Cost-Benefit Analysis of freshwater security options for Republic of the Marshall Islands being considered under PACC

Final Report

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Introduction

Under the GEF-funded, regional "Pacific Adaptation to Climate Change" program, the Republic of Marshall Islands (RMI) have US$800,000 for the "Marshall Islands PACC project: A whole island approach." The regional PACC program targets three development sectors, with an aim of increasing their resilience to climate change impacts (PACC Project Doc). The RMI project focuses on freshwater security, specifically the vulnerability of supply during drought periods posed by high consumption, inefficient collection and distribution system and inadequate storage capacity.

The purpose of this cost-benefit analysis (CBA) is to economically evaluate proposed sub-projectsto improve freshwater security. The CBA analysisvalueseach option's potential costs and benefits. The analysis provides information to decision makers on the relative benefits and costs that each option is expected to deliver, and allows them to rank options to assist with decision-making.

In effect, there are two main market segments for the Majuro Water and Sewage Company (MWSC): the first lies between Laura and the airport and the second between the airport and the town of Rita. The main urban area, DUD-Rairok, lies between the airport and Rita.A strategic decision was made at the start of the CBA to concentrate the analysis on project options that focus on the main market segment, the urban area DUD-Rairok, and the main water source that MWSC has, the airport rainwater catchment and its associated distribution network. . In times of normal rainfall, the airport is MWSC's main supply.The other source of water is a groundwater lens under the Laura region. Experts at MWSC, PACC, EPA, and JIRCAS do not consider the Laura groundwater lens a sustainable source, as it is being chronically overdrawn, polluted with agricultural run-off and septic tank seepage, and property rights are disputed (JIRCAS 2008, 2011; SOPAC 2010). In non-drought times, MWSC's strategy is to diminish its reliance on Laura's groundwater. Under current conditions (e.g., supply, storage capacity, and system losses), MWSC remains dependent on the Laura lens during drought times, however, speaking to the urgency of improving the airport-based systems.The team therefore decided to focus the CBA on improving the airport-based harvesting and distribution systems.

Background

Situation and context

The total population of the RMI is 53,138 inhabitants, with a 0.4% population growth rate due to high outmigration (EPPSO 2011). The Majuro and Ebeye urban centers host 74% of population, and urbanization is causing Majuro to grow faster than other areas(EPPSO 2011). The Majuro atoll has one of the highest population densities on earth, over 2,500 people per km^2 on a land mass totaling just 9.7 km^2.Around 80% of the 4,106 households on Majuro are in the DUD and Rairok areas (EPPSO 2011, SOPAC 2007), the focus of this CBA.

Being an atoll, fresh water is of utmost concern. DUD-Rairok households get fresh water through two means: via MWSC and by capturing rain from rooftops. A small amount is also drawn from groundwater. As mentioned, this CBA does not consider the groundwater supply in the DUD-Rairok area. On average, 131 inches of rain falls on Majuro each year (3.3 meters). The rainy season spans mid-April through December, averaging 0.39 in/day (10 mm), and the dry season spans January though mid-April sees an average of 0.26 in/day (6.5 mm/day) (SOPAC 2007, NWS 2011).[1] Rainfall in the dry season can be especially variable (SOPAC 2007, NWS 2011, PCCSP 2011), and the months after an ENSO event are characterized by much lower rainfall than average (idem). In atolls and Majuro in particular, about half of rainwater is lost to evaporation, an additional amount mixes with saltwater, and only some remains in freshwater lenses (SOPAC 2010).

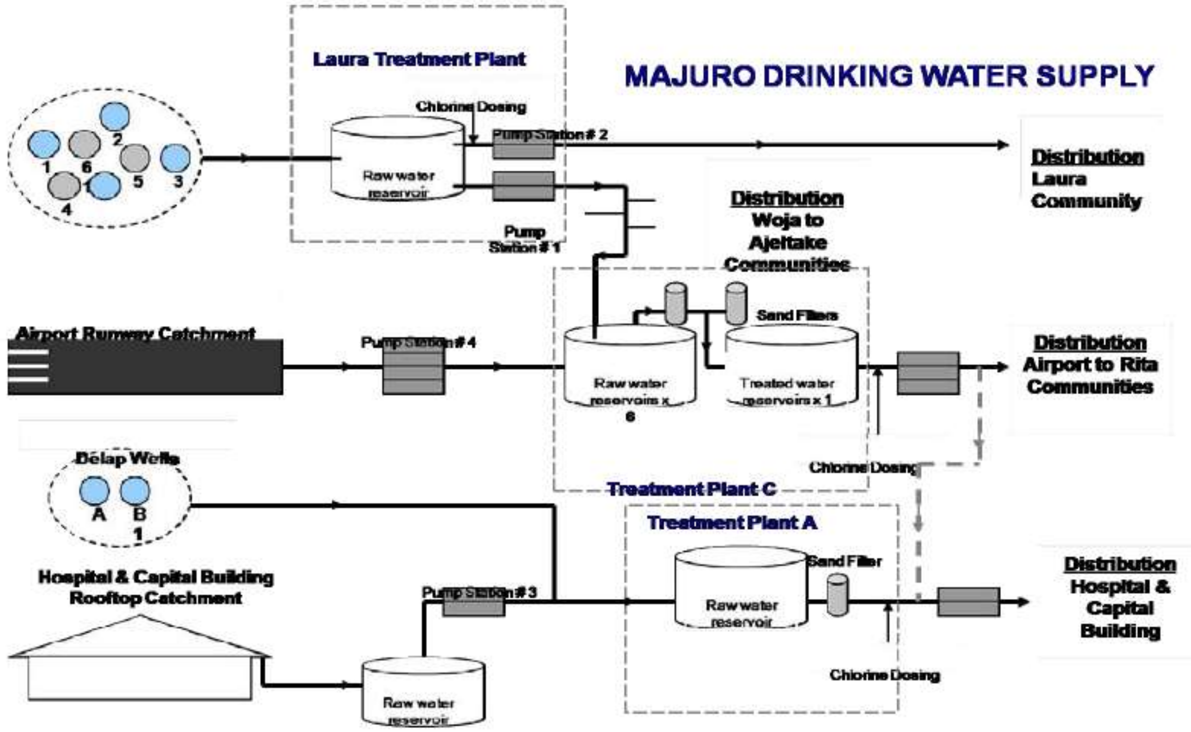
Of the 3,285 households in the DUD-Rairok area, only 34% are currently actively hooked up to themunicipal freshwater supply service provided by the Majuro Water and Sanitation Company (MWSC). In addition to supplying households, MWSC supplies fresh water to some public standpipes and delivers water via tankers.MWSC's water delivery is erratic, sometimes as low as 1-2 days per week. MSWC supplied metered residential customers with 3.8 million gallons a month (2003-2010 average) (MWSC pers. comm.), but MWSC likely pumped more than twice that from its treatment facility, as ~50% is unaccounted water due to system losses and illegal connections (SOPACunknown date b).This 50% estimate is uncertain. There are no flow meters in the system, so loss estimates are based on approximate storage volumes calculated by using dip gauges in the reservoirs (N. Duncan, pers. comm.).

