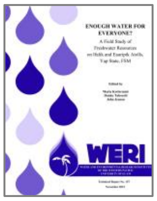

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Hydrologic Assessment of Selected Outlying Islands, Yap State, Federated States of Micronesia (FSM): Field and Modeling Results

Prepared for
Secretariat of the Pacific Community-Global Climate Change Alliance,
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by
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1. REASONS, OBJECTIVES, METHODS AND SCOPE FOR PROJECT

- Reason: Atoll islands are highly vulnerable to depletion of rainwater and fresh groundwater, especially during major droughts, but quantitative data for managing freshwater accessibility and quality in the atoll islands of the FSM are scarce.
- Objectives: (1) Obtain current data on existing freshwater availability, storage capacity, and use on a representative FSM atoll; (2) Use the new field data, along with existing data from historical literature to conduct studies of selected islands.
- Methods and Scope: This project undertook the following activities for four selected outer islands of Yap State—Ifalik, Eauripik, Satawal, Ulithi:
    - LITERATURE SEARCH: Project planning and implementation included a comprehensive and ongoing search of the historical scientific-technical literature on the selected islands
    - ON-SITE VISITS by a iREi/WERI field team to two atolls, traveling aboard the Yap Fishing Authority (YFA) vessel, Mathayal Yap, 12-25 August 2015:
        - Ifalik: one-week intensive field study, 17-22 August 2015
        - Eauripik: one-day incidental study, 23 August 2015
    - MODELING STUDIES: Groundwater/rainwater modeling studies by the CSU modeling team for Ifalik, Eauripik, Satawal, Ulithi, June-November 2015:
        - Ifalik modeling study incorporated data from the August 2015 field visit.

Eauripik, Satawal, Ulithi modeling studies utilized data from previous studies and general literature.

2. FIELD OBSERVATIONS AND RESULTS: IFALIK AND EAURIPIK VISITS (»)

2.1. Household/ compound inventory (»):

Village Name	Number of Compounds	Number of Residents[1]
FELAASHIGI VILLAGE	12	157
RAWAIU VILLAGE	17	179
IYEFANGI VILLAGE	7	85
IYEIURIU VILLAGE	7	110
Total	43	531

[1] Note that these numbers are based on interviews with each compound and might be underestimated. Nonetheless they should give a good estimate on the relative sizes of the villages for planning purposes. The total population of Ifalik based on the 2010 FSM census data is 578 while the Framework for Integrated Vector Management in Yap State 2015-2020 states a population of 780.

2.1. Ifalik groundwater wells (»). Each well on the island was visited and inventoried.

- Well construction: Thirty of the 99 wells have a raised rim; nine of the 99 wells are covered.
    - Raised rims and covers should be installed on all wells used for drinking and cooking.
- Groundwater protection: Cemeteries are currently appropriately placed away from well locations.
    - This practice should be maintained; individual burials on home sites (observed on other islands) should be discouraged.

2.2. Sanitation. General sanitary practices, especially disposal of human waste were observed:

- Toilet practices: Traditional toilet practice, *i.e.*, use of selected nearshore reef flat locations, is more hygienic and sanitary, and does not contaminate groundwater, as pit toilets would.
    - It is recommended, however, that such sites be confined to the ocean side; the lagoon side should be avoided because of restricted circulation.

2.3. Rainwater catchments (»): All 47 compounds (consisting of several households) and 8 communal sites were visited and inventoried. At each site, the team photographed the catchments, recorded GPS locations, measured the catchments' surface area and the portion that is guttered, noted the condition of the guttering, and recorded the type and capacities and extant water volume stored in each storage tank:

- Household catchments: Although most houses have traditional thatched roofs, every compound has typically several smaller structures (such as cooking or storage huts) with corrugated steel roofs that serve as catchments. The condition of these varies from more than adequate to virtually inoperable. One out of three compounds only has one storage tank while the others have two or more. In addition to storage tanks, most compounds use makeshift containers (from metal bowls to buoys) to collect water.
    - It is recommended that each household acquire and maintain two tanks, so alternate tanks can be cleaned regularly while the other retains stored water that can transferred into the other during cleaning.
    - Recommend cleaning at least twice a year, and especially at the beginning of each wet season.
- Communal catchments: The only communal tank on Ifalik that is still in use is located at the school. It is made of concrete. It was reported that it requires constant maintenance and repair – which the field team observed during their visit. Other public structures, of which there are about a dozen, are being utilized as catchments by neighbouring households.
    - Acquisition of a second household tank is beyond the means of most households. In the absence of external funding and assistance, the best alternative is rehabilitation of the school tank and acquisition of a communal tank for each village—Rawaiu, Felaashigi, Iyefangi, and Iyeluriu.
    - Village communal tanks should be made of light-weight material[2] and have a total capacity of at least 2000 gallons (7500 litres) for each village. Concrete tanks are not recommended, as they are difficult to maintain and impossible to dispose of when they cannot be repaired.
    - Communal tanks should be cleaned at least three times a year. This would be best achieved by cleaning one of the four communal facilities each month, so that each one is cleaned at 4-month intervals.

