

WATER RESOURCES ANALYSIS OF FAIS ISLAND, FEDERATED STATES OF MICRONESIA

by

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WERI

**WATER AND ENVIRONMENTAL RESEARCH INSTITUTE
OF THE WESTERN PACIFIC
UNIVERSITY OF GUAM**

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ABSTRACT

Fais Island is an elliptical uplifted carbonate platform with an area of approximately 0.75 square miles (2.0 km^2) and an elevation of approximately 66 feet (20 m). Although the approximately 310 residents of Fais rely almost exclusively on rainwater catchment systems for potable water, the island contains an aquifer with a viable freshwater lens. Currently, the rainwater catchment network is insufficient to collect and store enough water to meet the needs of the islanders during major droughts, especially those following El Niño events. The network is also vulnerable to the inevitable typhoons that could render it inoperative for many months. To enable us to prevent these natural disasters from effecting the health and quality of life of Fais Islanders, we studied their rainwater catchment systems and the island's basic geology and hydrologic features including its caves.

We conducted a comprehensive survey of all rainwater collection and storage components; a water usage and distribution survey of the residents; a visual inspection of all coastal areas, both on foot and by boat; a complete survey of all known caves and cave features; and well documentation and testing. To facilitate these tasks and assist in future studies we developed a series of GIS coverages and maps that include: previous maps of the geography, the land and water uses, and the three villages; GPS points of well locations, caves, and hydrologic features including freshwater discharge points; the topography of an ancient dug well; and a digital elevation model (DEM). We studied the well data and calculated the approximate properties of Fais' freshwater lens. We analyzed the rainwater catchment network using a modified multi-level version of RoofRain, a spreadsheet model developed by Dr. Leroy Heitz. We ran several potential solutions through this model to develop recommendations for system upgrades, modifications, and maintenance, as well as the development of Fais' groundwater as an emergency resource.

Water Resources Analysis of Fais Island, Yap State, FSM

1.0 INTRODUCTION

Residents of Fais currently rely almost exclusively on coconuts and rainwater catchments to meet their potable water needs. However, Fais lies within the Western Pacific typhoon corridor, and storms strike the island about every 10-12 years (Lander, 2006), destroying or damaging the rainwater catchments. These major storms also damage or destroy the coconuts, which are the preferred and primary routine source of daily fluid intake for most residents. The most recent damaging storm, Typhoon Lupit, struck in November 2003. Most of Fais' coconut trees were stripped of their fruit, leaving only a few days' supply. Many of the island's roofs were destroyed and most were damaged, preventing the residents from collecting all but small quantities of rainwater with makeshift systems. Some tanks were destroyed, reducing the total storage capacity on the island.

In addition to the threat from typhoons, the severe droughts that follow major El Niño events can leave residents virtually destitute of rainwater for months. Such droughts occur at eight-to-15-year intervals (Enfield, 2005). Once the rainfall stops, the island's water supply is consumed in less than two months, while the quality and quantity of the coconuts also deteriorate (Interviews, 2005).

When rainwater catchments, storage tanks, and the coconut supply are degraded by storm damage or drought, groundwater is the only immediate emergency source of drinking water. Despite the fact that the island possesses exploitable groundwater, it has yet to be developed as an emergency supply. Prior efforts to develop groundwater have produced usable sources, including an ancient hand-dug well and a concrete-lined well installed during the Japanese colonial era. Although these can and have been brought into service during emergencies, water must be extracted and carried from them by hand, and neither well is convenient to the current village locations. More recent efforts to install and develop wells from 1996 to 1999 (Zheng, 1996) near the villages have met with limited success. None of the four wells installed is currently in service, and only one is capable of being brought on line for emergency use. Despite the installation of these wells, no definitive study has yet been conducted to characterize the fresh water lens.

Residents of Fais continue to rely on extensive household and communal catchment and storage systems. To ensure residents are able to develop and maintain a water production and storage system capable of managing future emergencies, technical recommendations regarding maintenance and management of rainwater and groundwater production on Fais must be compatible with the island's social traditions, cultural values, and indigenous authority.

1.1 Objectives

This report is based on the research thesis of first author (MacCracken, 2006) whose objective was to make recommendations for creating a sustainable and self-sufficient water supply on Fais. The supporting steps in this study were thus to (1) describe existing practices of water production, distribution, and sharing; (2) evaluate catchment and storage capacity of existing rainwater catchments and groundwater resources; (3) estimate the current demand for water production and suggest appropriate

approaches for meeting it; and (4) identify the cultural factors that relate to water resource use. This report includes a digital elevation model and GIS (Geographic Information System)-based maps showing significant caves, wells, catchment systems, and natural features.

1.2 Geographic Description of Fais

Fais Island is a small (0.75 mi², or 2 km²), uplifted carbonate island, with a resident population of approximately 300 people. Maximum elevation is about 66 feet (20 meters). Archaeological investigations have confirmed that Fais has been continuously occupied for nearly 2,000 years (Intoh, 1997). For several years prior to and during World War II, the island's interior plateau was strip-mined by the Japanese for phosphate (Nugent, 1944), affecting approximately 45 percent of the island's surface area (Figure 1). Today the islanders' livelihood is based mainly on subsistence gardening and fishing. With the exception of two, small family-owned retail stores, there are no commercial establishments on Fais.

Fais lies in the Western Pacific between 140.51 and 140.53 degrees east longitude, and 9.75 and 9.77 degrees north latitude; 450 miles (720 km) southwest of Guam and 360 miles (580 km) northeast of Palau. Politically, it is one of the outer islands of Yap State, which is one of the four states of the Federated States of Micronesia (FSM).

The FSM comprises most of the Caroline Islands (Figure 2). Previously a United Nations trust territory, the FSM became an independent nation in 1986 when a compact of free association with the United States was implemented (U.S. Congress, 1986).

Yap State consists of 134 islands, 22 of which are populated, and extends of a total area of more than 100,000 square miles (260,000 km²) (Internet, 2005b). There are two separate, indigenous Austronesian languages spoken in Yap State: Yapese and Haselmathaw (the related dialects of the outer islands). Fais Islanders speak a dialect of Haselmathaw, and many are fluent in English as well. English is widely spoken and understood throughout the FSM, and many elderly Yapese are also fluent in Japanese.

The FSM's climate is tropical wet-dry, with average daily temperatures in the low 80s Fahrenheit (upper 20s Celsius) year-round (Internet, 2005a). The average annual rainfall on Yap is approximately 130 in/yr (330 cm/yr) (gage # 4951, Yap Island WSO Airport), most of which occurs during the rainy season (June-September). Annual rainfall, however, can be as low as 100 in/yr (250 cm/yr) following an El Niño event. Relative humidity ranges from 65 to 100 percent.



Figure 1. Composite aerial photograph of Fais Island (Aquarius Flight Inc. 1995).

1.3 Geologic Setting of Fais

Although Fais Island is part of the same political entity as its state capital (Yap proper), it lies on the opposite side of a trench that separates two tectonic plates and places Fais in a fundamentally different geologic setting (Figure 3). Yap lies on the eastern edge of the Philippine Sea Plate, close to the Yap Trench, where the Philippine Sea Plate converges with the Caroline Plate. The Caroline Plate is moving WNW relative to the stable Asian continent while subducting under the Philippine Plate. Fais Island is on the western edge of the Caroline Plate, and its origin is related to the collision of the Caroline Ridge with the Philippine Sea Plate during the middle Cenozoic (possibly during the early Miocene, approximately 24 Ma). It is uncertain if the Caroline Ridge is still colliding with the Philippine Sea Plate or has begun to subduct beneath it. Fais is on the northern section of the Caroline Ridge, which is separated from the southern section by the Sorol Trough trending WNW-ESE. The entire system of ridges was created in the

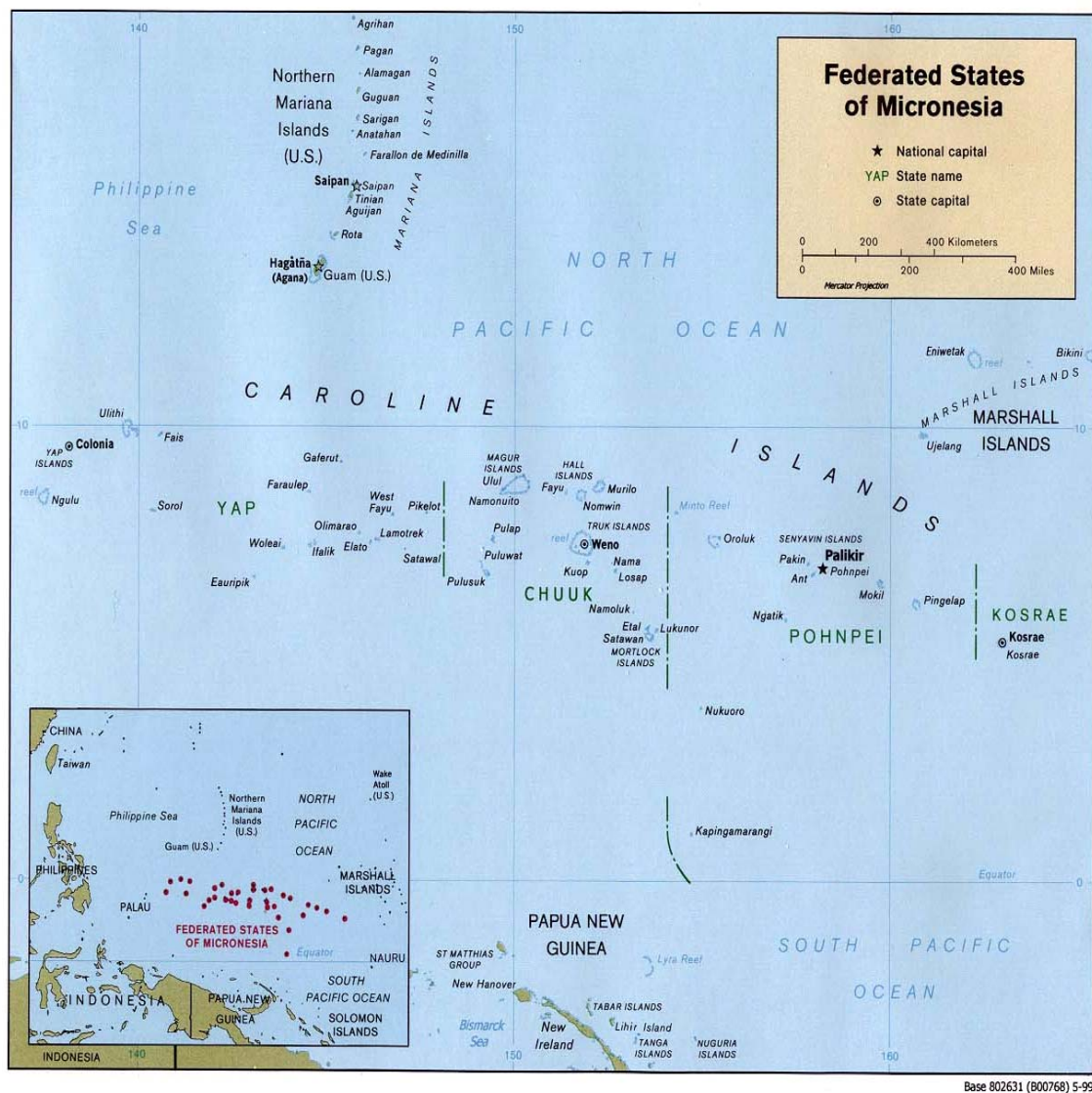


Figure 2. Federated States of Micronesia – Regional Map (United States Central Intelligence Agency, 1999).

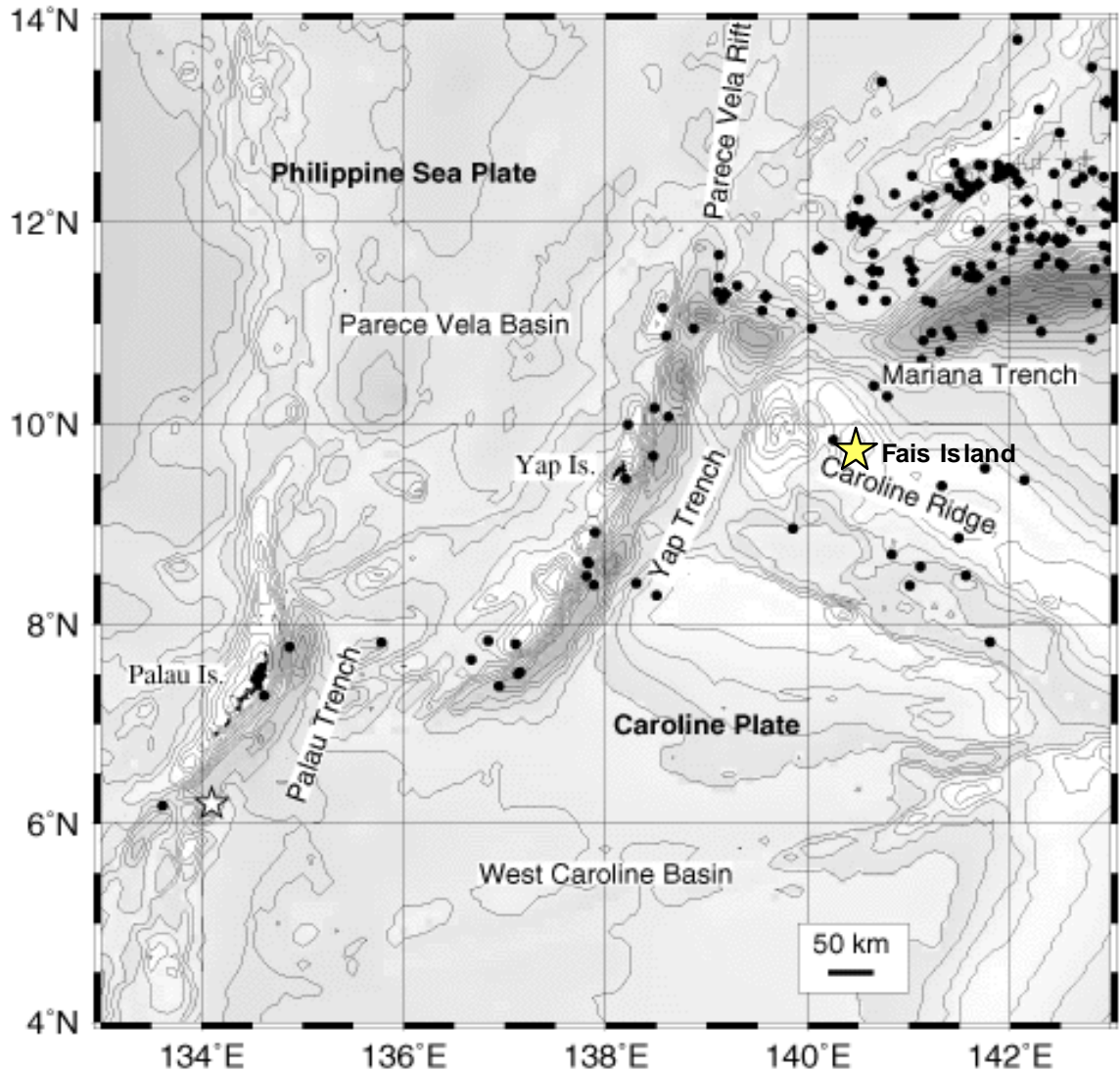


Figure 3. Bathymetry map of the Yap Trench. The dark dots designate seismic activity. (ETOP05 (Earth Topography - 5 Minute), 1988).