MWSC gets water from two sources: the Laura groundwater lens and the airport catchment. MWSC has six wells fitted with infiltration pipes, three of which were working at the time of the visit; water is extracted from the Laura lens irregularly, only when the reservoir level drops below a certain level (MWSC pers. comm.).MWSC's main source is the airport catchment. MWSC collects water that falls on 263,000 m^2 of runway at the airport, and stores it in reservoirs (with a combined surface area of 27,000 m^2 and 36.5 Mgal storage capacity). The water undergoes treatment (sand filtration and chlorination) and is pumped to the Rairok and DUD area via a 16 km distribution pipe (Figure 1). A parallel 16 km transmission pipe is intended to increase water pressure in Rita, at the far eastern end of the DUD area.In addition to freshwater, MWSC supplies salt water for use in toilets.

Figure 1. Majuro drinking water supply (USAID 2009, which cites SOPAC 2009 Powerpoint presentation)

[1] Table 1. Mean and upper and lower 95% CI precipitation in mm/day based on historical rainfall 1951- 2001 (SOPAC 2007)

	Ave	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Mean	9.12	6.88	5.90	6.80	9.23	9.09	9.65	10.16	9.09	10.92	11.31	11.01	9.42
Upper 95% CI	10.28	8.19	6.80	8.28	10.92	10.16	10.58	11.06	10.08	12.02	12.37	12.11	10.73
Lower 95% CI	7.98	5.57	4.54	5.41	7.54	7.95	8.81	9.26	8.60	9.74	10.24	9.99	8.11



The total airport area has been reported as 74 acres (ADB 2011a), 80 acres (SOPAC 2011), and 88 acres (USAID 2011), although the effective area is estimated to be closer to 65 acres (M. Stege pers. comm.), thus this is used in the analysis. Under current climatic conditions (rainfall (SOPAC 2007, NWS 2011) and evaporation (MWSC 2012)) and assuming 100% capture efficiency, the airport catchment system has the potential to supply 160 million gallons a year (607 thousand m^3), or 1.76 million gallons per inch of rainfall.

About 64% of households have rooftop collection systems, although many of these (22%) are in disrepair (EPPSO 2010). Assuming 100% capture efficiency, these systems can provide 97 million gallons per year (368 thousand m^3) during a normalrainfall year. An unknown amount of commercial buildings also have catchments. Drinking water is nearly universally supplied by rooftop catchment systems (76%) with only 5% of households using MWSC supplied water (EPPSO 2011).

Per capita water demand is reported between 33-45 gallons per day (SOPACunknown date b, 2007, EPPSO 2010), although this range seems unsubstantiated by any household studies or data. For lack of better estimates, assuming it is 40 gallons (0.15 m^3), the~22,000 people currently living in the Rairok-DUD area demand 324.5 million gallons (1.2 millionm^3) of water a year. Demandoutstrips the quantified potential supply (counting the airport and rooftop catchments only, delivering at 100% efficiency) by about 67 million gallons a year (253 thousandm^3). The actual deficit is likely far worse due to inefficiencies in capture, distribution, and storage. Indeed, nearly half of households reported facing water scarcity "often, " and an additional 42% reported "sometimes" (EPPSO 2010), and water shortages have been blamed for increased incidents of gastroenteritis, pink eye, and even a typhoid outbreak (idem).

During drought conditions when annual rainfall can fall to 87 inches (from a mean of 131) (or to 2.2 meters/year from a mean of 3.3) (SOPAC 2007; Slide shown by Mark Stege), MWSC's total available supply drops to 74 million gallons annually (281 thousand m^3), and rooftops drop to 64 million gallons (243 km^3). During drought periods, storage capacity becomes particularly crucial. Storage can ensure that during periods of low rainfall, adequate water is available to meet demand. MWSC has reservoirs that can hold 36.5 million gallons. The average household with a catchment has storage of 3,332 gallons (12.6 m^3) (EPPSO 2010), resulting in an additional decentralized storage capacity of 7 million gallons (26 thousandm^3). Commercial and government buildings provide an estimated 418,000 gallons (1.5 thousand m^3) (M. Stege, pers.comm.). Assuming all this water is available (100% efficiency), there is sufficient water to meet about 47 days of demand. This would be enough to get the city through most historical drought periods. With more realistic assumptions about storage efficiency (e.g., 90% of water from decentralized systems can be used and 50% for MWSC water due to distribution system losses), however, only 28 days of water is on-hand, highlighting the vulnerability of the supply system (and thus population) to inefficiencies.

To overcome these inefficiencies during periods with lower than average rainfall, MWSC has relied on pumping groundwater from Laura, a rural area at the opposite end of the atoll from DUD, and transporting it along a 30 km pipeline to be treated at the airport facility. USGS reports that in drought periods, up to 90% of MWSC's water derived from the Laura groundwater lens (USGS2005). The ratio of pumped water to water delivered for treatment at Plant C at the airport is around 10:1 (MWSC, pers. comm.). The Laura pipeline had more than 64% losses when measured over a decade ago (SOPACunknown date b). The PACC project has decided to focus on helping MWSC lessen the need to pump groundwater from Laura for a number of reasons. First, there are serious concerns about the quality of the groundwater due to pollution from agriculture, burials, piggeries, and septic systems (GEF unknown date). Second, there are property rights disputes with local landowners. Third, the groundwater lens in Laura is threatened by sea level rise and may not be a sustainable solution for urban water supply. Fourth, there is high potential to increase efficiencies within the rainfall capture systems to avoid the need to heavily rely on the groundwater lens. (Further, with 90% loss in the Laura-airport and 50% loss between airport and DUD, only 5% of extracted groundwater is reaching consumers.)