2.4. Water quality sampling (»). Twenty wells were sampled with field test kits for *E. coli* and nitrate; four wells were sampled for chloride. Since most catchment roofs are made of zinc-coated steel, water samples from three catchment tanks collecting water from such roofs were taken also to check the zinc concentration:

[2] By light-weight material we mean polymer or fiberglass, etc., as opposed to concrete or steel.

- Sample results: Of the 20 wells tested for *E. coli* and nitrate, all but one were positive for *E. coli*, but only one was above detection limit for nitrate.
    - Since *E. coli* is ubiquitous in tropical environments, the positive results need not be regarded as indicators of sewage contamination, especially since nitrate was absent in all locations, save one, in where it was only 10 ppm. (This well, primarily used for washing, was associated with a residential compound consisting of several households adjacent to a small cemetery.)
    - Given that there are no pit toilets in use on the island, groundwater is not at risk for human sewage contamination. Nevertheless, as recommended in para. 2.1 above, wells should be rimmed and covered at the surface to prevent animal or inadvertent contamination.
    - Chloride samples from the four wells tested showed the water to be of remarkably low salinity, with all sample less than 100 ppm chloride. (The USEPA secondary standard is 250 ppm.)
    - Tests revealed no evidence of zinc contamination.

2.5. Water use on Ifalik (»). Use of water includes drinking, cooking, dishwashing, cleaning of root crops, cleaning of meat, bathing, rinsing, showering, and washing laundry. Field observations and information from interviews (») regarding each include:

- Drinking: Rain catchments are the principal source for drinking water, but daily personal hydration is supplemented by one to four coconuts even when catchment water is available, and more coconuts when it is not.
    - Most households reported that during the driest time of each year they have had to obtain water from other households or have turned to groundwater, which they report that they boil prior to drinking.
- Cooking: Both rainwater and groundwater are used for cooking:
    - Rainwater is preferred for foods that absorb or contain lots of water, such as rice or soup.
    - Groundwater is used to boil foods that require long cooking and do not absorb much water, such as breadfruit or taro. This practice conserves rainwater for cooking high-water-content foods and other uses.
- Dishwashing: Inland households use groundwater, but households close to the shore tend to use seawater.
    - Only a couple of households reported using rainwater, and then only when it was in ample supply.
- Root crops: Root crops are exclusively washed and boiled in groundwater.
- Meat: Carcases of slaughtered animals are cleaned with seawater or groundwater. Chicken and fish are commonly boiled, but meat from larger animals (pig, dog, turtle) is roasted in an earth oven.
- Bathing: With the exception of babies, who may be bathed in plastic tubs filled with groundwater, island residents bathe exclusively in seawater.
    - Only a couple of households reported using rainwater, and then only when it was in ample supply.
- Rinsing and showering: Small amounts of groundwater are used from convenient wells. Rainwater is not used for rinsing or showering.
    - There are a number of wells along the coast, particularly near the canoe houses, from which people bail water with which to rinse after bathing in the sea.
    - Wells near taro patches are used for cleaning off after working in the taro patch.

- Laundry: Prewashing is often down in seawater; otherwise laundry is washed exclusively in groundwater.

2.6. Vegetation survey of Ifalik (»). Seven 10 m × 30 m plots, at locations spanning the island, were surveyed for vegetation. These are meant to serve as baseline for future environmental studies. In particular, evapotranspiration by vegetation is an important component of water budgets for groundwater availability studies.

- Locations: Plots were selected to provide representative coverage undisturbed vs. disturbed, and leeward vs. windward conditions.
- Species were counted within each of three layer: Herb layer, understory, and overstory/ canopy.