Oligocene by the Caroline hotspot (Keating, Matthey, and others, 1984). When these thickened, low-density ridges entered the subduction zone and the regional tectonics changed, creating many faults and complex displacements (Lee, 2004). It is likely that the basement of Fais Island was uplifted during this period's differential thinning and thickening of the Caroline Plate's crust. Fais and the nearby Ulithi Atoll are moving toward the Philippine Sea Plate at half the rate as the Pacific Plate and in a more northerly direction, differentiating the Caroline Plate's motion from the Pacific Plate's and demonstrating a more complex interaction than simple oceanic subduction (Kotake, 2000).

Unlike most other islands in the FSM, Fais is neither an atoll nor a volcanic island. Although it is possible that Fais has a volcanic basement, the early stage subduction and lack of forearc development related to the Yap Trench (Lee, 2003) makes

it equally likely that the island is a product of tectonic stresses and faulting in the back-arc region. Regardless of its origins, the island is now an uplifted, carbonate platform, showing evidence of exposure to different sea levels. Although no studies have been conducted on the island's lithology, carbonate development would have started as soon as the seafloor reached the carbonate compensation depth or CCD (the depth below which the pressure and temperature combine to cause carbonate detritus to dissolve and prevent it from accumulating). The range of the CCD in the Pacific Ocean is 13,000–16,500 feet (4000-5000 m deep). Given the likely rate of uplift, Fais Island could thus have been developing in this manner for as long as 20 million years.

1.4 Field Work

During this two-year project, first author MacCracken made three trips for a total of 21 days on Fais Island, accompanied by the rest of the authors and field assistants on various trips. The activities of each trip are briefly described below.

1.4.1 August 2004

While on Yap, en route to Fais, we acquired aerial photographs and topographic maps of Fais from the Department of Resources and Development. Once on Fais, the field team conducted a comprehensive survey of the households that included the size and state of repair of the existing catchment areas and storage tanks. They also tested accessible wells for productivity and salinity, conducted interviews about the history and quality of inaccessible wells, and mapped the well locations to facilitate further investigation. During this first visit, authors MacCracken, Jenson, and Rubinstein physically observed the entire island, taking notes and photographs. An extensive, but not exhaustive, land-based coastal survey conducted during the lowest tides of the visit revealed no seeps or other points of discharge anywhere on the island. Several caves were explored, included in the map, and earmarked for complete surveys. We also collected Global Positioning System (GPS) points to record the locations of important features and enable rectification of the geographic information system (GIS) maps.

1.4.2 May 2005

The goals of this visit were to collect GPS way-points and survey caves and geographic features. During this week, authors MacCracken, Jenson, and Ourloie surveyed cave features large enough to shelter a human and conducted a boat-based coastal survey of the island. They also conducted an in-water survey of selected cliffs and found fresh water discharge points at approximately one meter below mean low tide (Figure 4). Land-based coastal surveys during the lowest tides of the year revealed coastal seeps on three separate beaches around Fais.

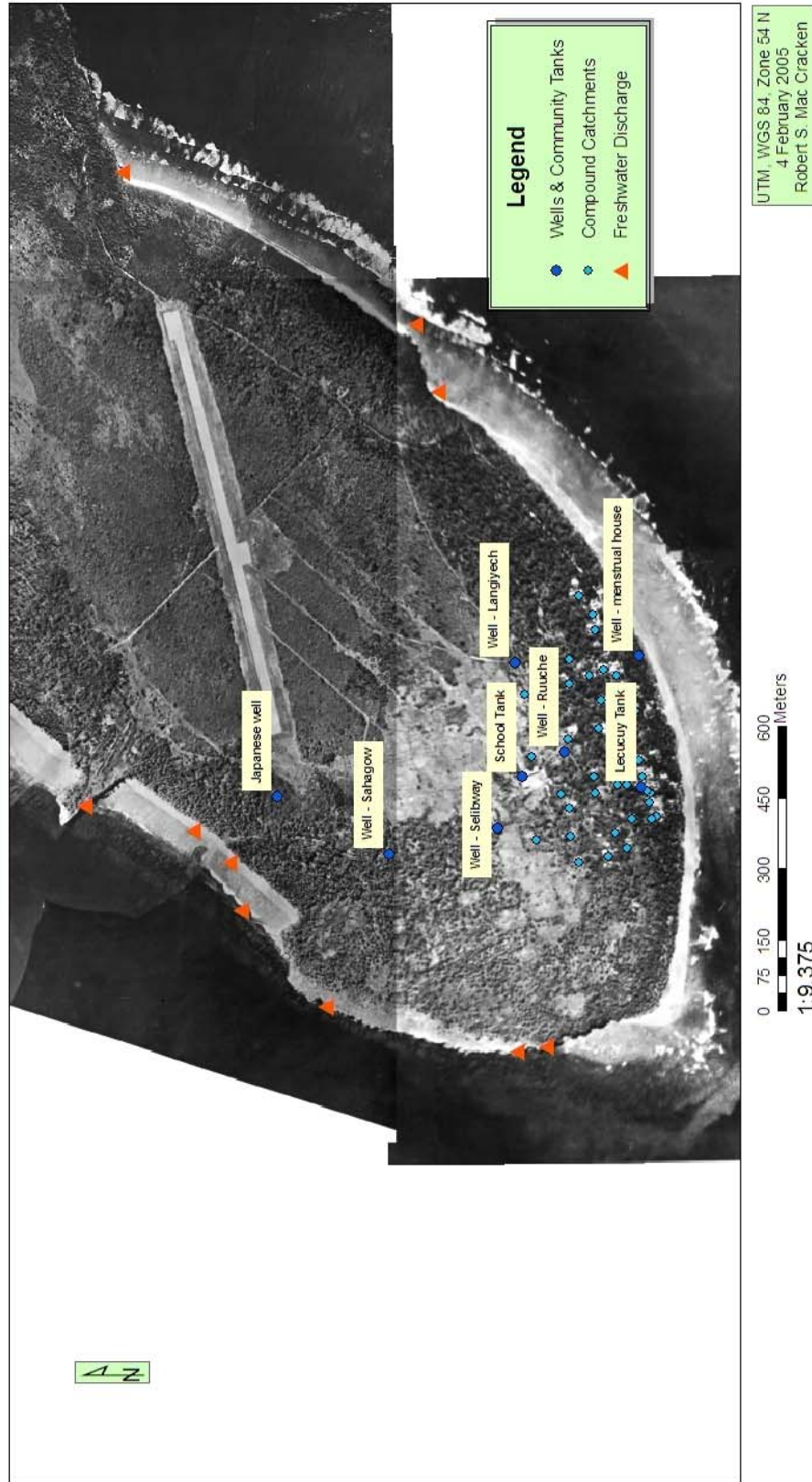


Figure 4. Water resources of Fais Island, Yap State, F.S.M.

1.4.3 June 2005

During the third and final trip, authors MacCracken and Rubinstein met with island leaders to explain the project objectives and its objectives. They specifically discussed the Water Usage Survey that was to be conducted during the subsequent days (Appendix A). To assist in correction of the geographic maps that author Rubinstein had created during his doctoral research in the 1970s, they also interviewed selected elders and field guides, and conducted a coastal survey of the southwest and northeast cliffs to acquire GPS way-points and designate authentic local names for the cave features that are not accessible by land. To support the groundwater investigation, they measured the hand-dug well known as the Old Well, investigated the surrounding cliff line, inspected several potentially useful wells, and measured their depths and water levels.

2.0 MAPPING

2.1 Human Geography

Fais Island came to the attention of the western world during the Pacific conflicts of World War II, when aerial photographs and detailed descriptions of the island began to appear in American military reports.

2.1.1 Previous Maps

In 1944 the JICPOA (Joint Intelligence Center, Pacific Ocean Areas) produced several photographs and an intelligence report (Nugent, 1944). The report describes Fais during Japanese occupation and at the height of phosphate mining operations. Its details and purpose were to provide military intelligence and data. The only entry relative to the indigenous population is the statement that, “A native village is on the south shore of the island.” Although some structures from the war era remain visible on Fais, their utility is gone, with the exception of the ‘Japanese Well’ shown in Figure 4. Today the remaining structures from the Japanese occupation and mining are of historical interest only.

In 1976, several aerial photographs were taken of Fais. These more recent photos show the scars of the earlier mining operations, the ruins of the pre-war and war eras, and the remnants of the roads that facilitated the phosphate removal. The architectural structures and layout of the indigenous villages that exist today are apparent in these 1976 photographs.

During the mid-1970s, author Rubinstein spent two years conducting doctoral research on Fais, from which he created several detailed geographic maps of Fais Island. These maps still constitute the most comprehensive geographical survey of the island to-date, and needed only slight revision during this project. Among them is a detailed map of the human geography of Fais, including land parcel names and borders, paths, village and family compound locations, and many physical geographic place names. Although residence patterns and land use are different today, the borders and place names remain the same. The physical features detailed in the map focus on the cliffs and coastal areas. A second map shows offshore fishing locations. Some stretches of the coast are designated fishing areas for each of the three villages. The map includes the approximate locations of the edges of sub-surface platforms (which might reflect ancient sea-level stands) and a key to simple land types on the island and its coast. A third map that proved useful to this project is a detailed map of the three villages of Fais, which shows the locations of family compounds and identifies the different buildings, borders, and

paths in and around the villages. Although more permanent concrete or wooden, tin-roofed houses have replaced some of the thatched-roofed structures, and other houses have been built on previously unoccupied compounds, the organization and borders of the villages remain the same.

In 1995, the Yap Department of Resources and Development hired Aquarius Flight Incorporated to take aerial photographs of Fais Island (Figure 2). The mosaiced photos were rectified to UTM coordinates with a WGS 84 projection using a base station on Yap (DAKIY 1990). From the mosaic, Aquarius developed an approximate topographic map of Fais. UTM coordinates on these maps are incorrect by approximately 120 meters, due east, and were corrected to within 7 meters in our GIS.

2.1.2 Current Development and Modifications

For this project, we had this series of three photonegatives backlit, photographed at high resolution, and converted to a Tagged Image File Format (TIFF), which was then used as the base map for GIS coverages of Fais. These coverages organize and integrate many of the data collected during the fieldwork on Fais. We collected GPS points accurate to 23 ft. (7 m) of visual markers (for rectifying the layers), household compounds, wells, and geologic features, including caves. From scanned topographic maps, we created a Digital Elevation Map (DEM) (Figure 5), which can provide the relative elevation at any point on Fais, and could thus be used to map underground features such as the fresh water lens. The absolute elevations above sea level are only approximate, and the amount of error is unknown, because they were developed from a control point on Yap, over 160 miles (260 km) away. The layer containing wells and catchment reservoirs, shown in Figure 4, can be used to perform spatial analyses on the water resources of Fais, such as supply-distribution.

Using the ArcEditor[®] platform from ESRI's ArcGIS[®] 9 suite, we developed GIS coverages that can be used for future projects on Fais. Limited only by the accuracy and precision of the data, the software can produce high quality maps, visually representing many types of data, and enabling spatial analysis on a broad area of subjects.

2.2 Hydrologic/Geologic Mapping

2.2.1 Dug Well

In a small, steep embayment at the south end of the Peyechich Beach Area, on the western shore of Fais, lays an ancient, hand-dug well (Figure 6). The area surrounding the well was measured and used to gain some perspective on the nature and location of the fresh water lens.

2.2.2 Caves

Fais exhibits caves in all areas where cemented carbonate rocks have been exposed to any combination of fresh water flow, fresh/saltwater mixing zones, fresh water discharge, and surf. On small carbonate island aquifers (Ourlroie and Carew, 1995) these mechanisms act most aggressively at or near the coast and have left a record of sea level changes on the flanks of all cliff lines on Fais (Figures 7a and 7b). This project included a comprehensive survey of the caves of Fais, which will be reported separately.