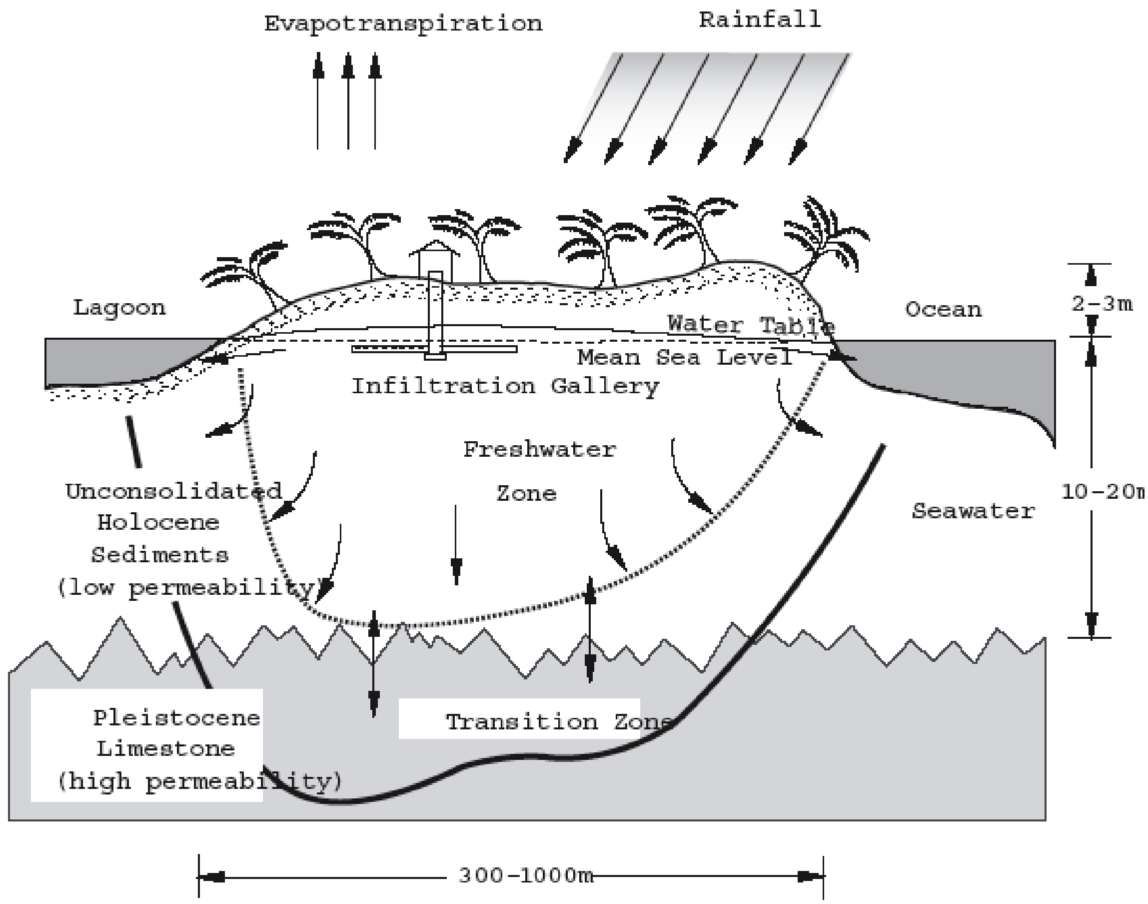
Water scarcity has been linked to health problems in Majuro, namely pink eye, gastroenteritis, and even a typhoid outbreak in 2006 (EPPSO 2010). Treatment of gastroenteritis cost an estimated US$1 million between 2001-2006 (idem).

Causes of water insecurity

Majuro's water security is threatened by climate change impacts. The PCCSP predicts the following (2011):

<u>Sea level rise.</u> As the assets supplying water lie along a thin, low (<2 meters above sea level) stretch of the atoll, Majuro's water security is highly vulnerable to sea level rise. Sea level has gone up 0.3 inches per year since 1993, resulting in erosion, flooding, and other destructive processes. Sea level is expected to continue to rise [very high confidence] between 2-6" by 2030 and 8-24" by 2090 [moderate confidence]. SLR threatens the water supply. Much of the infrastructure lies just above current sea levels; hydrostatic pressure is already causing cracks in the airport runway and the water distribution pipeline may be damaged by higher seas. The Laura groundwater lens will also be affected (Figure 2).

Figure 2. Sea level rise threatens the Majuro groundwater lens (figure courtesy of SPREP)



Rising temperatures. Temperatures have gone up 0.22 degrees F per decade (SOPAC 2007), and temperatures will continue to rise potentially +4.5 deg F by 2090 [very high confidence]. Increasing temperatures may result in higher evaporation from reservoirs.

Ocean acidification. Acidification will increase [very high confidence]. Aragonite saturation will reach below 3.5 by 2035 and continue to decline [moderate confidence]. The combination of acidification and rising temperatures poses a serious threat to coral reefs, and thus shoreline protection and food security.

Changes in rainfall patterns. Wet and dry season average rainfall will increase, though no change is foreseen through 2030, whereafter a >15% increase in dry season rainfall by 2090 is expected [moderate confidence].

Extreme events: Typhoons. Typhoons are expected to decline [moderate confidence]. Typhoons contaminate potable water supplies, saltwater intrusion of groundwater, and loss of infrastructure (SOPAC 2007). Generally RMI is outside the range of tropical cyclones and typhoons, but is affected greatly be storm surges associated with typhoons, which can damage infrastructure and contaminate catchments and reservoirs with salt water, making the water unsuitable for drinking.

Extreme events: Droughts. Droughts often occur after El Nino (rainfall can be reduced by as much as 80% for 6 months), and the effects are exacerbated because ENSO lowers the water table affecting groundwater supplies (SOPAC 2007). While rainfall in dry season has trended downward during 1950-2010, the incidence drought is expected to go down [moderate confidence]. Mild droughts will occur 8-9 times per 20 years in 2030 and 6-7 times by 2090. Moderate drought will go down from 2-3 now to 1-2 in 2090, whiles severe droughts will occur just 1 time every 20 years [low confidence]. Droughts shift demand towards groundwater, a very scarce resource in Majuro, with quality concerns.

Extreme events: Heat and rainfall days. The frequency and intensity of extreme heat days will increase [very high confidence] with a range of +2 degree F (2055) and +4.5 deg F (2090) in temp on the 1:20 year hot day [low confidence on range]. Extreme rainfall days will increase [high confidence]; rainfall on these days will be 0.8" more than normal (in 2055) and 1.8" more than normal (in 2090) [low confidence], and will occur with increasing frequency (1:20 year event will occur 7-8 times per year [low confidence on range]).

A recent Vulnerability Assessment (ADB 2011b) and Adaptation Plan (ADB 2011c) conducted by the ADB and a Vulnerability Assessment done by USAID (2009) identified a number of key vulnerabilities to the freshwater supply in Majuro and associated adaptation measures that are relevant for the PACC project.

The ADB study identified the airport catchment as the most important source of water for the atoll. The airport catchment and reservoirs, as well as the pump stations and treatment plant, were found to be highly vulnerable to salt water intrusion due to storm surges, typhoons, and king tides. As a result, ADB proposed a number of adaptation measures (Table 2). Other adaptation measures proposed by ADB include activities in the Eastern part of the atoll to expand rainwater harvesting and improve the management efficiency of the groundwater system, shoreline protection measures in Darrit, revision of zoning laws and building codes to guide adaptation and disaster risk reduction, and capacity building in the Office of Environmental Planning, Policy, and Coordination (OEPPC).