2.7. Other surveys. Scientific data recorded to support groundwater modeling and subsequent environmental studies include 1) ground elevation, 2) tide measurement, 3) well-level response 4) sea-level indicators, and 5) long-term storm frequency and severity.

- Ground elevation (»): The field team attempted, without success, to find a 1961 USGS benchmark, but constructed an unofficial benchmark on a limestone block embedded in the ground about 5 m W from the south frontal post of the main Men's House.
- Tide measurement (»): The team installed a temporary tide gauge in the lagoon, west of the Men's House, anchoring a level-logger attached to rebar, over which a 2-inch (5 cm) diameter PVC pipe was installed to act as a stilling well. Tidal measurements were taken at 5-minute intervals from 1516 local time 16 Aug 2015 to 1257 local time 22 Aug 2015.
- Inland well-level responses to tidal signal (»): To provide field measurements of hydraulic conductivity with which to parameterize the groundwater model, the team took hourly manual measurements of water levels at two inland wells from early morning until 2200 on 16 and 17 Aug 2015.
    - Subsequently, the team rotated a level-logger through a set of inland wells along a transect perpendicular to the coast, extending inland from the location of the tide gauge.
- Sea-level indicators (»): A reconnaissance study was made of microatolls (coral heads with the vertical growth limited by tidal exposure) on Ifalik and Eauripik atolls. Objective was to evaluate recent sea-level change trend and the sea-level drop associated with the ongoing epic El Niño.
    - The shape and two cross-sections of the microatolls on Ifalik indicate that they formed in sea-level rise conditions, while on Eauripik the shape and conditions of the microatolls indicate a stable relative sea level, possibly even a slight sea-level drawdown.
    - Microatolls exhibited several centimetres of recent bleaching downward from top of the coral, presumably due to the recent El Niño-driven drop in sea-level across the western Pacific—the first one of such magnitude since the 1997-1998 El Niño.
- The reef and island morphology (»): This was observed to tentatively estimate the storm frequency and severity on the island, both crucial for island and its population storm vulnerability assessment.
    - The observations indicate that Ifalik has been formed under occasional severe storm conditions, while Eauripik formed in relatively storm free environment with rare surge.

Detailed recommendations based on field observations and interviews are provided in the online report (»).

3. MODELING RESULTS (»)

3.1. Ifalik.

- Rainwater Catchment Modeling: A water balance model was applied to each rainwater catchment system to determine performance in drought periods and future climate scenarios. In total, 100 rainwater catchment systems were surveyed and included in the modeling effort.

- Only about 1/3rd of the 100 systems will maintain adequate water supply during a major drought, even if rationing is used.
- If total available roof area is used, then the ability of the systems to maintain adequate water supply is enhanced significantly.
- Performance of rainwater catchment systems under future rainfall patterns is not significantly different than under historical rainfall conditions.
- The total volume of captured rainfall is influenced by the following system components, in order of decreasing importance: 1) guttered roof area; 2) gutter efficiency (how much the gutter leaks); 3) volume of storage tank.

- <u>Design Curves for Rainwater Catchment Systems</u>: Historical rainfall data and future rainfall data were used to create design curves for the catchment systems. These curves represent pairs of roof area and storage tank volume that will meet a certain degree of reliability.
  - Curves can be used to 1) assess the reliability of current rainwater catchment systems; and 2) design new systems. For example, if the tank size is known, then the curves can be used to determine the required roof area.
  - As the rainfall data pertains to the general Yap State geographic area, these design curves can be employed for island communities throughout Yap State.
  - Design curves were also created using future simulated rainfall data. However, these curves are not reliable as the future rainfall patterns do not include intense droughts.
- <u>Response of Aquifer to Climate Scenarios: Sea Level Rise</u>: A tested freshwater lens simulator was used to determine the thickness of the freshwater lens during the years 2030 and 2050 under various scenarios of future rainfall and sea level rise.
  - Under maximum sea level rise conditions (0.24 in/yr [6 mm/yr]), the lens under the northern section of the island decreases by 35%, from 7.2 ft to 4.6 ft (2.2 m to 1.4 m), and the lens under the southern section decreased by only 7%, from 15.4 ft to 14.4 ft (4.7 m to 4.4 m).
  - The average lens thickness across all sea level rise scenarios is 6.6 ft (2.0 m) for the northern section and 15.1 ft (4.6 m) for the southern section.
- <u>Response of Aquifer to Future Varying Rainfall</u>: To determine month-by-month fluctuation of freshwater lens thickness and volume, a numerical model (SEAWAT) was constructed for Ifalik and run using GCM output for the years 2010-2040.
  - During the 30-year period, maximum lens thickness is 15.7 ft (4.8 m) and minimum lens thickness is 7.5 ft (2.3 m), with an average of 10.8 ft (3.3 m). Periods of low rainfall resulted in periods of a thin lens, but depletion did not occur.
  - Overall, the freshwater lens on Ifalik is fragile, and extensive development of groundwater resource is not recommended.