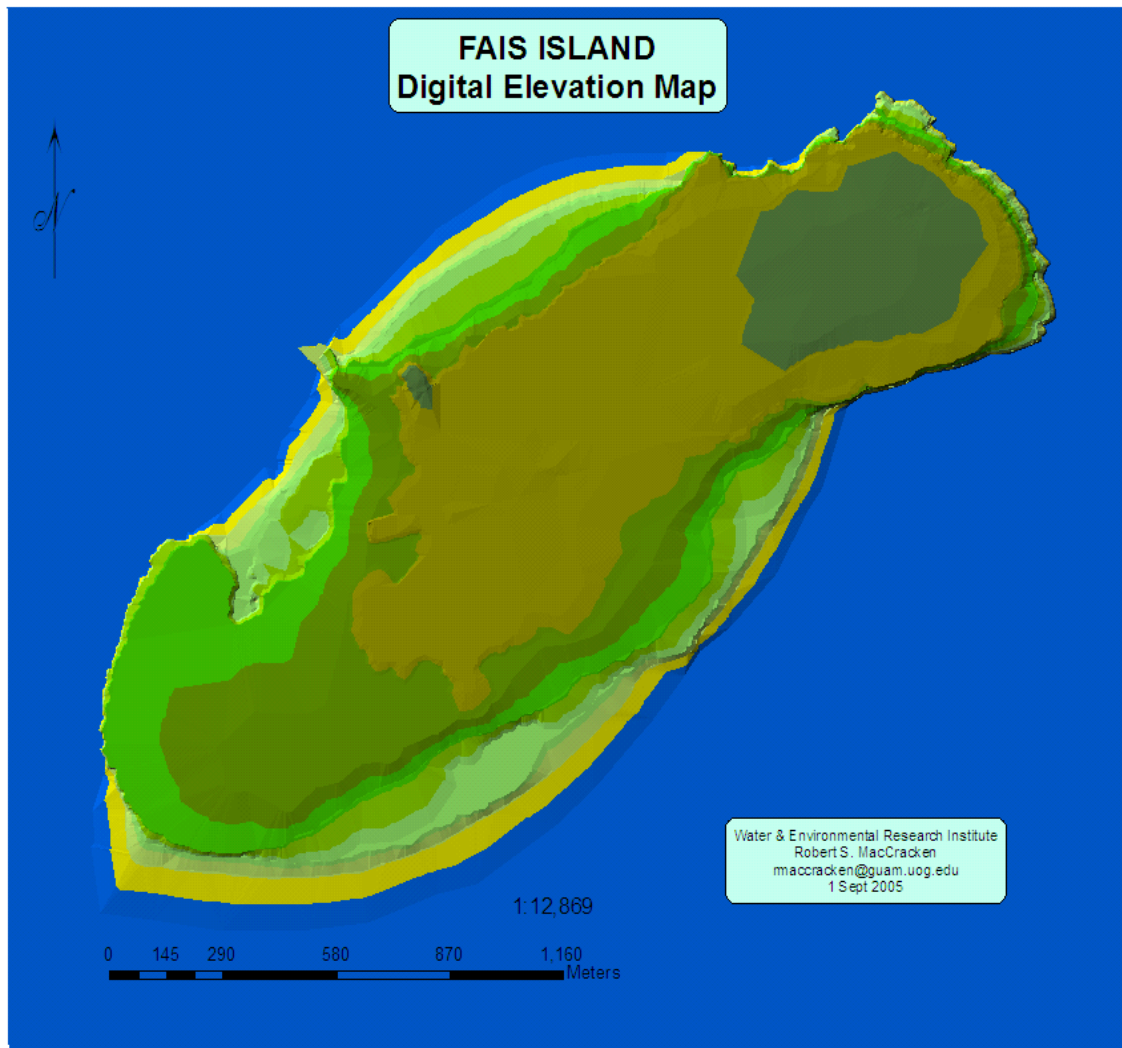


Figure 5. Digital Elevation Model (DEM) of Fais Island.

3.0 WATER RESOURCES

Some 300 current residents of Fais Island maintain a subsistence econoour that supports comfortable lifestyle, providing there is a reliable source of fresh water. Without technology-related demands on their water supply, they are able to forego some water usages that would be considered ‘normal’ in communities that have become accustomed to municipal power and water supplies. At this time, demand for water therefore does not extend beyond drinking, cooking, dishwashing, laundry, and rinsing with fresh water. Residents use the inter-tidal zones for bathing and human waste disposal; therefore there are no showers or land-based toilets or sewage systems. Although this means that requirements are relatively low, it also means that because water consumption is serving basic needs, any interruption or restriction of supply immediately affects comfort and lifestyle. A serious shortage can threaten health and well-being and ultimately require emergency assistance of outside sources.

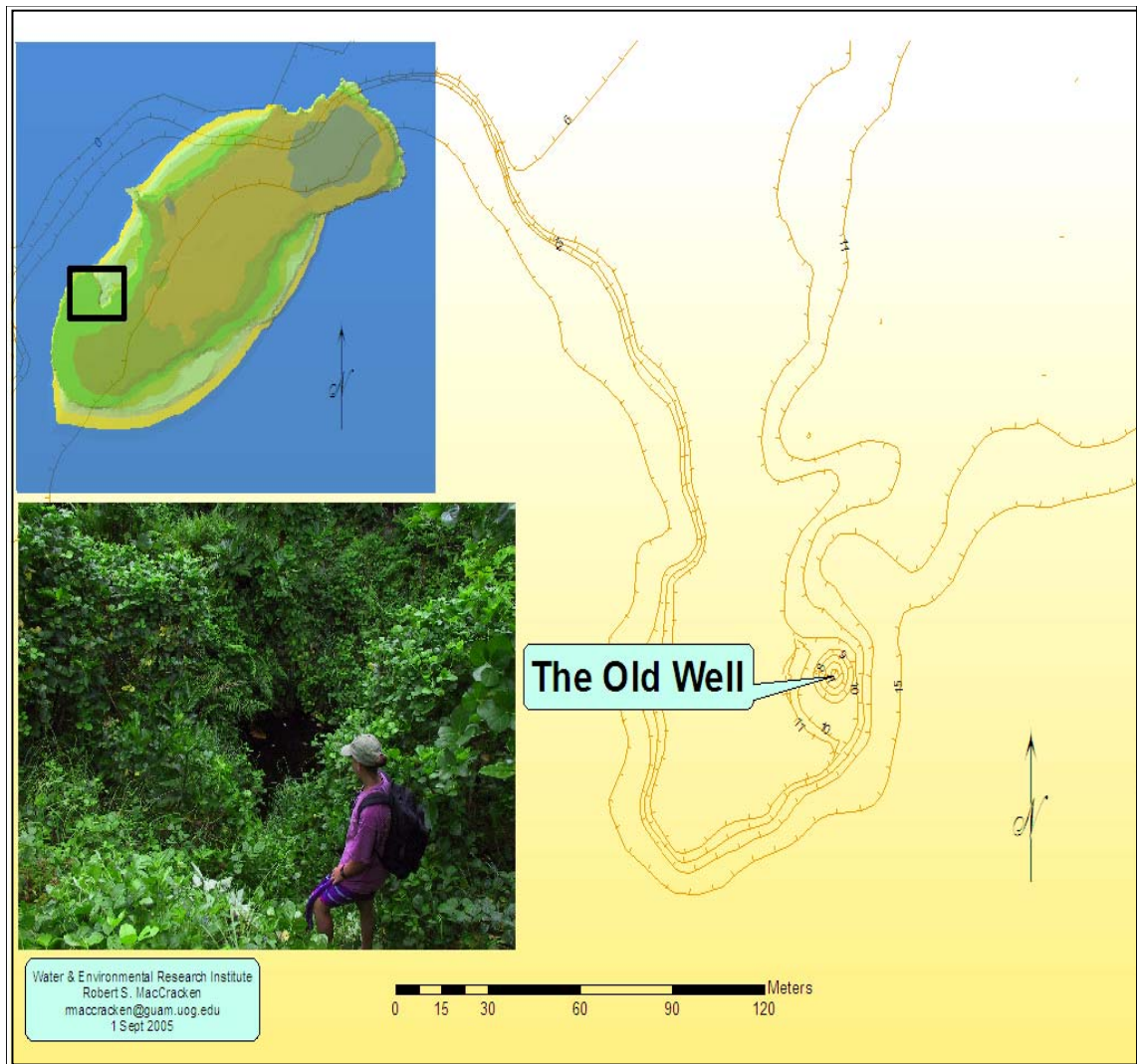


Figure 6. The location and topography of the 'Old Well'. Contour lines in meters. Inset location on Fais Island and picture of 'Old Well' depression.

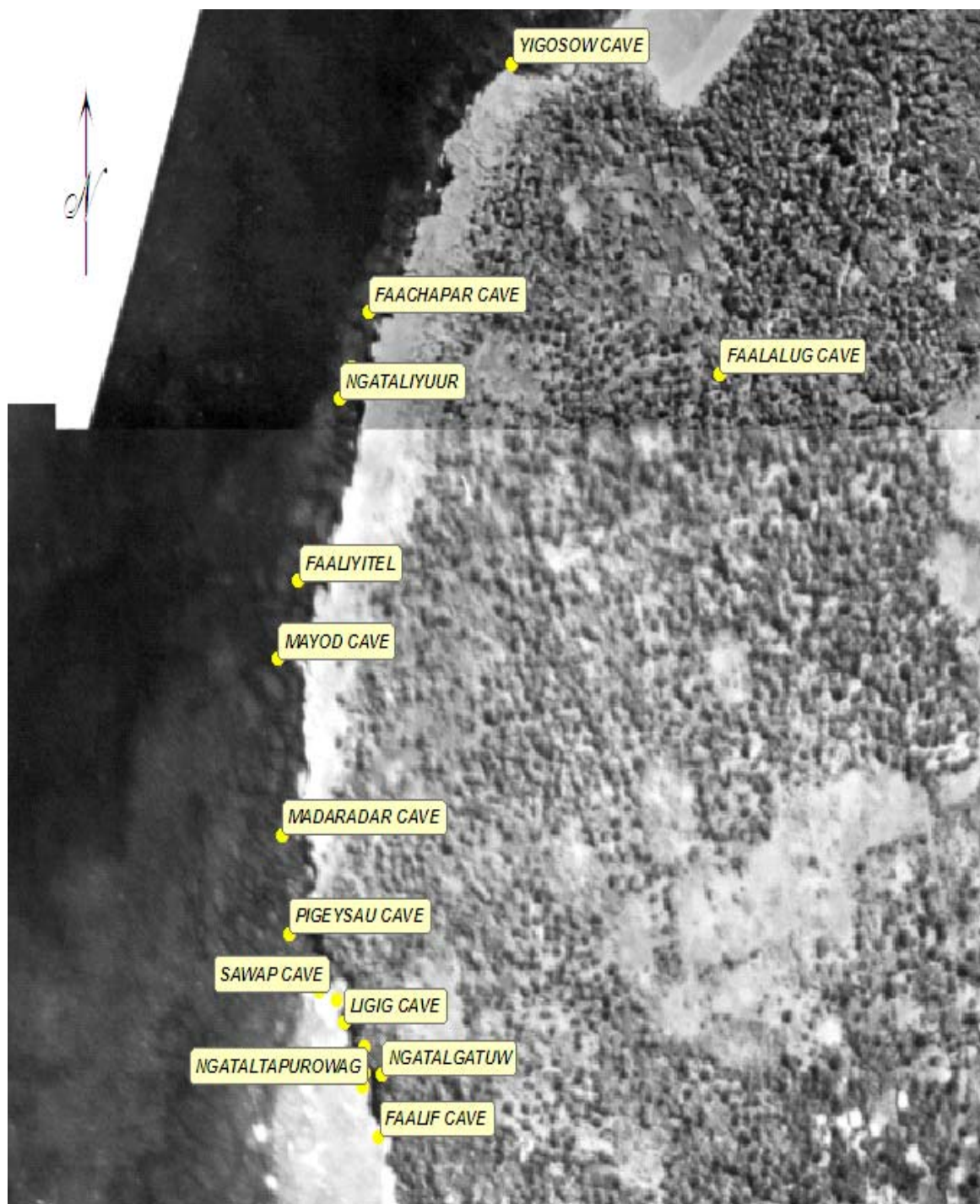


Figure 7a. The southwestern caves of Fais Island.



Figure 7b. The northeastern caves of Fais Island.

3.1 Rainwater Catchments

The residents of Fais rely almost exclusively on rainwater catchments for their fresh water supply. Coconuts can provide an adequate source of drinking fluid until the coconuts wither, but other uses of water, particularly dishwashing, laundry, and bathing (fresh water rinsing), necessitate the development of more expensive and labor-intensive resources if the catchment systems were insufficient to meet demands.

Although Fais lies in a region of the Western Pacific that has a high average annual rainfall, drought years can bring as much as 23 percent less rain than average and more importantly, periods of almost no rain that last as long as four months. Figure 8 shows the average monthly rainfall compared to the monthly rainfall during the 1983 El Niño related drought. The island's catchment network needs to be large enough to collect and store sufficient quantities of water to meet household needs through these difficult times.

3.1.1 Demand

Fais has three adjacent villages near the southern beach, as shown in Figure 4. Each village includes ten or more family compounds that generally include three to five structures each. The 34 occupied compounds house between three and 15 individuals each for a total island population of around 310 people.

Water use on Fais is limited to the health and comfort needs listed in Table

1. Conveniences that require plumbing and pressurization, such as flushing toilets and

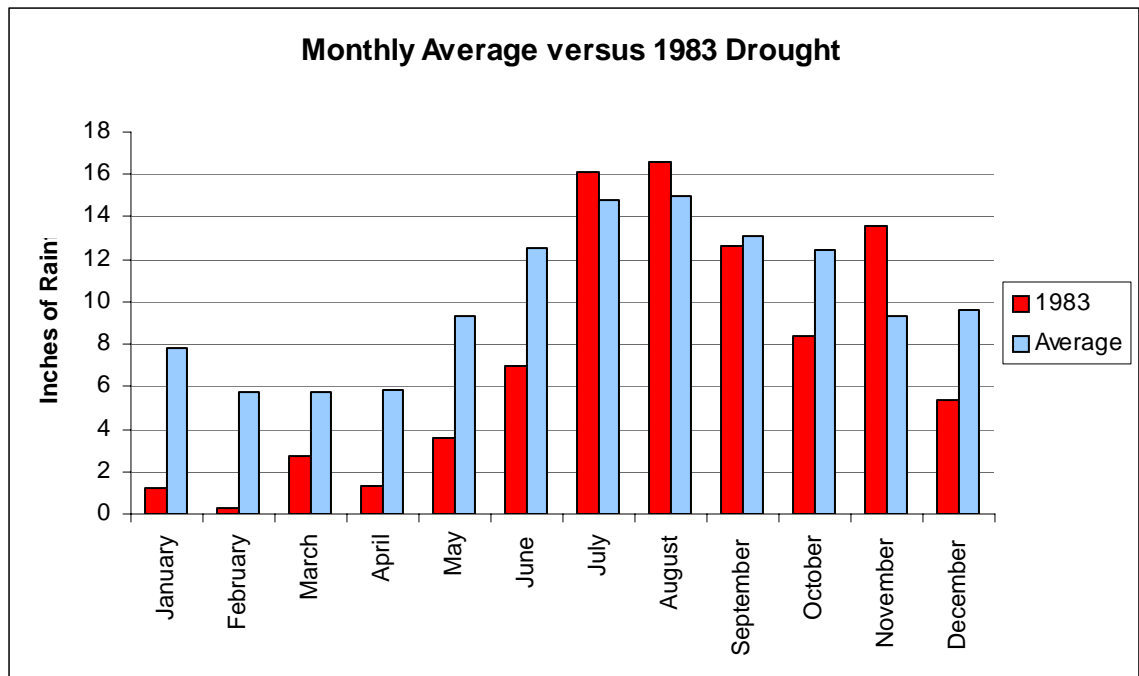


Figure 8. Average monthly rainfall versus monthly drought rainfall after 1982 El Niño.

showers, do not exist on Fais. The subsistence farming on Fais puts only a minor demand on the water supply for the raising of approximately 24 pigs. Table 1 shows usages of collected water in order of importance to the people. The lower the priority of a particular usage type, the more quickly it will diminish and eventually be discontinued during a water shortage. Drinking is not a high priority because most of the drinking water consumed on Fais comes from the plentiful and readily accessible coconuts.