Table 2. ADB priority adaptation measures for the airport system (ADB 2011c)

Output 1: The airport rainwater catchment system, Plant C water treatment facility, and interlinking roadway are protected from flood conditions during extreme events and future sea level rise.
Activity 1.1: Stabilize and reinforce riprap revetment and backfill along the airport lagoon coastline.
Activity 1.2: Stabilize ocean side boundary wall
Activity 1.3: Stabilize the narrow zone between the riprap and concrete wall on ocean side (e.g. concrete infilling, compacting, vegetation control,revegetation)
Activity 1.4: Extend catchment surface area on the southern length of the current pavement to provide additional 0.03 km^2surface area with an impervious layer that connects to the existing water catchment system.
Activity 1.5: Identify and repair leaks in the reservoir as part of a maintenance program and install flow meters (this is part of the SPREP PACC adaptation program)
Activity 1.6: Restore and upgrade pump station including provision of four new pumps, valves and flow meters (this proposal has been given a high priority and is under consideration by FAA). This should include the flushing mechanism.
Activity 1.7: Support water authority in developing and implementing an effective operations and maintenance program for the water catchment.
Activity 1.8: Install riprap revetment and backfill along approx. 1.0 km of the reservoir lagoon coastline paying particular attention to the pumping station and treatment plant (this proposal has been given a high priority and is under consideration by FAA and RMI).
Activity 1.9: Stabilize and reinforce the ocean side riprap revetment (e.g. concrete infilling,

compacting, revegetation)
Activity 1.10: Install bund around the Pump Station #4 and Plant C water treatment facilities in particular to reduce potential for saltwater intrusion in the underground tanks.
Activity 1.11: Install roll out emergency/typhoon cover on the largest raw water reservoir to guard against saltwater contamination from salt spray (this proposal has been under consideration by PACC)
Activity 1.12: Design and survey potential of land reclamation in the zone between airport and reservoirs
Activity 1.13: Extend ocean side riprap revetment approx. 0.3 miles (0.4 km) from the reservoirs to airport
Activity 1.14: Backfill 10,000 sq. meter reclaimed land behind the riprap, using free draining material on reef hard pan
Activity 1.15: Establish recreation and sporting facilities (e.g. access to the beach, vegetation, picnic facilities, sports field).

USAID identified four thematic areas for adaptation options to address freshwater vulnerabilities: (1) improved management, (2) preparing for drought emergencies, (3) managing demand, and (4) outreach on water management and climate (Table 3).

Table 3. Priority adaptation measures identified by USAID (USAID 2009)

Option	TypeofAdaptation
ImprovedManagement of Freshwater Resources	
Conducta comprehensive audit of the public water supply system	Capacity Building
Implementperformance-basedmanagement system	Capacity Building
Design and install major capital improvements to thewater supply	Infrastructure
Increase household access to water	Policy/Infrastructure
Improve rainwater collection system cleaningand maintenance	Best Practice/Capacity
Strengthen building codes to require rooftopcollection andstorage	Policy
Developandcarryoutpilotprogramsforcommunitybasedcollection	Infrastructure/Capacity
Assess coastal erosion surrounding the freshwater lensat Laura	Capacity Building
Implement and enforce pollutionand waste management laws	Policy/Capacity
Extendwell survey(conductedin Laura) to other privatewells in Majuro	Capacity Building
Seal wells which are no longer in use to prevent contamination of the	Best Practice
Preparing for Drought Emergencies	
Strengthen drought emergency capacity	Capacity Building
Design andimplementdroughtwarning system	Best Practice
Procure emergency equipment	Infrastructure
Developtrainingprograms	CapacityBuilding
Managing Demand	
Developpolicies andincentives for water conservation	Policy/Best Practice
Train andequipinspectorstosupportwater conservation and	Capacity Building
Outreach on Water Management andClimate	
Design andimplement a outreach campaign on rainwater harvesting	Capacity Building/Best
Provide an education/awareness programon water conservation	Capacity Building/Best
Developcurriculain schools on climate change and water	Capacity Building
Design andimplementa “SchoolMet”system	Capacity Building

Other drivers

Quantity:

- Growth in demand in Majuro (urbanizing population, industry, tourism, retail)
- High levels of unaccounted for water (50% of municipal supply) due to poor management and maintenance (water pressure, theft, leakage) (SOPAC 2007, GEF unknown date, USAID 2009)
- Low efficiencies due to poor airport catchment maintenance (SOPAC 2007)
- Poor coverage and maintenance of HH catchment systems (ADB 2011a; EPPSO 2010; USAID 2009)
- Weak conservation and demand management due to lack of public awareness and inadequate pricing and charging (SOPAC 2007, USAID 2009)
- Lack of integrated management, capacity, sector policy, etc. (SOPAC 2007)

Quality:

- Nitrate pollution of groundwater in Laura small scale commercial agriculture (SOPAC 2007)
- Lack of sewage leading to contamination of groundwater, especially in Laura (no wastewater system, *E. coli* in groundwater)
- Main water line contaminated due to incorrect chlorine dosages and backflow from illegal connections (SOPAC 2007)
- Saltwater infiltration to groundwater lens (JIRCAS 2008, 2011; USAID 2009)
- Lack of runway catchment cleaning and maintenance (SOPAC 2007)
- Solid waste, burial sites, sewage contaminating groundwater (SOPAC 2007)
- Poor maintenance of HH catchment (ADB 2011a)

Problems to be addressed by PACC

During a meeting on June 26, the PACC team decided to focus on the following issues:

Table 4. Priority issues to address in CBA

Water sector problem	Related climate change issue
Current rainwater capture facilities (decentralized and centralized) inadequate to meet demand.	SLR, La Niña, storm surge, king tides threaten catchment facilities Rainfall patterns may become more erratic
Large inefficiencies in both decentralized and MWSC systems.	Rising temperatures may increase evaporation, SLR may damage facilities, which will lead to higher losses
Shortages especially in times of drought exacerbated by inefficiencies.	Incidence of droughts to continue
Water contaminated by salt water.	SLR, storm surges, typhoons, king tides threaten infrastructure with salt water contamination

<u>Methodology</u>

A cost-benefit analysis (CBA) can help the PACC project team prioritize adaptation projects. CBA analysis is a tool that systematically estimates the "efficiency" of projects. "Efficiency" is a technical economic term, roughly referring to a situation where the maximum public benefits are achieved for the minimum cost. The basic principle underlying CBA is that those who gain from a given project could, in principle, fully compensate those who would lose while still being better off (i.e., that the benefits outweigh the costs). A positive ratio of benefits to costs indicates that this criterion was met; the higher the number, the "better" the project in terms of bang for buck. Of course, the total costs are also important, as are the distribution of the costs and benefits (who wins and who loses). The ratio does not capture these concepts.

The first step in the CBA involved defining the policies under consideration, namely defining the various climate adaptation project optionsPACC is considering to improve freshwater security. The team selected the following options in a meeting on June 26, 2012 to include in the CBA (Table 5).[2]

TABLE 5. Options analyzed in CBA.

Baseline: Do nothing 0. Cost of current and future supply, shortages, health damages, climate change impacts, loss of tourism
Increase available supply from airport by reducing losses at airport facility (Activity 1.5: Identify and repair leaks in the reservoir as part of a maintenance program and install flow meters) 1. Reline reservoir 2. Evaporation cover
Reduce unaccounted for water lost in conveyance system 3. Repair and/or replace pipes
Improve airport runway catchment to improve efficiency and withstand SLR (Activity 1.7: Support water authority in developing and implementing an effective operations and maintenance program for the water catchment.) 4. Improve maintenance of pressure release valves in airport runway and improve efficiency of capture from airport runway catchment
Increase size of airport capture to increase supply 5. Put in system to capture water from planned expansion of runway
Improve decentralized rainwater capture 6. Increase # HH with catchment systems and state of existing systems

The second step in a CBA is to identify the impacts of the project options under consideration, and to classify them as either costs or benefits. The baseline (without project) scenario guides the impacts we need to assess for each option (Table 6).

