brackish water reverse osmosis plants, but low maintenance standards are the norm.

Because of the relatively low standards for water management and the much lower rainfall in the northern atolls, water supply shortages develop very quickly during droughts. The 2016 drought impacted all outer islands, but was more significant in the lower rainfall northern islands. Food shortages were prevalent and supplies were shipped to the islands.

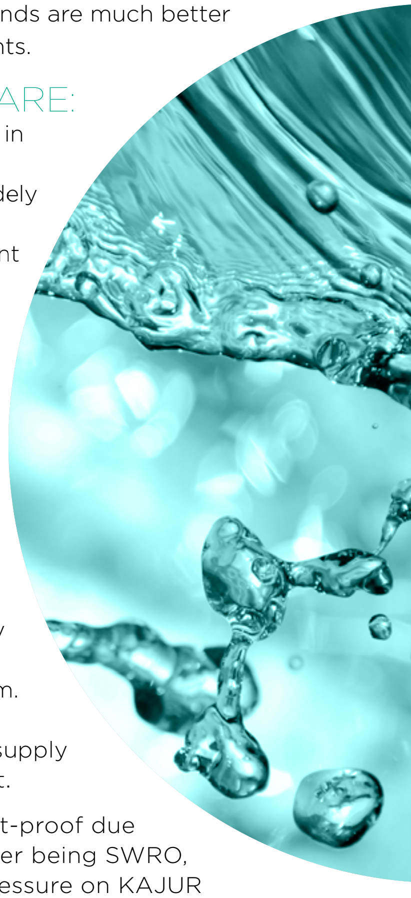
The common emergency water supply during droughts are 54 “suitcase” size SWRO plants, each with a nominal capacity of 1100 Lpd extracting brackish water from wells. MWSC’s charter is to serve the urban community on Majuro island. However, under the National Disaster Management Plan, MWSC assumes leadership of the water, sanitation and hygiene (WASH) committee and provides installation and maintenance support for the suitcase SWRO units throughout the country. The suitcase SWRO units are returned to MWSC and are cleaned and stored. MWSC undertakes six-monthly servicing of the suitcase units to ensure they are ready for use when the next drought occurs. Distribution, maintenance and return of the units to Majuro are major exercises, with transportation costs being extremely high.

International support under the State of National Emergency and the State of Disaster was very important for serving the outer island during the 2016 drought. The Australian government provided permanent 3000 Lpd SWRO plants for Jaluit, Gugeegue and Wotje three of the most populated outer island with boarding high schools, amongst other support.

CONCLUSIONS

The Marshall Islands are a graphic demonstration that high rainfall does not necessarily mean water supply security. Quantifiable understanding of the various factors influencing water security, along with sensible management practices by appropriately qualified and experienced water managers are prerequisites. Application of experiences from the 2016 drought, along with previous droughts, means that the communities of the Marshall Islands are much better placed to manage future droughts.

KEY CONCLUSIONS ARE:



1. Water resource management in the RMI requires a number of diverse approaches in the widely dispersed atoll country with specific conditions for different communities, from highly urbanised in Majuro and Ebeye to small communities on outer islands
2. Majuro is dependent on rainwater harvesting and surface runoff and thus is subject to rapid development of drought conditions (two to four weeks of no rainfall) for the 75 percent of the community who are not connected to MWSC’s public supply system. Those connected to MWSC’s system had a reliable water supply throughout the 2016 drought.
3. Ebeye is essentially drought-proof due to its primary source of water being SWRO, but there is considerable pressure on KAJUR providing reliable operations and maintenance practices to avoid a major outage, resulting in an artificial “drought”.
4. The outer islands are highly reliant on temporary “suitcase” size SWRO plants that are flown or shipped to the outer islands at the onset of the drought and are returned to MWSC for warehousing between droughts.
5. Water resources will be an ongoing challenge for RMI but continuing development of good planning and management practices by the leaders of MWSC and KAJUR and a better understanding of drought management by the general community will mean that 3000 mm of rain per year will be adequate!

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REFERENCES

CIA 2017 - The World Factbook; Central Intelligence Agency; 12 January 2017

MWSC, 2016 - 2016 Community Survey Analysis Report; MWSC; November 2016

EPPSO, 2010 - Majuro and Kwajalein Atoll Household Water Survey; Economic Policy, Planning and Statistics Office; February 2010

EPPSO, 2012 - 2011 Census of Population and Housing; EPPSO

NOAA, 2015 - Pacific ENSO Update, Quarterly Report, Quarter 4, 2015, Vol 21 No.4, November 13, 2015

MWSC, 2015 - MWSC Drought Management Plan 2015

SPC, 2016) - Assessment of the 2015-2016 Drought Impacts on Laura Fresh Groundwater Lens, Majuro Atoll, Republic of Marshall Islands; Peter Sinclair, Sandra C. Galvis, Amini Loco, Anesh Kumar; April 2016