We conducted a detailed water usage survey in June of 2005 (Appendix A) by interviewing representatives of ten compounds, evenly distributed throughout the three villages. This sample constitutes approximately 30 percent of the population so that an accurate assessment of usage and conservation measures could be established. The survey provided the data needed for a resource analysis.

Usage Description	Importance	Notes
Cooking	High	Necessity
Washing Clothes	High	Health related
Watering Pigs	High	Agricultural necessity
Washing Dishes	Medium	Health related
Rinsing after bathing	Medium	Luxury
Drinking	Low	Coconuts are main source
Bathing	Low	Ocean is main source

Table 1. Water usage categories, relative levels of importance, and notes explaining each level of importance

When the water supply on Fais is plentiful, per capita consumption generally ranges between two and four gallons per day (gpd) (8-15 liters/day) among compounds, with an average of 2.77 gpd (10.5 l/d), for an island-wide total of 860 gpd (3,200 liters/day). Approximately 1.5 gpd (5.7 liters/day) are used for each of the approximately 24 pigs. The ratio of adults to children (younger than 12 years) on Fais is approximately 7:5; the water consumption of older children is thought to exceed that of adults, while the consumption of younger children is much less. For this reason, along with the impossibility of quantifying age-based consumption, we used the arithmetic mean for consumption statistics. Figure 9 shows the current estimated average annual compound consumption for each of the three villages and for the entire island. The Fais community's current estimated annual consumption is approximately 313,000 gallons (1,180,000 l) or about 860 gal/day (3,246 l/day).

When questioned about the conservation practices employed during times of low supply some common patterns emerged. Most individuals do not consider themselves to be in crisis until their compounds' tanks contain less than a foot (0.3 m) of usable water. Part of the reason for this delay in concern is that most compounds simply transfer their low priority demands over to the closest community tank well before they have reached a crisis level. When a crisis level is reached, most compounds reported that they do not stop consuming for low priority usages, but instead lower the quantities used for these non-vital purposes. Some compounds are able to, and do, lock their supply tanks to monitor use and prevent waste by the young children. Although most people surveyed were reluctant to admit to asking for water from their neighbors, there were some who reported that other compounds had acquired water from them. Sharing among the compounds occurs routinely during crises, especially between compounds with high capacity catchments and surrounding compounds with low capacity. Because of this sharing, incremental transfer of demand to community systems, and minor conservation methods, most compounds reported they have never run completely out of water.

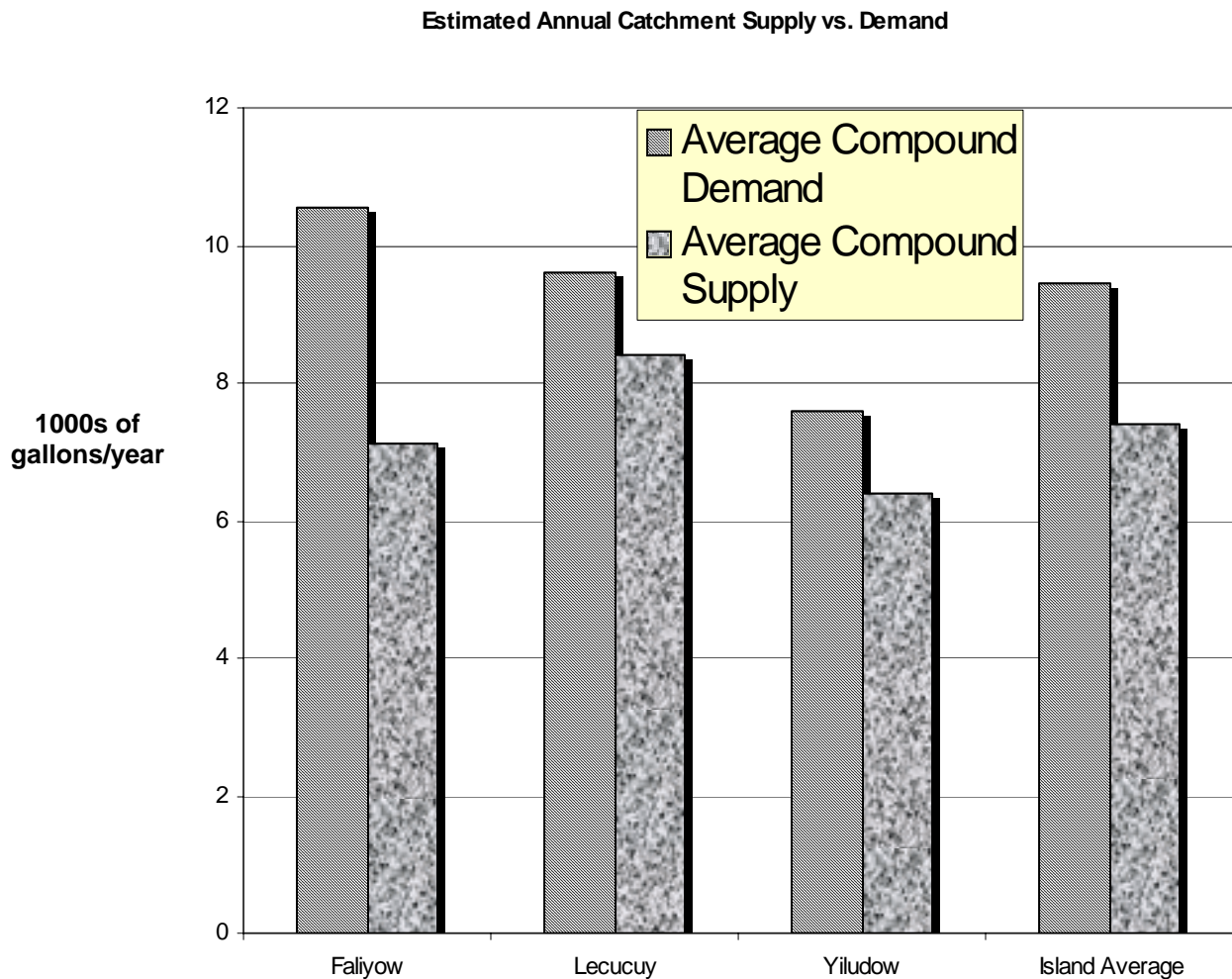


Figure 9. Current estimated average annual catchment demand versus supply for the three villages of Fais and for Fais Island. In their current state, the island's catchments and storage tanks are not sufficient to meet either routine demand or emergency needs. Faliyow Village's supply is short of demand by more than 32 percent over the course of an average year. Lecucuy and Yiludow Villages are better, with 12 and 16 percent shortages, respectively. Overall island supply falls short of demand by 22 percent annually.

3.1.2 Supply

Many structures on Fais have concrete or corrugated steel roofs used for rainwater catchment. Rain water is diverted using plastic gutters and pipes at the bottom edges of the sloped roofs (Figure 10 a-c). Presently, the only village community tank in operation is in Lecucuy (Figure 4). The system collects water from an area of 390 ft² (36 m²) and has a storage capacity of 8,500 gallons (32 m³). The Yiludow Village tank on the east, if in operation, could collect from an area of at least 100 ft² (9 m²) and has a storage capacity of 3,600 gallons (17 m³). The Faliyow Village tank could collect from an area of at least 390 ft² (36 m²) and has a capacity of 13,200 gallons (50 m³). The island's primary community tank is the 'School Tank,' at the Elementary School. It is operational and is used by the entire population. The system collects water from an area of 3,200 ft² (300 m²) and has a capacity of 52,500 gallons (200 m³). The community tanks are used

throughout the year, not only during crises. The residents that live close to the community tanks draw a large part of their water from the community supply. Not surprisingly, the compounds surrounding the community tanks tend to have some of the lowest water production capabilities.

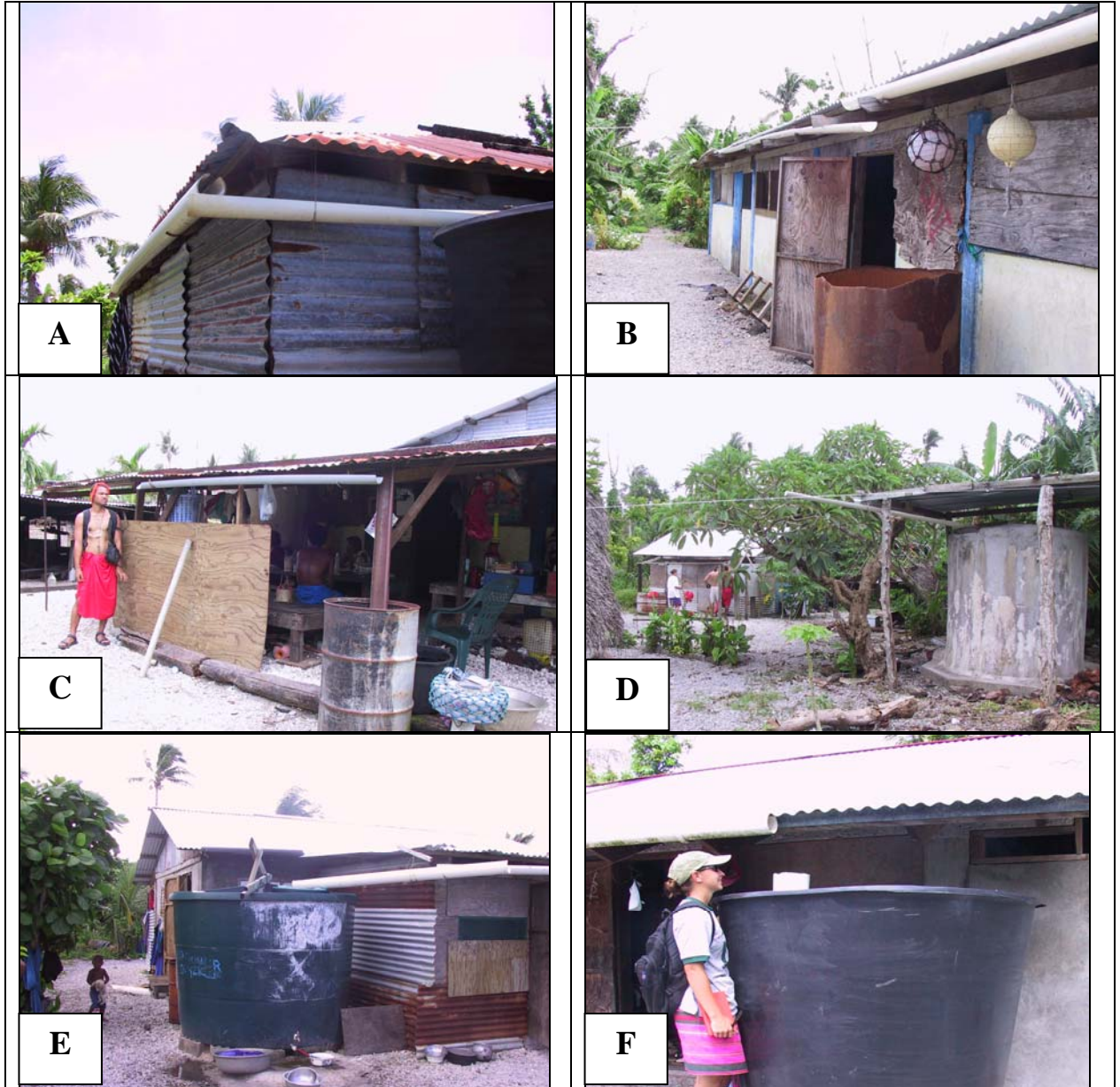


Figure 10. Catchment components on Fais. a-c) Gutters; d) Ferro-concrete tank (~ 1000 gallon / 3.8 m^3); e) Polyethylene tank (1200 gallon / 4.5 m^3); f) Polyethylene tank (500 gallon / 1.9 m^3)

Village	Compound	Occupants	Catchment in use (sq ft)	Potential Catchment Area (sq ft)	Tank volume (gallons)
N/A	School		3220.0	8200	52496
Faliyow	Fararep east	12	129.2	290	1363
	Fararep west	14	330.0	1710	500
	Pisofo	11	590.0	1000	500
	Sangacig	8	223.0	220	500
	Peyur north	13	763.0	210	750
	Peyur south	14	1090.0	1800	2250
	Matarong	10	250.0	1390	500
	Faaluc	7	732.0	1170	1160
	Faliyow	6	486.8	900	500
	Limatayfoy	15	650.0	2830	1800
	Kumar	6	416.0	910	500
	Mooliyar	7	70.0	560	500
	Yilar	5	104.1	520	1008
	Community		NOT IN USE	390	13209
	Sub-totals	128	5834.2	13900	25040
Lecucuy	Ruuche	6	188.4	660	1000
	Peyeliwer	7	420.0	710	1292
	Ipur (upper)	8	177.3	350	500
	Ipur east	5	635.5	650	500
	Itaraw	10	355.2	450	500
	Togowar	11	237.3	580	500
	Maroc east	15	175.0	420	500
	Maroc west		87.2	460	
	Peyemay south	15	274.7	730	500
	Peyemay west		NOT IN USE	240	
	Peyemay north	9	93.0	290	500
	Faalikil	12	118.8	340	500
	Ipur west	10	94.9	530	1500
	Tapira	8	400.0	1720	500
	Community		387.5	390	8454
	Sub-totals	116	3644.8	8520	16746
Yiludow	Woolimelag	8	280.0	960	2000
	Lugumal	5	1153.6	1150	1250
	Harachuy & Wodol	8	278.0	1850	500
	Maroc	11	255.0	1090	1000
	Faaligurugur west	6	254.0	590	1000
	Lifal south	3	153.4	360	500
	Fayipar	10	213.6	390	1500
	Yifisifis	8	135.6	620	500
	Faaligurugur (behind)	8	644.0	1270	1800
	Community		NOT IN USE	100	3566
	Sub-totals	67	3367.2	8380	13616
Totals		311	16066.2	39000	107898

Table 2. Catchment network specifications for every system on Fais Island; data collected during full survey of catchment systems in August, 2004 and updated in June, 2005.