Table 6. Baseline situation without any intervention

	Baseline
Water supply	- Potential supply from airport catchment 160 Mgal/year in mean rainfall years and 74 Mgal/year in extreme drought years (based on historical mean rainfall) - Rainwater harvesting (RWH) supplying 97 Mgal/year in mean year, 64 Mgal/year in extreme drought years - MWSC effective supply less than 50% due to inefficiencies which are likely to get worse over time - RWH systems on 64% of houses, likely to increase to 100% due to GRMI policy (RMI 2012) - Rainfall likely to increase slightly, droughts to continue at current frequency and duration (PCCSP 2011)

[2] "Activity X.X" refers to activities identified in the ADB Vulnerability Report and/or Adaptation Report.

Water demand	- Per capita demand between 33-45 gallons a day; trending upwards rapidly (very uncertain data) - Total demand in Riarok-DUD area 302 thousand gallons per day (324 Mgal per year), based on population of 22 thousand in Riarok-DUD area - Population growth affected by urbanization and outmigration (1.4%), so demand likely to grow - Shortages likely to continue
Water related health issues due to water scarcity	- 2000 incidents of pink eye - 8.5% of Majuro population with gastroenteritis in 2006 (133% more than 2001) costing $1 million over 6 year period for outpatient treatment - typhoid outbreak in 2006 - water scarcity-related illness incidents likely to continue to increase without health policy and/or water sector policy reform

In our case, assessed impacts were limited to potential additional fresh water supplied to households within the DUD-Rairok area due to the interventions (these are the "benefits") and the fiscal outlays for construction and maintenance (considered the "costs") (Table 7).Except where otherwise noted, we assume zero losses in the system when calculating the potential additional water (hence "potential"), so results should be interpreted with caution. Additional freshwater will occur as a function of improving the capture and use of precipitation. For the baseline case, a 1959-2001 historical average rainfall of 9.3 mm/day was used (0.36 inches per day) (SOPAC 2007).As a result of this very narrow scope, key impacts were ignored. The geographic extent of the impacts was limited, as were the stakeholders. Externalities, both positive and negative, were excluded.

TABLE 7. Benefits and costs of each option. Construction costs typically include capital, equipment, materials, and labor. Maintenance generally includes equipment, materials, and labor. While many benefits will accrue from water security, the CBA focuses only on the impacts from increased supply for human daily use.

BENEFITS					
1: Reline	2: Cover	3: Pipes	4: Valves	5: Expand	6: RWH
Additional water for year-round consumption	Additional water for year-round consumption	Additional water for year-round consumption	Additional water for year-round consumption	Additional water for year-round consumption	Additional water for year-round consumption
Additional water during drought periods	Additional water during drought periods	Additional water during drought periods	N/A	N/A	Additional water during drought periods
Lower incidences of water-related health issues	Lower incidences of water-related health issues	Lower incidences of water-related health issues	Lower incidences of water-related health issues	Lower incidences of water-related health issues	Lower incidences of water-related health issues
Less lost tourism revenue	Less lost tourism revenue	Less lost tourism revenue	Less lost tourism revenue	Less lost tourism revenue	Less lost tourism revenue
COSTS					
Construction:	Construction:	Construction:	Construction:	Engineering	Retrofitting

replacing liner	installing cover	repairing or replacing pipes	fixing cracks	Design	existing systems
Construction: cost of liner	Construction: cost of cover			Construction of expanded catchment	Installation of new system
Maintenance	Maintenance	Maintenance	Maintenance	Maintenance	Maintenance

The third step is to monetize impacts. In theory, impacts should be valued at their full social value (i.e., the amount of welfare they produce/reduce). In reality, we do not have data to estimate these values, so instead use proxies. For the additional fresh water supplied, we apply two prices: full cost recovery for periods with adequate rainfall and substitution costs for periods of drought.These values are \$1.03 per m^3 and \$264 per m^3, respectively; the former is the price MWSC charges its residential customers, the latter is the market price for water purified using a reverse osmosis device. MWSC was unable to provide estimates of the full cost recovery of water, so market price was used. Costs are the actual construction and maintenance costs borne by MWSC or homeowners.

Box 1: Method to calculate the portion of water saved during drought periods

Drought can be defined in a number of ways, but typically refers to long periods of abnormally low precipitation during which demand outstrips supply. Droughts have historically plagued Majuro. Three-month droughts (simply defined as a period of where monthly rainfall was too low to meet household demand) occurred five out of the last 20 years. Drought of six months or more occurred in 1998, 2001, and 2005 (NWS, 2011). Droughts can have far reaching impacts on, for instance, agriculture, human health, and the environment. Shortages can be mitigated by adequate storage, rationing, improving efficiencies, increasing supply from alternate means, and other measures. The resiliency of Majuro to drought falls outside the scope of this CBA, however, drought periods affect the value of water, and thus the benefits. As such, we model the expected portion of water savings that occur during drought periods and apply a higher value (the cost of a substitute, such as reverse osmosis, the principal alternative on-island).

To calculate the expected portion of water saved during drought periods, we use a risk-based assessment. The recent country assessment by PCCSC predicts that moderate and severe droughts will occur 2.5 and 1 times per 20 years, respectively (PCCSC 2011). This gives a drought likelihood of0.175 per year. Assuming that a drought occurs 3 months (out of 12), and that water demand is equal for each month of the year, we can calculate the annual expected saved water during drought periods as follows:

Portion occurring during drought = 0.175 * Total annual saved water * 3/12

This is the portion of saved water that is valued at the higher (scarcity) value. The remaining water savings are valued at the regular (full cost recovery) value.

Notably, this scarcity value is only applied to options that increase available water due to improved efficiencies of existing supply (lining and covering reservoirs, repairing pipes, and improving/installing RWH systems). The gains from the options involving the airport catchment will only occur when there is rainfall, thus no "scarcity" benefits will accrue during drought. One could argue that the scarcity value should be applied to these options as well because the saved water might fall prior to a drought, be stored, and then consumed in drought periods. We assume that storage is maxed out, however, so no scarcity value is accrued.

The fourth step is to calculate the present value of the net benefits. Because projects will have impacts far into the future, we project the impacts out for 30 years and reduce their value according to how far into the future they occur. This is done by applying an annual 4% discount rate.All but one option (the geomembrane) can realistically be assumed to have a useful life of around 30 years, assuming proper maintenance. The geomembraneoption's replacement every 5 years is reflected in its NPV calculus.

The final step is to prioritize projects, and to test the sensitivity of the CBA outcomes to key assumptions. In this case, prioritization is based on: B:C ratio, total costs, and total benefits.