3.2. <u>Eauripik.</u> Each well on the island was visited and inventoried

- <u>Design Curves for Rainwater Catchment Systems</u>: The design curves described in 3.1 for Ifalik also apply for Eauripik.
- <u>Response of Aquifer to Climate Scenarios: Sea Level Rise</u>: The freshwater lens simulator was used to determine the thickness of the freshwater lens during the years 2030 and 2050 under various scenarios of future rainfall and sea level rise.
  - Under maximum sea level rise conditions (0.24 in/yr [6 mm/yr]), the lens of the island decreases by 24%, from 8.8 ft to 6.6 ft (2.7 m to 2.0 m).
  - The average lens thickness across all sea level rise scenarios is 8.2 ft (2.5 m). HOWEVER: based on the numerical modeling results (see next bullet point), these results should not be used for planning purposes.

- Response of Aquifer to Future Varying Rainfall: To determine month-by-month fluctuation of freshwater lens thickness and volume, a numerical model (SEAWAT) was constructed for Eauripik and run using GCM output for the years 2010-2040.
    - During the 30-year period, maximum lens thickness is 2.7 ft (0.85 m) and minimum lens thickness is 0.0 ft (0.0 m), with an average of 0.3 ft (0.1 m).
    - Overall, a lens does not form adequately on Eauripik for general groundwater use. This condition likely will not change under future climate scenarios.

3.3. Satawal.

- Design Curves for Rainwater Catchment Systems: The design curves described in 3.1 for Ifalik also apply for Satawal.
- Response of Aquifer to Climate Scenarios: Sea Level Rise: The freshwater lens simulator was used to determine the thickness of the freshwater lens during the years 2030 and 2050 under various scenarios of future rainfall and sea level rise.
    - Under maximum sea level rise conditions (0.24 in/yr [6 mm/yr]), the lens of the island decreases by only 3%, from 30.8 ft to 30.2 ft (9.4 m to 9.2 m).
    - The average lens thickness across all sea level rise scenarios is 31.1 ft (9.5 m).
- Response of Aquifer to Future Varying Rainfall: To determine month-by-month fluctuation of freshwater lens thickness and volume, a numerical model (SEAWAT) was constructed for Satawal and run using GCM output for the years 2010-2040.
    - During the 30-year period, maximum lens thickness is 25.9 ft (7.9 m) and minimum lens thickness is 15.7 ft (4.8 m), with an average of 19.4 ft (5.9 m).
    - Overall, the size of Satawal is conducive to a moderately sized freshwater lens. Groundwater can continue to be used for domestic water needs.

3.4. Falalop, Ulithi.

- Design Curves for Rainwater Catchment Systems: The design curves described in 3.1 for Ifalik also apply for Falalop.
- Response of Aquifer to Climate Scenarios: Sea Level Rise: The freshwater lens simulator was used to determine the thickness of the freshwater lens during the years 2030 and 2050 under various scenarios of future rainfall and sea level rise.
    - Under maximum sea level rise conditions (0.24 in/yr [6 mm/yr]), the lens of the island does not decrease from present-day conditions due to an increase in rainfall rates.
    - The average lens thickness across all sea level rise scenarios is 20.0 ft (6.1 m).
- Response of Aquifer to Future Varying Rainfall: To determine month-by-month fluctuation of freshwater lens thickness and volume, a numerical model (SEAWAT) was constructed for Falalop and run using GCM output for the years 2010-2040.
    - During the 30-year period, maximum lens thickness is 23.0 ft (7.0 m) and minimum lens thickness is 14.4 ft (4.4 m), with an average of 18.0 ft (5.5 m).
    - Overall, the size of Falalop is conducive to a moderately sized freshwater lens. Groundwater can continue to be used for domestic water needs.