The catchment areas for compound catchment systems vary throughout the island (Table 2). During our survey of the island, we measured areas as large as 1100 ft² (100 m²) and as small as 100 ft² (9 m²). Only about 60 percent of the total available catchment area is guttered to collect water. We also observed that most gutter systems collect approximately half of the water that hits their respective catchment areas. Regardless of these limitations in the collection methods, more water would be available if not for deficiencies in the other major limiting factor—the storage.

The individual family tanks vary between 212-gallon and 1700-gallon capacities (800-6,400 l). Most family compounds have two tanks each. Four small stainless steel tanks and several ferro-concrete tanks are used on Fais. Seventy-five percent of the 48 tanks on Fais are polyethylene 500-gallon (1,900 l) tanks that the residents reported the Federal Emergency Management Agency (FEMA) provided during past crises on Fais (Figure 10 d-f). The FEMA tanks are strong, low-maintenance, and easily moved, but they are too small to store the increased volume of water that would be supplied by appropriately improved catchment areas. Their presence has suppressed the interest of Fais Islanders in building larger, permanent storage tanks. The majority of surveyed residents explained that they have not built larger tanks because the FEMA tanks usually suffice to store the water collected from their roofs. Even though the island was provided with appropriate construction supplies, only two new tanks were built since the FEMA tanks were introduced to Fais. Most compounds reported that their tanks would go from full to less than half-full in approximately two weeks without rain. The average productions for each village and the entire island are shown in Figure 9. In their current state, the island's catchment systems supply approximately 252,000 gallons (950 m³) of fresh water per year.

The residents employ an informal system for sharing water during periods of low rain. When some of the compounds' tanks become empty, their relatives from nearby compounds will share their water with them. All compounds transfer their demands over to the community tanks as their own tanks get low. The closer to the community tanks they are, and the less productive their system is, the more likely they are to depend on the community tanks early in a shortage period.

3.1.3 Shortage

In their current state, the island's catchments and storage tanks are not sufficient to meet either routine demand or emergency needs. Demand is defined here as the actual usage of the supply stored in tanks, which was inferred from the data collected during the survey described in the *Methods* section of this report. As shown in Figure 9, Faliyow Village's supply is short of demand by more than 32 percent over the course of an average year. Lecucuy and Yiludow Villages are better, with 12 and 16 percent shortages, respectively. Overall island supply falls short of demand by 22 percent annually.

The statistics shown in Figure 9 are annual estimates for system production in its current state for the period of the rain record (51 years); they do not reflect the real threat, i.e., the system's failure to meet demands during the droughts following an El Niño event. Figure 11 shows the supply versus projected demand on the island's School Tank for a hypothetical drought of the same severity of the drought in the first half of 1983. Demand greatly exceeds supply for the first five months, with a deficit remaining even in

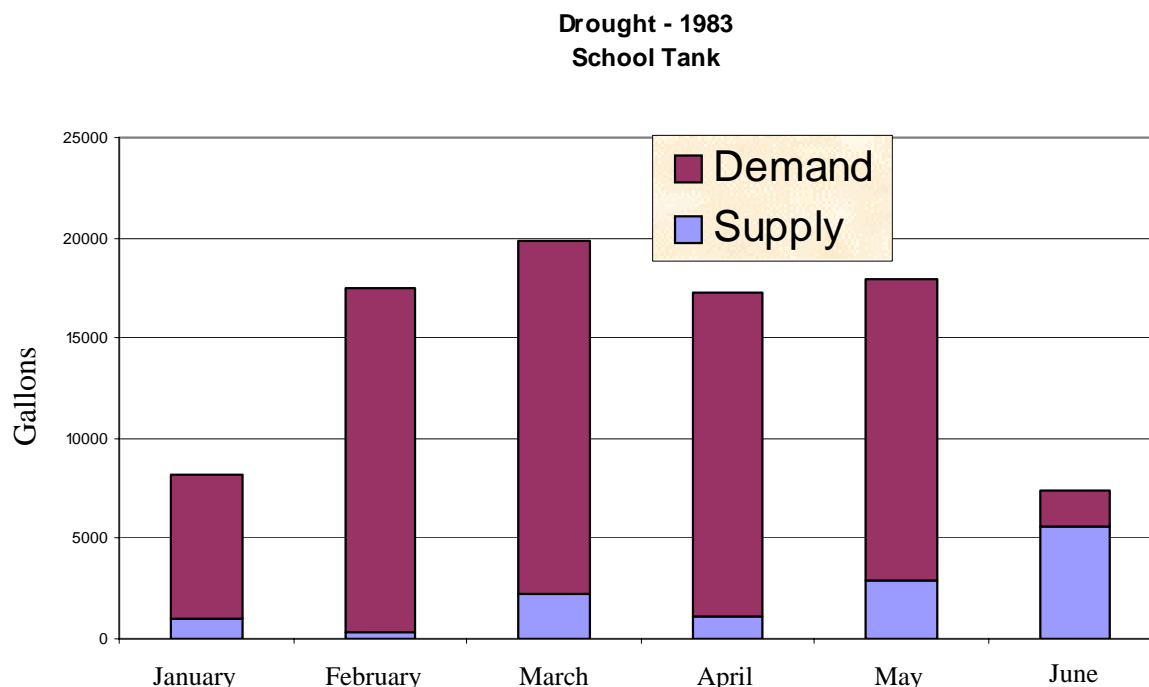


Figure 11. Estimated monthly supply versus projected demand on the island's School Tank for a hypothetical drought of the same severity of the drought in the first half of 1983 following an El Niño Event in 1982.

June when rainfall is increasing and demand on the school catchment is decreasing. A drought this severe could cause periods of 'no water' as long as 33 days, and in fact the 1983 drought required assistance from FEMA to supply water to Fais. Other droughts in recent history also required emergency assistance from Yap and the U.S. (Meeting, 2004).

The shortages that Fais has experienced during droughts, however, are less due to the lack of rainfall than to the failure to collect enough of the rain that actually fell. The available supply from rain catchment systems is a function of both catchment area and storage capacity. Table 2 shows that, in most cases, both of these functions are deficient in Fais' compound systems. The potential storage and catchment areas of the two 'inoperative' community village systems are a large part of this deficiency. The causes and possible remedies for this deficiency will be discussed in the *Conclusions and Recommendations* section of this paper.

Catchment system designs are vulnerable to cyclonic storms, especially those systems with above-ground tanks and roof catchments. Fais' entire network could lose its production capability if a major typhoon were to hit the island. The plumbing, gutters, and attaching hardware are easily destroyed by the high winds, and even the plastic storage tanks would be threatened by flying debris during such an event. The powerful Western Pacific storms easily remove the roofs from buildings such as those on Fais. This level of destruction has occurred approximately every 20 years (Meeting, 2004). During El Niño events, the spawning ground for tropical disturbances shifts east, allowing storms to develop into typhoons before they reach Micronesia on their western tracks. Thus, any given locality can be hit by a major storm only to be followed soon

after by months of drought. In the nearby Marshall Islands, severe drought conditions existed for more than six months after Typhoon Paka hit in December 1997 (Rejcek, 2002). If a major storm during the end of a rainy season were to be followed by a major drought, even rebuilding efforts would be futile in replenishing the water supply, and a true ‘worst case scenario’ would occur. One possible answer to such a major crisis could be preparations to use Fais’ groundwater.

3.2 Groundwater

Fais Island’s combination of elevation, area, composition, and oval shape is unique among the outer islands of the FSM and make the land mass an aquifer that may have enough storage and recharge to support sustainable development. With over 65 feet (20 m) of elevation and an average diameter of over 0.6 miles (1 km), Fais’ area of over 0.75 miles² (2.0 km²) can contain a fresh water lens that is many times larger and deeper than any of the Micronesian atoll islands.

3.2.1 Fais’ Fresh water Lens

The presences of wells that contain drinkable water demonstrates that Fais contains a fresh water lens. However, the properties and productivity of the aquifer are not precisely known. Although the exploratory drilling and systematic pump testing that would be needed to quantify the aquifer parameters have not been conducted, we made some observations that provide a basis for first-order estimates of aquifer properties. The details of the analyses are discussed in the *Results & Discussion* section of this paper.

Residents reported that when the Old Well was pumped dry during the construction of the airstrip in the 1980s; the well took “more than an hour to fill up again.” We used this information, along with the well parameters and island dimensions, to simulate a slug test and find an approximate hydraulic conductivity. After developing a simple water budget for the groundwater by subtracting estimated evapotranspiration from the rainfall data, we applied standard formulae to estimate the elevation of the water table above sea level and the thickness of the fresh water lens. The details of the analysis are discussed in the *Results & Discussion* section of this paper.

3.2.2 Drilled Wells

During World War Iwe the Japanese installed a concrete-lined well near the northwestern side of Peyechich Beach (Figure 4). Water from the surface of the water table in this well contained 0.1 mg/L chloride (the EPA National Secondary Drinking Water Regulations suggest a maximum of 250 mg/L; most thresholds for tasting chloride are >96 mg/L), and bottom of the well was about 3 feet (1 m) below the water table. Although this well is still in excellent condition, seems to cut deep enough into the lens to draw water, but is also shallow enough not to draw saltwater during low-demand pumping, its distance (over 1,600 ft / 500 meters) from the village and specifically from the island’s main cistern makes it very inconvenient.

In the early 1990s several wells were drilled as part of Yap State’s capital improvement project: Yap CAP (Yap Community Action Program). Notable among these are the well at the school, where the village’s community tank is located, and the well at Langiyech. The ‘School Well’ would be perfectly located to supplement the island’s reserves, however, residents reported that the well produced ‘salty’ water, so that

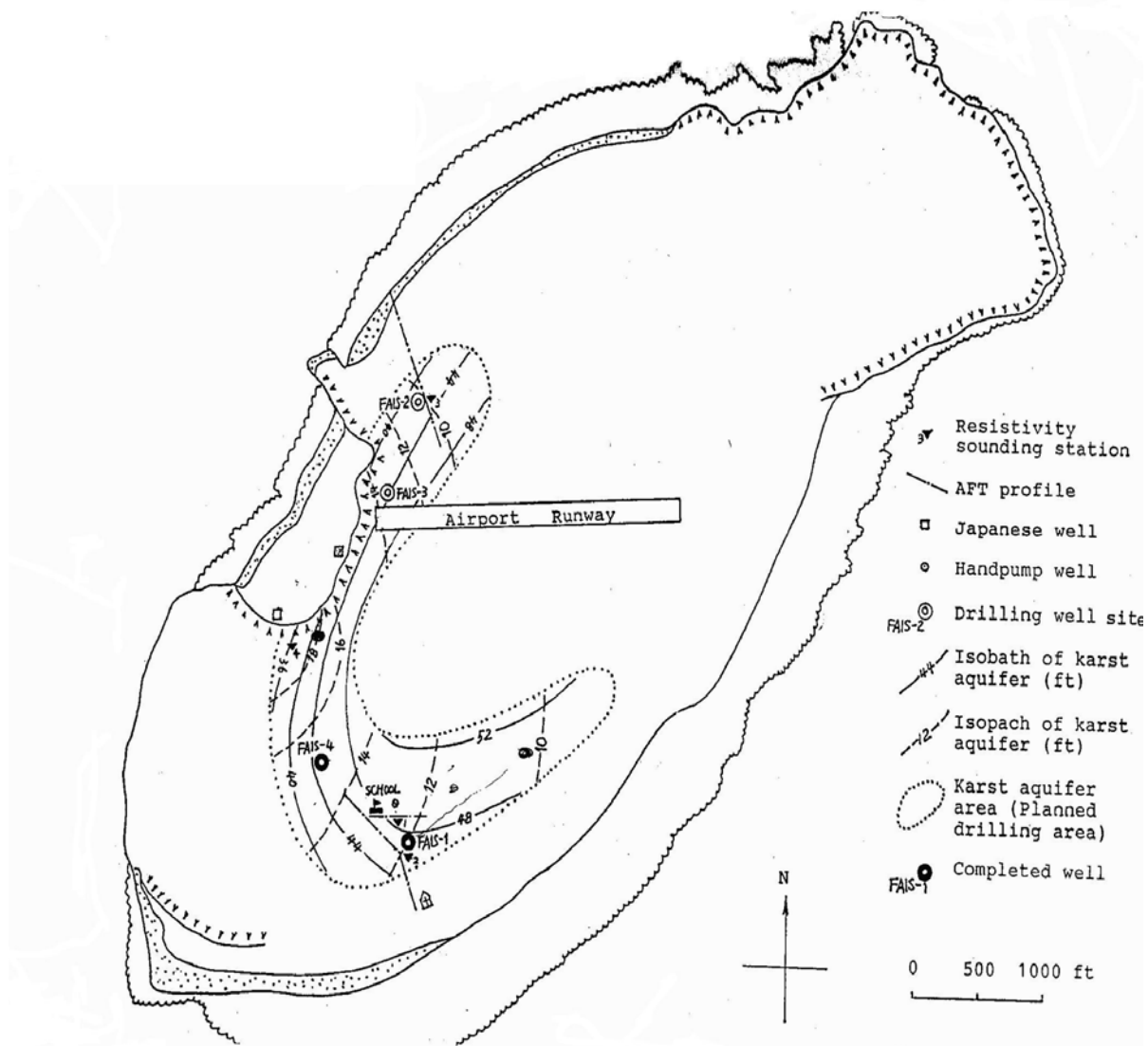


Figure 12. United Nations estimated hydrogeologic map (FSM/UN Water Resources Assessment and Development Project, 1996).

they eventually gave up using it and it fell into disrepair. The Langiyech well is less than 820 feet (250 m) from the community tank, but residents report that it was only marginally productive and went completely dry in 1997. Like most wells on Fais that are not used and protected, it has fallen into disrepair and become obstructed by debris.