Data

Data were drawn from existing studies (see citation lists), databases,interviews with project and MWSC staff (Joe Cain, Mark Stege, Martha, Hallston "Wadi" deBrum, and Wally) andmarket surveysconducted during the field visit in July 2012 (Table 8). Specific sources for each parameter and assumption are included as comments in the associated Microsoft Excel CBA model.

Table 8. Data required

	Data Required	Source
Without scenario		
Water supply	- Quantity of water supplied (Area of catchment, Rainfall, Inefficiencies, Water pumped through Plant C, RWH systems) - Price of water during non-drought - Price of water during drought periods - Running costs MWSC - Running costs RWH	USAID (2009) ADB Assessments (2011a, 2011b, 2011c) EPPSO (2011) Water Survey (2010) SOPAC (unknown date a, 2007) MWSC data, interviews Market survey at stores
Water demand	- Quantity of water demanded (Per capita demand, Population, number of HH) - % HH covered by MWSC service - rate of growth in connections	MWSC (2011) SOPAC (2007) ADB (2011b) MWSC data, interviews EPPSO (2008, 2010, 2011)
Water related health issues	- 2000 incidents of pink eye - 8.5% of Majuro population with gastroenteritis in 2006 (133% more than 2001) costing $1 million over 6 year period for outpatient treatment - typhoid outbreak in 2006	EPPSO (2008, 2010)
Option 1: Install liner in reservoirs		

Costs		
Capital Costs	Quantity of material Cost of liner Cost of installation	Fabtech bid
Maintenance Costs	Quantity of labor Cost of labor (wage rate) Quantity of materials Cost of materials	Fabtech MWSC data, interviews
Benefits		
Additional Water Supplied	Quantity of water saved (leakage) during normal year Quantity of water saved during drought period Drought duration/frequency Value of water (full cost recovery, replacement)	MWSC data, interviews Shapiro (2011) Market survey

Option 2: Cover

Costs		
Capital Costs	Quantity of material Cost of material Cost of installation	Fabtech bid
Maintenance Costs	Quantity of labor Cost of labor Quantity of materials Cost of materials	Fabtech MWSC data and interviews
Benefits		
Additional Water Supplied	Quantity of water saved (evaporation) during normal year Quantity of water saved during drought period Drought duration/frequency Value of water (full cost recovery, replacement)	MWSC Market survey

Option 3: Pipes

Costs		
Capital Costs	Quantity of material, equipment Cost of material, equipment Quantity of labor Cost of labor	MWSC
Maintenance Costs	Quantity of labor Cost of labor Quantity of materials to maintain Cost of materials	MWSC
Benefits		
Additional Water Supplied	Quantity of water saved during normal year Quantity of water saved during drought period Drought duration/frequency Value of water (full cost recovery, replacement)	MWSC GEF (unknown) Market survey

Option 4: Valves

Costs		
Capital Costs: resurfacing	Quantity of material, equipment Cost of material, equipment Quantity of labor	MWSC

	Cost of labor	
Maintenance Costs: valves	Quantity of labor Cost of labor Quantity of materials to maintain Cost of materials	MWSC
Maintenance Costs: surface	Quantity of labor Cost of labor Quantity of materials to maintain Cost of materials	MWSC
Benefits		
Additional Water Supplied	Quantity of water saved during king tides Quantity of water saved during normal year Quantity of water saved during drought period Drought duration/frequency Value of water (full cost recovery, replacement)	M. Stege MWSC Market survey

Option 5: Expand

Costs		
Capital Costs	Quantity of material, equipment Cost of material, equipment Quantity of labor Cost of labor	MWSC M. Stege
Maintenance Costs	Quantity of labor Cost of labor Quantity of materials to maintain Cost of materials	MWSC
Benefits		
Additional Water Supplied	Quantity of water saved during normal year Quantity of water saved during drought period Drought duration/frequency Value of water (full cost recovery, replacement)	MWSC Markey survey

Option 6: RWH

Costs		
Capital Costs: retrofit	Quantity of material Cost of material Quantity of labor Cost of labor	Market survey
Capital Costs: install	Quantity of material Cost of material Quantity of labor Cost of labor	Market survey
Maintenance Costs	Quantity of labor Cost of labor Quantity of materials Cost of materials	M. Stege Interview with RWH contractor
Benefits		
Additional Water Supplied	Quantity of water saved during normal year Quantity of water saved during drought period Drought duration/frequency Value of water (full cost recovery, replacement)	EPPSO(2010, 2011) Market survey

It is important to note that a number of key assumptions need to be confirmed, as data were not available at the time of the analysis. A list of these data were left with PACC and MWSC staff. In particular, the assumptions regarding the full cost recovery of water, as well as the cost of construction and maintenance for each option should be reviewed by MWSC staff.

Results:

Table 9. Summary of NPV and B:C ratios for all evaluated options using baseline assumptions

Option	NPV	B:C ratio	NPV C
1 – Liner	$8.6 million	2.7	$ 0.25 million
2 – Cover	$0.97 million	18.8	$ 0.05 million
3 – Pipes	$16.0 million	6.6	$2.8 million
4 – Runway maintenance			
a. valves	$0.002 million	1.03	$0.056 million
b. cracks	$0.36 million	3.6	$0.135 million
5 – Runway expansion			
a. geomembrane	$2.0 million	3.5	$0.8 million
b. asphalt	$0.8 million	1.4	$2.0 million
6 – RWH			
a. retrofit	$ 3.4 million	1.4	$ 3.5 million
b. install	$ 14.7 million	5.1	$ 7.1 million
c. both	$ 20.8 million	4.8	$ 10.6 million

Table 10. Option-by-option results

Table 10a. Option 1 - Liner

NPV:	$8.8 million
B:C ratio:	2.7
Total discounted net cost:	$0.250 million
Assumptions: Results for relining of tanks 4 and 5 only. Tank 4 leaked 50 thousand m^3 a year, tank 5 leaked 2 thousand. This is based on 2 tests run by MWSC (1st between June29-June1, 2012, 2nd July 2- 4, 2012), where they shut output valves from tanks 1, 2, 4, and 5. Tank levels were Juneeach day. Water loss from each tank was calculated as: tank area*change in height – evaporation + rainfall. Liner will last 30 years.	

Table 10b. Option 2 –Evaporation

NPV:	$0.97 million
B:C ratio:	18.8
Total discounted net cost:	$0.054 million
Assumptions: Only tank 3 is covered. Evaporation avoided is 3.4 mm/day; rainwater hitting covered tanks is captured. The cover will last 30 years, materials and installation cost $50 thousand in year 0, and annual maintenance will cost $145 per year. Rainwater that falls on cover will not be captured.	