The largest well drilling project to date began in 1996 as part of the FSM/United Nations Water Resources Assessment and Development Project (Zheng, 1996). The project intended to help residents develop their groundwater, while teaching them how to use the drilling equipment. The project proposed and described four wells that would be drilled in an arc that the project team believed lied along the thickest part of the lens (Figure 12). Of the four proposed wells, only two were actually drilled.

The UN project drilled Site 1 in the Ruuche area near the dispensary, some 330 feet (100 meters) from the community tank. The project reported the water table to be 45 feet (13.7 m) below the surface, which according to the topographic map would put the water table at 16 feet (4.8 m) above MSL at this location, which seems too high for an island karst aquifer. This discrepancy is due to the inaccuracy of the elevation relative to sea level on the topographic map, which used a base station on Yap. Although the UN stated that a successful pump test produced 5 gpm (19 L/min) of fresh water with chloride contents of 3.6 mg/L and 4.8 mg/L three days later, the residents of Fais reported that the well was always salty, but was still used until the pump failed. We attempted to pump-test and determine the water quality of the well and found only a couple of centimeters of water at the bottom of the 47-foot (14.4 m) hole.

Sites 2 and 3 were not drilled during or after the project. Originally the sites were not drilled because of equipment failure, but their distance from the community tank may have deterred future efforts at these sites.

The project drilled Site 4 in the Selibway area on the trail leading north to Pechich; only 390 feet (120 m) from the community tank (refer to Figure 4). The project team reported that a successful pump-test produced 4 gpm (15 L/min) of fresh water with a chloride content of 8.1 mg/L. The residents reported that the well had not been pumped recently because of the lack of need and the difficulty of setting up the one set of pumping equipment that the island presently has. We attempted to pump-test and determine the water quality of the well and found that it had become clogged with debris, preventing the submersible pump from descending more than 4 meters. The poorly built and maintained protective fences around the wells on Fais have allowed most of the sites to be destroyed or badly damaged.

Within a few years of the UN project, the residents of Fais used their newly gained knowledge and the equipment left by the 1996 project to drill a well in the Sahagow area on the same trail as the 'Selibway Well'. This site has always been able to produce fresh water, and in August of 2004, we pumped 1250 gallons (4.7 m³) from the well over the course of three days. During that period, the chloride content varied between 0.1 and 0.2 mg/L. The pump rate was highly variable due to the changing insolation to the solar cells powering the submersible pump. The pump rates varied between 0.0 gpm during evening hours and 1.8 gpm (6.8 L/min) during peak sunshine. The limiting factors on the pump rate were the equipment and power supply rather than the well itself; therefore the actual capacity of the well is unknown. The well was drilled to a depth of 49 feet (15 m) and the water table was 39 feet (12 m) below the surface at 1300 on June 22, 2005, during an extremely low (-0.7 ft / -0.2 m) tide. The certainty of fresh water productivity (at low pump rates), the relative proximity to the community tank (1,050 ft / 320 m), and the low cost of operating this site make it a viable choice for supplementing the island's rainwater supply, so long as pumping equipment is available.

3.2.3 *Old Well*

The Old Well, as it is referred to by the Fais Islanders, could easily be mistaken for a sinkhole. It was dug by local residents sometime in the past, perhaps the very distant past. Although the exact origin and age of the well are unknown, its purpose is clearly to provide fresh water for the island's inhabitants. Today the numerous rainwater catchments are the primary source of water, but the Old Well is a reliable emergency

source, which does not require pumping, and has been used as recently as 1983. The well was probably dug in its current location based on the islanders' knowledge of groundwater acquired over generations. The well was dug in the soft sands of what was originally a Pleistocene beach, as previously illustrated in Figure 6. This small embayment within the larger Peyechich embayment may have been a reef flat leading up to a beach that terminated in the surrounding cliffs during the last interglacial sea-level highstand (about 125,000 years ago). The surrounding cliffs show evidence of surf erosion and flank margin discharge, and the area is thickly covered in sandy soil. The area is a topographic low, allowing easy access to the fresh water lens; yet it is far enough from the shore and sea level to ensure an untainted supply of fresh water.

The pool of water is circular, approximately three meters in diameter and one meter deep. The surface water is free of chloride. The water is currently contaminated with rotting vegetation, and the jungle has reclaimed the surrounding area, previously developed for easy water extraction. The residents report that if a need for the water were to arise, the island would organize a work party that would clear the area of vegetation and remove the detritus from the water. This operation would take only one day, followed by a few days to let the water clear. Afterwards the water could be boiled and used for human consumption.

Figure 13 shows our cross-sectional survey of the Old Well. Although the water table is at the surface here, the survey provides an estimate of its elevation above mean sea level. This will be compared to other extrapolated elevations from the wells and discussed in the *Results and Discussion* section of this paper.

3.3 Other Sources of Hydration

3.3.1 Fruits

An important source of hydration for the residents of Fais is the water content of several fruits in their diet. Papayas, citrus, and other tree-born fruits are regularly consumed, and provide water and nutrients.

3.3.2 Coconuts

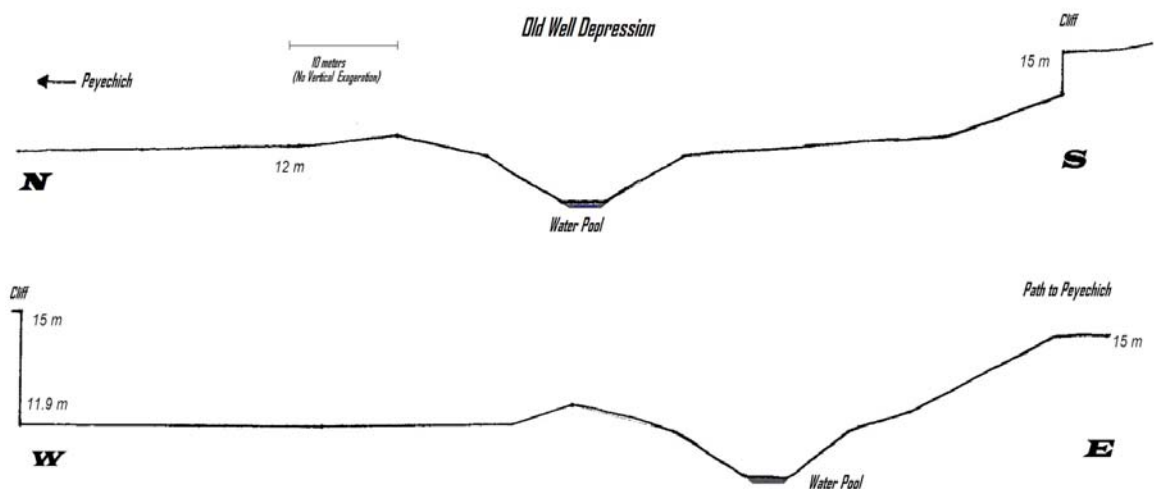


Figure 13. Old Well depression cross-sections. Profile to-scale (no vertical exaggeration). Elevations are based on the 1995 topographic map and are approximate.

The primary source of hydration on Fais is the plentiful coconut. Coconut trees grow year-round in all forested areas. Each coconut contains 8.5-12 fluid ounces (250-350 ml) of liquid, which is an excellent source of water and electrolytes that can sustain proper hydration without any other source, so long as coconuts remain available.

Our own observation was that Fais Islanders seldom drink plain fresh water, but prefer coconuts and water-based beverages such as instant coffee or Tang[®], when available. People we interviewed reported per capita consumption rates of three to five coconuts per day. With an average consumption rate of 3.6 10-ounce (300-mL) coconuts per day, the island therefore consumes approximately 1,100 coconuts for a total of 90 gpd (340 l/day) from the coconut crop. If the average tree in this region produces 200 coconuts per year (Levin, 1976), the current consumption rate would require approximately 2,000 trees. Although we did not attempt to inventory the coconut trees on Fais, there are certainly many more than the 2,000 needed to supply the residents. This resource is an important part of life on Fais and any statistics on total water use must include the amount consumed from the coconuts.

When other sources of fresh water on Fais are depleted or unavailable the coconut crop can meet the populations' basic needs for personal hydration for at least a couple of months after the onset of a drought. People we interviewed, however, reported that after about two months of continuous drought, the quantity and quality of juice in the coconuts begins to deteriorate until after about five months the coconuts are no longer a reliable source of fluid.

The coconut crop is also vulnerable to typhoon damage. While a drought takes months to damage the coconut crop and has many warning signs, a single storm can virtually eliminate the entire standing coconut crop. This level of damage occurs approximately every ten to fifteen years (Meeting, 2004). Compounded with the other damages sustained during a major storm, the loss of the coconuts must be considered in any plan for meeting emergency needs. The fragility of the coconut resource, during the two times when it would be needed the most, along with the fact that even when available, its use is limited to drinking and cooking, precludes it from being a reliable emergency water source. Other sources must supply water for household and personal sanitation. Thus, while the fluid supplied by coconuts is an important component of the ordinary water needs of the residents, the coconuts cannot be considered a component of the island's emergency supply system.

4.0 METHODS

4.1 Water Resources Analysis

4.1.1 Population Survey

We surveyed representatives from 10 of the 34 compounds (Appendix A). The compounds were chosen to be typical in family size, typical in catchment size and configuration, and well distributed throughout the three villages. The 10 compounds surveyed constitute approximately 30 percent of the population.¹

4.1.2 RoofRain Analysis

In August of 2004 (Table 2) we sketched the layout of every compound showing the location and relationship of all catchment areas and tanks and recorded the name and age of every resident at each. At the same time, we conducted a comprehensive survey that included measurements of the horizontally projected area of every roof, the total potential catchment area for each compound, and the areas that were actually collecting water, along with the volumes of manufactured and custom-built storage tanks. In June of 2005, we re-measured the 10 compounds to determine their change over time. To evaluate the adequacy of the catchment systems on Fais, we applied *RoofRain*, an analytical spreadsheet program developed specifically for application to island household rainwater catchments (Heitz, 2003). The program calculates the needed catchment and storage for each household, based on number of members of the household, their usage practices, and the projected rainfall.² Based on tank capacity, input, and usage data the model determines the volume of water available at the end of each day of usage. It also considers loss due to overflow and adjusts the output (usage) based on water level in the system's tank. To deal with the complexities of water distribution and accommodate realistic shortage patterns during crises on Fais, we extended the original *RoofRain* program to account for transfers between household, village, and island catchments. We then considered several alternative solutions to find out what changes in what parts of the catchment network would best meet the needs of the island's people. The primary modifications involved increasing the catchment areas to approach their potential and increasing the number and size of storage tanks. The current state of the system was used as a basis for comparing all possible remediations.

4.1.3 Groundwater

For background on groundwater, including the most recent attempts at development, we interviewed the two people most knowledgeable of groundwater resources on Fais, Mr. Jesse Haulifar, a participant in the 1996 UN well-drilling project; and Mr. Jesse Raglmar, Chief Clerk of the Yap State Legislature, who provided information on the history and status of the existing and proposed wells on Fais.

¹ Posing questions that would be readily understood and elicit accurate responses was a vital part of this survey (e.g., we asked how long it would take for their water tank to go from full to half-full without rain instead of asking them to estimate how many gallons they used per day). It also became apparent that when dealing with the question of water sharing, it was better to ask if other families borrow water from the respondent's family than to ask if their family borrows from others, because of their tendency to deny asking others for help.

² The rain data recorded by the rain gage at the airport in Yap from 1953 to 2003 (gage # 4951, Yap Island WSO Airport) were used in this analysis because of the proximity (160 miles / 260 km), the similar latitude (approximately 0.3 degrees difference), and the absence of rain gages on Fais Island.

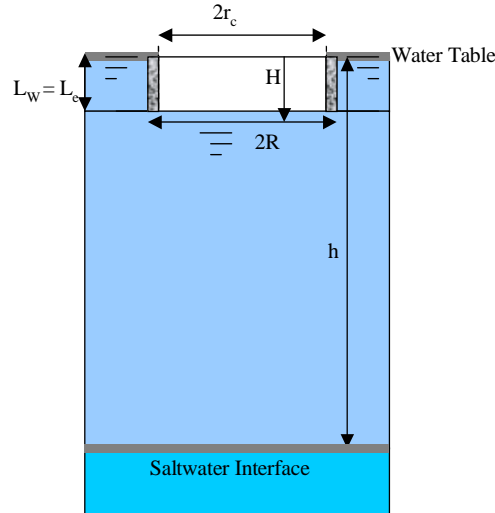
We visited all the existing well sites and recorded their locations with a GPS receiver (Figure 4). We also took water samples from accessible wells with a weighted 250-ml sample bottle on a 20-m twine cord, and inferred chloride concentrations with a portable conductivity/salinity meter. During our 2004 visit, Mr. Haulifar lowered a 24-volt submersible well pump powered by a two-panel solar cell into the Sahagow well. This equipment is owned by Fais Island, has been designated for emergency well use only, and is maintained by Mr. Haulifar. We were able to determine that the Sahagow well can sustain a pumping rate of 400 gpd ($1.5 \text{ m}^3/\text{d}$) for at least three days, providing over 1,200 gallons (4.5 m^3) of fresh water. To determine the relative location of the water table, we measured the depth of the water surface and the depth of the well at Sahagow with a float-tipped tape measure and a weighted tape measure, respectively. In 2005, attempts to pump-test other wells, close to the School Tank, were hindered by malfunctioning equipment, low water table levels, and debris-clogged well casings.

Using the report that the Old Well's pool (approximately 1,900 gal / 7.1 m^3) took over an hour to recover from being pumped down during an attempt to use the water for construction of the air strip (Section 3.2.1, page 30), one can make a simple slug-test (Bouwer, 1989; Bouwer and Rice, 1976) calculation to estimate the local hydraulic conductivity, which can be taken as a minimum estimate of the regional, or island-scale conductivity. A simple water budget can be used to estimate the recharge rate.³ The conductivity and recharge estimates can then be applied to a static solution of the groundwater flow equation for circular island aquifers (Fetter, 1972) to estimate hydraulic head and lens thickness.⁴ Figure 14 summarizes the implementation of the slug test and static model to estimate the hydraulic gradient around the well during the slug test, local hydraulic conductivity, and the local head and lens thickness. To collect data on the drilled wells on Fais, we conducted interviews, made field observations, pumped selected wells, and tested water samples from accessible wells.

³ To estimate the recharge, we conducted a simple water budget using 0.35 inches/day (0.009 m/day) for average daily rainfall based on Yap (gage # 4951, Yap Island WSO Airport) minus the estimated evapotranspiration (ET) for Fais. The total ET was estimated by finding the weighted average ET of coconuts (0.5 in/day / 12 mm/day) for 55 percent of the area (0.73 miles² / 1.9 km²) and for tropical grasslands (0.06 in/day / 1.4 mm/day) for 35 percent of the area.

The rainwater input to the island is approximately 4.5×10^6 gpd ($1.7 \times 10^5 \text{ m}^3/\text{day}$), while the output from evapotranspiration is approximately 3.5×10^6 gpd ($1.3 \times 10^5 \text{ m}^3/\text{day}$), leaving an estimated 1,000,000 gpd ($3,800 \text{ m}^3/\text{day}$) for input to the lens.

⁴ we used the average conductivity provided by the slug-test, 43.5 for G (the density of fresh water divided by the difference in density between high temperature Pacific Ocean water and fresh water), 2,300 feet (710 m) for island radius (GIS measurement), 1,300 feet (410 m) for radial distance from center of island (GIS measurement), and the estimated recharge from our water budget.



Hydraulic Conductivity

$$K = \frac{r_c^2 (R_e / R) 1}{2 L_e t} \ln \left(\frac{H_0}{H_t} \right)$$

$$K = \frac{(1.5)^2 \ln(75\text{m}/1.9\text{m})}{2(1.0\text{m})} \frac{1}{0.063\text{d}} \ln \left(\frac{1.0\text{m}}{0.1\text{m}} \right) = 150\text{m/d}$$

$$K = \frac{(1.5)^2 \ln(300\text{m}/1.9\text{m})}{2(1.0\text{m})} \frac{1}{0.042\text{d}} \ln \left(\frac{1.0\text{m}}{0.1\text{m}} \right) = 310\text{m/d}$$

Freshwater Lens – Circular Island

$$h = \sqrt{\frac{\omega(R^2 - r^2)}{2K(1+G)}}$$

$$h = \sqrt{\frac{0.002\text{m/d}((710\text{m})^2 - (410\text{m})^2)}{2(230\text{m/d})(44.5)}} = 0.18\text{meters}$$

$$z = 7.8 \text{ m}$$

Hydraulic Gradient

Q = Volume of cylinder/ Time to fill / Area of infiltration

$$\left(\frac{dh}{dl} \right) = \frac{-Q}{KA} = \frac{-6}{(230)(23)} = -0.0011$$

Figure 14. The Old Well geometry and calculations used to find the range of estimated conductivity due to the possible ranges in time and effective radius, and the lens thickness, and local hydraulic gradient based on the average calculated hydraulic conductivity (750 ft/day / 230 m/day) of the Old Well. r , the radius of the well casing, is the radius of the Old Well's water pool (5 ft, 1.5 m). R is the radius of the envelope created by the well's supporting cobbles (6 ft, 1.9 m). Separate calculations are for assumed effective radii of 246 ft (75 m) and 1000 ft (300 m) respectively. The depth of the pool (3.3 ft, 1.0 m) is used for the length of the screen, L_e . H_t , drawdown at $t = 0$, is 0.33 ft (0.1 m). A recovery time, t , of 90 minutes (0.63 days) is applied to the equation with the smaller (75-m) effective radius, and 60 minutes (0.42 days) to the equation with the larger (300 m) effective radius, to provide minimum and maximum estimates of hydraulic conductivity, K . Calculation of hydraulic head, h , and depth to interface, z , follows Fetter (1972). Hydraulic gradient next to the well is based K obtained from the average of the low and high estimates

4.2 Map Development

GIS coverages of Fais Island were developed to support the field investigation and water resource analysis. This study is the first to use GIS datasets and map layers to represent Fais. To support the project objectives the coverages had to include a base map for planning and documenting field investigations, a GPS waypoints layer for recording significant geologic features or human-interest locations, and a topographic Digital Elevation Model (DEM), previously presented as Figure 5.

We built the coverages using photographs and maps from the Department of Land and Natural Resources, Yap State; ESRwe software – ArcGIS 9[®] (ArcEditor[®]); and a handheld GPS receiver (Garmin Geko[®] 301). First, we acquired three large-format photo-negatives of aerial photographs of Fais Island and three topographic maps that

were derived from the photos to create TIFF (image files) on which to base the GIS layers. A photographic studio backlit the negatives and took high-resolution (approximately 1×10^4 by 1.5×10^4 pixel) digital pictures to create TIFFs; a print shop used a large-format scanner to create TIFFs of the topographic maps. The procedures that we used to develop the GIS coverages are detailed in Appendix B.

4.3 Survey Techniques for Caves and Old Well

4.3.1 Physical Measurements

We used cave survey techniques (Dasher, 1994) applying tape measure, a clinometer, and a compass to measure the topography surrounding the Old Well (Figure 13), with the critical addition of a machete. As our field assistants cleared a line-of-site, we measured the distance and inclination of four splays radiating out from the water pool at 0, 90, 180, and 270 degrees. We surveyed each of the four directions by measuring the inclination and distance from our eye to the forehead of our guide, Mr. Jesse Haulifar. We alternated between forward shooting and back shooting, depending on the conditions of each shot. To keep us on track and verify our distance to the pool, we used the compass and a GPS (Magellan Meridian Marine®). We surveyed out from the pool until we reached landmarks that were easy to identify on the topo-map: usually the cliff line that borders the site on the east, south, and west. we recorded the location of the pool in the GPS as a user waypoint.

4.3.2 Identification and Orientation

During our three visits to Fais, we took several hundred digital photographs of the caves and hydrogeologic features of the island. We used the GPS to record the locations and temporary names of all caves, many of which are located along the coastal cliff lines and are inaccessible by land. We hired a Fais motorboat and pilot/guide (Mr. Jesse Haulifar) to circumnavigate the island while we took photos, saved GPS waypoints, and swam selected sections of the cliffs. We investigated some water caves by swimming into them. We noted fresh water discharge at several locations, approximately one meter below the mean low-tide level.

Using the pictures and GPS points as a reference, we worked with Mr. Haulifar and other residents to determine the local names of every cave and coastal feature and verify their exact locations on aerial photographs. we updated our cave survey, GPS points, field notes, and maps to reflect the correct names and locations.

5.0 RESULTS & DISCUSSION

5.1 Rainwater Catchment System

5.1.1 Current Status

In its current state, the network of rainwater catchment systems on Fais is not able to provide enough fresh water for the island's residents for routine use or for emergency supply. Although the RoofRain Model calculates that the current network of rainwater catchment systems on Fais would be adequate during 98 percent of the days of the 51 years of record, the two percent of the time that it fails to meet the needs of the people constitute 327 days without water, with a longest continuous period of 33 days. To remediate the effects of these inevitable droughts the network must be improved to a capacity consistent with likely climatic rainfall variations. There must be the right amount of storage to make it through extended periods of little or no rain, enough

horizontally projected area to collect an the required harvest of rainwater, and an appropriate level of efficiency in the network's guttering and piping. The individual catchment systems must meet these criteria independent of the island's network because their storage tanks are not connected. If each tank is not matched well to its respective catchment areas then there could be waste from overflowing tanks, or large inequities in the per capita production for compounds allowing some families to reach a crisis level well before others.

5.1.2 Modification Solutions

We developed seven potential solutions to the estimated shortage on Fais and ran them through our RoofRain model of the island's catchment network. The first solutions focused on the most obvious deficiencies highlighted by our model. Some of the compound systems are so unproductive that their families are often forced to depend on the community supplies. The inequity of these solutions led me to consider some island-wide improvements. Beginning with low cost and high production solutions and continuing with the highest island-wide impact solutions, we simulated realistic improvements, showing the impacts of each, and finally combined the most effective (lowest total shortage days) modifications to reach a production level that would have no shortages during the 51 years of record. Total unmet demands for all viable improvement solutions are compared to each other and to the current status in Table 4 and Figure 14.

5.1.2.1 Solution 1 – Develop the four lowest-producing compounds to self-sufficient production levels

The first potential Solution that seemed an obvious answer to the shortage problem is to remove the demands on the community from the compounds that were the most dependent on the community tanks. If the four lowest per capita producers of water or the 34 compounds (Table 3) became self-sufficient, the island would not experience an out-of-water situation. Although this seems like a simple Solution to the problem, it is not a practical one. Considering catchment area and tank size, most compounds' systems would never be able to reach self-sufficiency. The actual impermeable roofs that exist in a compound limit potential catchment area improvement. Storage volume increases are constrained by the cost of building or purchasing new tanks.

Compound	Code	Annual Demand (k gals.)	Annual Supply (k gals.)	Annual Shortage (k gals.)	Percent Shortage
Peyur south	PRmr	24.8	9.5	15.3	61.7
Maroc east	MRml	14.7	6.6	8.1	55.1
Fararep west	FPmw	12.8	5.4	7.4	57.6
Faalikil	FK	11	4.5	6.5	59.1
Fararep east	FPml	11.0	4.9	6.1	55.3
Ipur west	IPmw	9.1	3.6	5.5	60.4
Fayipar	FR	7.5	2.1	5.4	72.0
Peyemay north	PMmg	8.1	3.4	4.7	58.0
Mooliyar	ML	6.6	2.8	3.8	57.6
Peyemay south	PMmr	14.3	9.9	4.4	30.8
Sum				62.7	

Table 3. The 10 compounds with the highest average annual shortages in order of severity. The four highlighted values are for the compounds addressed in Solution 1

5.1.2.2 **Solution 2 – Improve 10 lowest-producing compounds to collect rainwater from full potential catchment areas**

The most straightforward, practical approach to reducing the transferred demands of the island's lowest producing compounds is to bring each of their catchment areas up to its potential. Improving only ten of the thirty-four compounds by including all metal or concrete roof areas within each compound, and collecting an estimated maximum runoff of 80 percent by improving the guttering hardware, the island's shortage could be eliminated. Because of the inequity of improving only selected compounds, and to appropriately distribute potential improvement funds, more island-wide modifications must be considered.

5.1.2.3 **Solution 3 – Develop all community catchments and tanks**

The first island-wide modification that we analyzed involves the two village community catchments that are currently out-of-service (Table 2). The Faliyow catchment would provide an additional 388 ft² (36 m²) of area, and 13,000 gallons (49 m³) of storage to the network. The Yiludow catchment would provide an additional 97 ft² (9 m²) of area, and 3,600 gallons (14 m³) of storage. In this Solution the School catchment would also need its guttered area to be improved from 50 percent to 100 percent. These improvements alone would reduce the island's shortage days from 327 to a mere 19. The total unmet demands during the 50 years of record would be approximately 12,000 gallons (45 m³).

5.1.2.4 **Solution 4 – Improve all catchment areas and runoff amounts by 10 %**

Solution 4 involves a 10 percent improvement of all compound catchment areas, and an improvement of their runoff factors (the percentage of rainwater falling on a catchment area that its respective gutter system delivers to the storage tank) from 50 percent to 60 percent. These improvements require minor upgrades to the existing systems. A small amount of the unused roof areas would be guttered, and all gutters would be repaired and properly mounted to collect more of the rainwater. These improvements alone would reduce the island's shortage days to 48. The total unmet demands during the 50 years of record would be approximately 29,000 gallons (110 m³).

Solution	Action	Shortage Days	Total Unmet Demands (gallons)	% Unmet Demands
0	No Improvement	327	196,000	5.9
1	Make 4 lowest producing compounds self-sufficient	0	0	0.0
2	Improve 10 lowest producing compounds to potential	0	0	0.0
3	Bring all community catchments online	19	12,000	0.6
4	Improve compound catchment areas & runoffs by 10%	48	29,000	1.3
5	Improve areas, runoffs by 10% & increase storages to 1200 gals.	12	6,500	0.3

6	Improve areas, runoffs by 10% & improve school tank to potential	12	6,100	0.3
7	Improve areas, runoffs, storage & school tank	0	0	0.0

Table 4. Modification solutions: Action description, shortage days, unmet demands, and percent of demands that are not met during 50 years of record. Solutions 5 and 6 are solution 4 with additional improvements. Solution 7 is the combination of solutions 4, 5, and 6

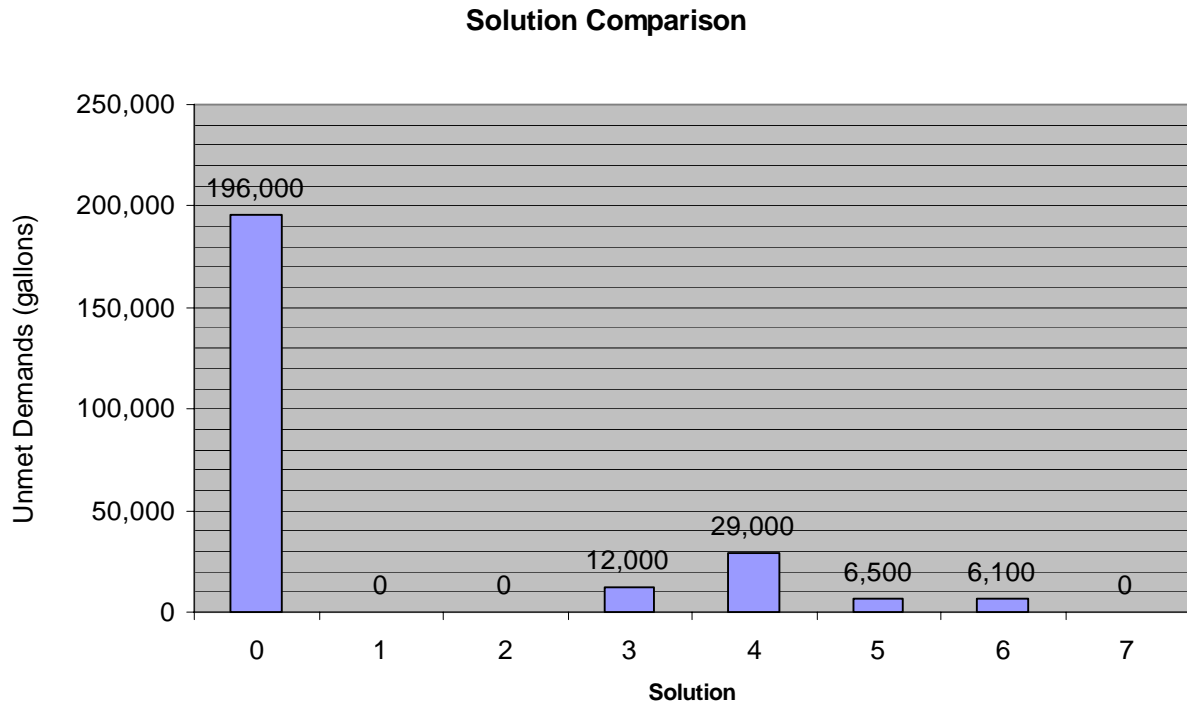


Figure 14. Total unmet demands for all improvement solutions compared to the current state of the system

5.1.2.5 **Solution 5 – Improve all the catchment areas and runoff amounts by 10 percent, and increase all the catchment storage capacities to a minimum of 1200 gallons (4.5 m³)**

Solution 5 involves an improvement of catchment areas and storage volumes. Like Solution 4, the catchment areas would be improved by 10 percent while the efficiency of the collection gutters would be improved to 60 percent. In this Solution the storage volume at each compound is brought up to the minimum reasonable size of 1,200 gallons (4.5 m³). These combined improvements would reduce the island's shortage days to 12. The total unmet demands during the 50 years of record would be approximately 6,500 gallons (25 m³). Total unmet demands for all viable improvement solutions are compared to each other and to the current status in Table 4 and Figure 14. The Solution of only improving the island's tank volumes was dismissed because, in almost every case, the lack of catchment areas was the main limiting factor in production.