Table 10c. Option 3 - Pipes

NPV:	$16.0 million
B:C ratio:	6.64
Total discounted net cost:	$2.0 million
Assumptions: Current flow into pipe 347 thousand cubic meters per year. 50% current loss can be reduced to 25%. Approximately 10% of the 27 km of pipeline will need to be repaired or replaced. Labor to fix pipes is 3 days/m, materials and equipment $400/m; once replaced, maintenance will cost 0.1 day/m/year, and $1/m/year in materials.All repairs occur in year 0 and are effective for 30 years.Note that benefits from all options (other than repairing the pipes) should be adjusted by the system losses – no one ever consumes that water, so those benefits are lost.	

Table 10d. Option 4 - Airport catchment efficiency

Sub-option 1: Clean pressure relief valves

NPV:	$0.002 million
B:C ratio:	1.03
Total discounted net cost:	$0.056 million
Assumptions: King tides occur 6 days a year, and the total rainfall on these days (12.4 mm/day which is maximum daily from historical record) is lost. Maintenance of the 60 release valves would require 135 days per year; equipment is free as a truck is available to MWSC (sponsored by the FAA). No water is valued at scarcity value.Benefits accrue over a 30 year time horizon.	

Sub-option 2: Improve efficiency of runway during entire year

NPV:	$0.36 million
B:C ratio:	3.6
Total discounted net cost:	$0.135 million
Assumptions: Current capture is 80% of potential (of 550 thousand m^3 per year), and future efficiency reaches 85% in year 1. Labor to fix cracks, etc. would involve 40 people-days and materials would cost $50,000. Annual maintenance would require 120 people-days and $2,000 in materials. No water is valued at scarcity value.Capture efficiency is improved in year 0, and with proper maintenance, benefits accrue over 30 years time horizon.	

Table 10e. Option 5 - Airport catchment expansion

Sub-option 1: Geomembrane

NPV:	$2.0 million
B:C ratio:	3.5
Total discounted net cost:	$0.8 million
Assumptions: 58 thousand square meter expansionvia a geomembranecosts $200thousand, and lasts 5 years. NPV reflects value of replacing membrane every 5 years for a 30 year time horizon. Capture efficiency from the area is 80%. One day per week is needed for maintenance, and materials cost $100 annually. No water is valued at scarcity value.	

Sub-option 2: Asphalt

NPV:	$0.8 million
B:C ratio:	1.4
Total discounted net cost:	$2.0 million
Assumptions: Asphalt expansion costs $2 million upfront, and lasts 30 years. Capture efficiency from the area is 80%. One day per week is needed for maintenance, and materials cost $100 annually. No water is valued at scarcity value.	

Table 10f. Option 6 - Rainwater harvesting expansion

Sub-option 1: Retrofit existing systems

NPV:	$ 3.4 million
B:C ratio:	1.4
Total discounted net cost:	$ 3.5 million
Assumptions: 64% of households have systems; average area of roof is 53 m^2. RWH systems can capture 50% of rainfall, but 22% currently in disrepair (and catch 0%). Fixing systems can reduce 22% to 11% for 30 year time horizon. Cost to retrofit 22% of systems is incurred every 5 years. No water valued at scarcity value.	

Sub-option 2: Install new systems

NPV:	$ 14.7 million
B:C ratio:	5.1
Total discounted net cost:	$ 7.1 million
Assumptions: 64% of households have systems; average area of roof is 53 m^2. RWH systems can capture 50% of rainfall, but 22% currently in disrepair (and catch 0%). Install new systems such that coverage increases by 10% a year, reaching 100% in Y6, and benefits accrue for total of 30 years. (22% overall still remain in disrepair.)Assume initial new systems need to be replaced every 5 years. No water valued at scarcity value.	

Sub-option 3: Retrofit existing systems and install new systems

NPV:	$ 20.8 million
B:C ratio:	4.8
Total discounted net cost:	$ 10.6 million
Assumptions: See above.	

<u>Sensitivity analysis</u>

It is important to note that the benefits calculated for options 1, 2, 4, and 5 assume that all potential water savings accrued prior to distribution are actually available for consumption. Actual system losses within the 13.3 km between the water treatment plant and the majority of consumers are very high, however, estimated at more than 50%. Without reducing losses from the distribution pipe *all estimated benefits for options 1, 2, 4, and 5 are actually far below the potential*. Table 11 illustrates the benefits if the pipe not repaired prior to undertaking other projects.

Table 11. NPV and B:C ratios of options if distribution losses remain at 50%

Option	NPV	B:C ratio
1 – Liner	$4.2 million	1.3
2 – Cover	$ 0.45million	9.4
4 – Runway maintenance a. valves b. cracks	 $ - 0.03 million $0.1 million	 0.5 1.8
5 – Runway expansion a. geomembrane b. asphalt	 $0.6 million $-0.6million	 1.7 0.7

As the PACC team identified reservoir liner replacement as a priority option, an analysis can provide insight into the sensitivity of this option to key assumptions, namely the tanks targeted for relining and leakage from each tank. Leakages from each tank were roughly estimated based on a 6-day test where valves were closed and reservoir levels measured (for Tanks 1, 2, 4, and 5). Once rainfall and evaporation were factored in, it was estimated that each tank leaked slightly (on the order of 5 m^3/day), with the exception of tank 4 which leaked more than 137 m^3/day. Using these leakage estimates, if only Tank 4 is relined (instead of both Tank 4 and 5), the B:C ratio jumps to 5.2, with a cost of US$125 thousand, and an NPV of US$8.4 million. If leakages are closer to twice the measured amounts, the B:C ratio reaches 5.4, and the NPV is US$17.4 million.

Sensitivity of the potential NPVs to a number of key assumptions is shown in Table 12 below:

- Per capita demand (tested effect of halving per capita demand, i.e., 40 gallons per person per day to 20)
- Value of water (tested effect of assuming cost recovery value of water is 1.5 times residential market price)
- Portion of water supplied during drought (v. non-drought) periods (assumed that drought conditions persist 6 months, rather than 3)
- Expected rainfall (assumed future rainfall will be closer to historical lows than mean, i.e., 7.98 mm/day annual average instead of 9.2; and that rainfall on king tide was 75% of maximum, not 100%, i.e., 9.28 instead of 12.4 mm/day)
- Efficiencies/losses (for the pipes option: assumed current losses 25% which would be brought to 12.5%; runway capture: assumed 60% current efficiency improved to 70%; for new runway expansion, assumed capture efficiency will be 40% (not 80%); and for RWH assumed capture coefficient 75% (not 50%).
- Length of project (option) life (adjusted evaluation period for liner (from 30 to 20 years); evaporation cover (from 30 to 20 years); geomembrane (extending the period of replacement from 5 to 10 years); and asphalt (from 30 to 20 years).

Table 12. Sensitivity of NPV to key assumptions

	Baseline	**Demand**	**Value**	**Drought**	**Rainfall**	**Efficiencies**	**Lifespan**
Option							
1- Liner	8.78	8.78	9.23	16.89	8.78	8.78	8.59
2 - Cover	0.97	0.97	1.01	1.90	0.97	0.97	0.87
3- Pipes	15.97	15.97	16.71	33.23	15.97	44.18	15.97
4a - Valves	0.002	0.002	0.031	0.002	-0.013	0.002	0.002
4b - Cracks	0.36	0.36	0.60	0.36	0.36	0.82	0.36
5a - Geomembrane	1.98	2.67	3.36	1.98	1.98	0.59	2.33

5b - Asphalt	0.75	1.45	2.14	0.75	0.75	-0.64	-0.75
6a - RWH retro	3.38	3.38	3.59	8.24	2.71	6.03	3.38
6b - RWH install	14.66	14.66	15.42	32.36	12.24	24.30	14.66
6c - RWH both	20.76	20.76	21.83	45.82	17.33	34.41	20.76

Overall, the vast majority of the projects' NPVs and relative rankings are largely insensitive to the tested assumptions – NPVs stay in the same order of magnitude, and the ranking of options remains unchanged. Specifically, demand does not affect our results ("Demand" column above). This was expected as the CBA modeling is based on supply. The NPVs are robust to increasing the value assigned to water during non-drought periods ("Value" column).For many options, the NPV changes the most when we double the proportion of water valued at scarcity value (the "Drought" scenario). This is not surprising, as the value of water delivered in drought conditions is over 200 times more valuable than water in non-drought times. There is no change in option order, however. Reducing the available water ("Rainfall") by using the lower bound of historical precipitation greatly affects the options dependent on rainwater (as opposed to efficiency improvements), i.e., Options 4b – 6). The only case of a negative NPV is for the valve maintenance option in the low rainfall scenario. Altering the assumed efficiencies at the outset and the gains that can be made affect the results for the pipes option, as well as the RWH options. Finally, adjusting the project life down for options 1-4, 5b and 6 decreases the NPV slightly. Increasing the lifespan of the geomembrane used in expansion improves its NPV.

Equity/distributional issues

Because of the nature of the options assessed, that is, improving the water supply from the airport facility to the DUD-Rairok area, beneficiaries are limited to current and future inhabitants of these areas. While only residential benefits were assessed, increased water supply could be used for commercial, agricultural, and other purposes, and might end up used by other types of users (government, commercial). Benefits of all but the RWH option will accrue only to the customers of MWSC water. The affordability of MWSC water services has not been assessed. Poor households may not be able to afford MWSC water, thus to ensure the equitable distribution of benefits leveraged by the PACC project, its supply-side measures may need to be complemented by subsidies, means-adjusted tariffs, or other measures that are calibrated to household means. A study investigating the affordability and access of water by poor households could guide the design of such measures.

For the RWH, beneficiaries will be households with RWH systems; the distribution of those benefits will depend on the current distribution of RWH systems (that would be retrofitted) and the equity of the expansion. Particular care should be paid to ensuring that poor households are equally able to access the funds to retrofit and/or install systems.

Some benefits may accrue to Laura residents, as improving efficiencies in MWSC supply will reduce MWSC's demand on the groundwater resources at Laura, but the benefit to them will depend on whether MWSC actually reduces its withdrawals, as opposed to expanding service. To alleviate current conflicts, MWSC has committed to a number of immediate improvements for Laura communities, including water tanks, as well as reduced pumping.

Capital costs are being borne by the international community through development assistance. Long-term operation and maintenance for all options should be recouped through cost recovery by MWSC.

Conclusions and recommendations

The importance of fixing the losses along the distribution pipe is clear: actual benefits of any interventions that increase available supply at the airport are far lower than their potential (Table 13). The top priority should be to improve the efficiency of the pipeline. Further study is needed to pinpoint leaks and estimate the cost of repairs and maintenance.

All projects and options had positive B:C ratio.Evaluating *potential* additional supply (this assumes the supply is actually delivered, e.g., no losses), installing the evaporation cover results in the highest ratio of benefits to costs (18.8), followed by pipe repair (6.6).All projects had positive NPVs. The highest overall NPVs were for the combined RWH projects (retrofitting and installing new systems) (US$20.8 million), pipes (US$16.0 million), and liner (US$ 8.6 million).

Table 13. NPV, B:C ratio without and with current losses

Option	NPV (Potential) $ million	B:C ratio (Potential)	NPV (With losses) $ million	B:C ratio (With losses)	NPV C $ million
1 – Liner	$8.6	2.7	$4.2	1.3	$ 0.25
2 – Cover	$0.97	18.8	$ 0.45	9.4	$ 0.05
3 – Pipes	$16.0	6.6			$2.8
4 – Runway maintenance					
c. valves	$0.002	1.03	$ -0.03	0.5	$0.056
d. cracks	$0.36	3.6	$0.1	1.8	$0.135
5 – Runway expansion					
c. geomembrane	$2.0	3.5	$0.6	1.7	$0.8
d. asphalt	$0.8	1.4	$-0.6	0.7	$2.0
6 – RWH					
d. retrofit	$ 3.4	1.4			$ 3.5
e. install	$ 14.7	5.1			$ 7.1
f. both	$ 20.8	4.8			$ 10.6

Constraining choices to those within the $0.8 million PACC project budget, based on the potential water savings and list of options provided by PACC, the CBA prioritizes the evaluated options as:

(1) Fix portion of pipeline
(2) Install multiple evaporation covers
(3) Install new liners in Tank 4 only
(4) Repair cracks in existing runway catchment
(5) Expand airport catchment using geomembrane

The B:C ratio for the pipe repairs scales with the number of kilometers repaired. That is to say, if the project budget can only afford a fraction of the estimated US$2 million required to fix the leaks in the 27 km of distribution pipe and transmission pipe, it would still be worth concentrating on fixing only a portion of water.[3]If the pipes are not repaired, then the potential benefit of the other options also scales with the distributional losses, currently estimated to be 50% (Table 13).

It would be worth considering installing evaporation covers on more than one tank. According to the model, the B:C ratio scales for multiple tanks. Covers could be put on all tanks at an initial cost of US$363 thousand, which would deliver an NPV of nearly US$7 million (maintaining a B:C ratio of 18.9). It would be important to verify the 3.4 mm/day evaporation rates provided by MWSC to confirm water savings. The evaporation covers only make sense if rainwater that falls on the covers will also be captured.

Assuming that the leakage estimates are correct, then relining only Tank 4 (as opposed to Tank 4 and 5 originally evaluated) increases the B:C ratio to 5.2, and the NPV to US$8.6 million for a total upfront cost of US$125 thousand. A better estimate of leakages from each tank is required to confirm these results.

Fixing cracks in the existing runway would be a relatively cheap project that would deliver good results. This option should be studied more carefully, as some assumptions in the CBA regarding current losses and potential gains, costs, and so forth need to be verified.

Expanding the airport catchment with geomembrane had the next highest B:C ratio. The initial cost to install the full 58.5 thousand m^2 would require the entire project budget. However, the ratio scales with the area, so an option would be to set a more moderate expansion goal. For example, expansion of 29 thousand m2 would still have a B:C ratio of 3.3, at a cost of US$413 thousand, delivering an NPV of US$0.98 million.

[3]This assumes that leaks will not get worse elsewhere in the pipe due to repairs in part of it, something that the engineers should verify.

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