5.1.2.6 Solution 6 - Improve all catchment areas and runoff amounts by 10 %, and improve School catchment to its potential area

Solution 6 involves a combination of Solution 4 improvements to catchment areas and efficiencies, with the additional guttering of the School catchment, bringing it from 50 to 100 percent guttered. These combined improvements would also reduce the island's shortage days to 12. The total unmet demands during the 50 years of record would be approximately 6,100 gallons (23 m³).

5.1.2.7 Solution 7 – Improve all catchment areas and runoff amounts by 10 %, increase all catchment storage capacities to a minimum of 1200 gallons (4.5 m³), and improve School catchment to its potential area

Solution 7 involves the combination of three of the 'island-wide' improvements. This Solution includes a 10 percent improvement of all compound catchment areas, an improvement of the runoff factor from 50 percent to 60 percent, an increase in the storage volume at each compound to the minimum reasonable size of 1,200 gallons (4.5 m³), and an improvement of the School Catchment from 50 to 100 percent guttered. These combined improvements encompass all compounds in all three villages of Fais Island and would eliminate the island's shortage problem.

5.1.3 Typhoon/Drought Scenario

The modification solutions address the possible improvements that can be made to the existing network to make it productive enough to perform well during every stage of a rain history similar to the 51 years of record. Although these modifications can handle the prior drought cycle they would not be as reliable in the event of a disaster, such as a major typhoon. It would be reasonable to assume that a typhoon direct hit could destroy most of the catchment areas (roofs), some of the storage tanks, and the entire coconut crop, in a matter of hours. If this disaster occurred at the onset of a drought similar to the El Niño drought of 1983, the results would be devastating.

Based on past experience, even if the School Catchment survived and was repaired quickly, the island would not be able to rebuild all of its smaller catchments for at least six months and as long as a year (Interviews, 2005; Meeting, 2004). The island's entire demand would be shifted to the community tank, including the 0.3 gpd (1.1 L/day) per capita consumption from the destroyed coconut crop. If the school tank was near full before the storm hit (as is predicted by the model), during the next six months the island would be completely out of water for 78 days. The unmet demands would approach 50,000 gallons (190 m³) or 34 percent of its total demands. A large amount of costly assistance would be needed from FEMA or other outside agencies.

Because of potential storm damage to, and inevitable deterioration of, the catchment network, precautions must be taken and preparations made to expand the water resources of Fais, beyond the minimum production based on rainfall alone. Considering the current level of groundwater development on Fais, the cost of the improvements needed to exploit this resource for emergency use would be an excellent investment.

5.2 Groundwater

The groundwater in Fais may be a viable source of supplemental water to the island's rainwater resources. However, using the existing wells could provide enough

additional water to protect the residents from the hardships of shortage. Before development to expand water usage into new areas could be considered, the exact properties of Fais' aquifer would have to be quantified. From our measurements of the Old Well and anecdotal reports of its response to bailing, we estimate the local hydraulic conductivity to be 750 ft/day (230 m/day), the maximum water table elevation to be 0.6 ft (0.18 m) above M.S.L. and the lens to be no greater than 26 ft (8.0 m) thick.

5.2.1 Fais' Fresh water Lens

The thickness of Fais' fresh water lens is a vital component of the island's potential productivity. The island's unique and poorly understood geology and age set it apart from other islands in the region. While the exact properties of the aquifer's carbonate rocks are unknown, several characteristics of its fresh water lens are known. we measured the depth of the water table at three locations: The Old Well, the Sahagow Well, and the Ruuche Well. Although the absolute elevations are based on a distant control point (YAP DAKIY) their relative elevations should be useful. In the three measured sites, the water table varies within a range of approximately 0.7 ft (0.2 m).

Although the simplicity of our data required me to calculate the lens properties using a homogenous, isotropic model, the island's aquifer is most likely heterogeneous, anisotropic, and triple-porosity, and therefore fracture and conduit controlled. The coastal and submarine discharge seeps occur in areas that show evidence of fractures and faults with displacements that cut deep into the island). These preferential discharge patterns and the reported salinity of many of the drilled wells suggest that the lens is asymmetrical and may be more vulnerable to pumping in areas that are well connected to the ocean by conduits or fractures. However, the more successful, fresh water producing wells (Selibway, Sahagow, Japanese, and Old Well) are north of the villages and nearby the most noticeable discharge features. The slight variation in the water table elevations suggest that the thickest part of the lens may be north of the island's axis in the southern half of Fais.

The Sahagow Well, which we successfully pumped, produced 1,200 gallons (4.5 m³) of fresh water (approximately 0.15 mg/L chloride throughout). This well was drilled to ten feet (3 m) below the water table and neither breached the saltwater interface, nor was pumped at a high enough rate to cause significant upconing or drawdown. Wells drilled to similar depths relative to the water table, and pumped by similar equipment, should be equally productive. Although the repair, development, and maintenance of the wells closest to the community tanks and the acquisition of the pumping equipment would be costly and labor-intensive, the production of even 500 gpd (1,900 L/day), during a crisis, would give the residents a margin of safety and security. Fais Islanders consume approximate 960 gallons (3,600 L) of fresh water, per day. The conservatively estimated productivity of an emergency well could cut the demands on the network of catchments in half.

5.2.2 The Old Well

The Old Well is an ancient and valuable resource. It has served the inhabitants of Fais for many years, and has, in recent history, provided water to the residents when no other source was available. The well has historical significance and present utility.

The Old Well is the only place on Fais where the water table is exposed to the surface. Our measurements of the Old Well revealed that the elevation of the surface of the pool is close to the elevations of two of the drilled wells, which is a good indication of the consistency and shape of the fresh water lens (refer to Figure 13). Although the well can continuously provide fresh water (0.0 mg/L chloride on the surface), there are two indicators that the area is one of relatively low permeability: 1) The residents explained that the water level in the pool varies completely out of phase with the tides, and 2) When the airstrip was constructed in the early 1990s, the workers attempted to use the Old Well as a water supply. They were able to pump the approximately 1,900 gallons (7.1 m³) of water from the well in a matter of minutes, and the well took over an hour to refill. For this reason, and the fact that surface waters are usually contaminated, water should only be extracted from the Old Well manually, and not be combined with any community supply.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The existing buildings on Fais are capable of collecting enough of the rainwater that falls on the island to meet the needs of its people (Figure 14). Modification of existing structures and acquisition and maintenance of new tanks and equipment must occur to enable adequate water collection. In case the primary system is damaged, emergency resources must be developed and protected to ensure a constant water supply for Fais (Table 5).

6.1 Rainwater Collection

The people of Fais consume approximately 1,000 gallons (3,800 L) of fresh water, per day. The current network of systems cannot meet this demand during periods of low rainfall. The systems must be improved to sustain a level of production and storage that eliminates shortage periods. The network must produce enough fresh water to meet the average demands of the consumers and have sufficient additional capacity for emergency drought conditions. It must be able to store enough water in reserve to protect the people against shortages through all periods in the Western Pacific's drastic climatic cycles. There must also be enough tools and materials on hand to maintain the system, and most importantly to repair or rebuild it after a damaging storm.

The following recommendations are a compilation of select actions from the seven solutions chosen for their performance in the RoofRain model and presented in order of cost and effectiveness. Development should be focused on island-wide or village-wide upgrades. The first tier of the network lies with the individual compound catchments, and the first efforts should take place there. Helping the compounds become more self-sufficient will have the most direct impact on the needs of the people, and is also the least expensive way to increase the productivity of the network.

Tools and materials necessary for the guttering of roofs should be made available to the residents of Fais so that the catchment areas can be expanded and the efficiency of the water routing improved. Most buildings on Fais can be easily improved by guttering 10 percent more area, and repairing the existing gutters to collect 60 percent of the rainwater as analyzed in Solution 4, and many buildings can be improved well beyond this if provided with the proper materials

Recommended Action	Production (gallons per year)	Storage (gallons)	Necessary Equipment
Improve all compound catchments by 10%	150,000	0	120 feet of guttering and attaching hardware (Total)
Increase all compound catchment storage capacities to 1200 gallon minimum	0	14,400	Twelve 1,200 gallon polyethylene water tanks (Total for island)
Repair all community catchment systems	340,000	16,800	Lumber, steel galvanized roofing, and hardware for 500 sq. ft. of peaked roof. 250 feet of guttering and hardware.
Stockpile enough equipment to replace 40% of island's guttering and school tanks roof	1,170,000	43,000	Lumber, steel galvanized roofing, and hardware for 8,000 sq. ft. of peaked roof. 400 feet of guttering and hardware.
Develop Sahagow Well to supply water to school tank in an emergency	146,000	0	Submersible well pump, dedicated solar panel, and 1,200 feet of properly sized PVC piping and couplers.

Table 5. Recommended improvement actions, expected results, and necessary equipment. Estimate annual island consumption is 350,000 gallons.

As analyzed in Solution 5, every household on Fais should have at least 1,000 gallons (3.8 m³) of storage on-site. At least twelve additional 1,200-gallon (4.5 m³) polypropylene water tanks should be provided for Fais. The addition of this storage capacity would allow the catchment areas used to reach their full production potential. The tanks could replace the insufficient 500-gallon tanks in some compounds, while allowing the remaining compounds to have at least two of the smaller tanks.

As analyzed in Solution 3, the two village community tanks' roofs should be rebuilt to bring the systems back into use, and the guttered sections of the School Catchment should be improved from 50 percent to 100 percent. These repairs would create another 2,000 ft² (190 m²) of catchment area, and another 17,000 gallons (64 m³) of storage capacity for the island. This would provide a vital safety cushion against the inevitable failure of the compound systems to provide enough fresh water during a severe drought.

In the event of a major storm that damages the island's catchment areas, the people of Fais would need supplies and materials, stored on the island, to repair the damage quickly. Guttering, lumber, corrugated galvanized steel roofing, and hardware should be warehoused on Fais, safe from the elements and termites considered as community property, and kept for emergency use only.

Without the proposed improvement of the village catchments, the modified network would barely be able to meet the water demand on Fais. The additional production of the village systems would ensure an adequate supply system with little chance of shortage-related impacts on the people. The improvements to the compounds' systems will be inexpensive, but highly productive. Without the proper materials and tools the systems will not be improved, but will degrade over time (the 10 compounds that we resurveyed showed an average 17 percent drop in collection area between August 2004 and June 2005 despite the fact that the period between surveys was the driest of the year; a time when one would want to collect the most water possible). The distribution of plastic tanks, rather than materials for constructing ferro-concrete tanks, would ensure that the supplies sent to Fais were used for the intended purpose of improving the water resources, although ferro-concrete tanks are cheaper. In the past, materials intended for tank production were used for other purposes (Interviews, 2005). Although the repairs on the community catchments would be costly, the cost per unit volume of water produced would be relatively low because the concrete and block walls and floors are still structurally sound. Only the roofs and gutters would need to be rebuilt.

6.2 Groundwater Development

In the event of a catastrophe that destroys the catchment areas and coconut crop, the groundwater would be the only immediate source of fresh water on Fais. The groundwater must be developed to help the people endure these inevitable periods with a minimum amount of hardship.

The well at Sahagow should be connected by PVC pipe and pumped to the 52,000-gallon (200 m³) School Tank. A submersible well pump and 24-volt solar power source must be acquired and stored in reserve for crisis periods. The piping and pump must be properly sized to overcome the 60 feet (18 m) of head necessary to reach the top of the tank. The pipe should be installed on the surface and protected for the entire 1,050-foot (320-meter) distance to the School Tank.

6.3 Management

If the Yap State and FSM National governments address the needs of Fais, procure the funds to purchase the recommended materials, and deliver them to the island, the proper management and distribution of the goods will then be the responsibility of the Fais community. If the materials are not used properly, maintained, and protected, the water productivity of the island will not reach or maintain its potential.

Materials intended for catchment or well systems must not be used for any other purpose. Tools and equipment must be set aside for use during inevitable crises. Specifically, the well pump, tank, and power source must be used exclusively for emergency well operations, testing, and periodic operation to prevent deterioration. (The previous pump and power source allocated for well use have been used for other

purposes, including private power supplies, and have been prematurely worn or damaged as a result.)

Much work would need to be done if the recommended supplies are provided to Fais. The most technically proficient individuals on the island must install the equipment and provide guidance to others as they improve their own systems. Most importantly, the entire community must take responsibility for maintaining their compounds' systems and the community's resources. Certain individuals will have to be designated to maintain and monitor these village and island-wide community systems.

Making the proposed improvements a success will require the Fais Islanders to take responsibility for the system, but without effective leadership all good intentions will be useless. The villages must delegate not only technical responsibilities, but leadership roles as well. Some individuals must coordinate village and island improvement activities, and take personal responsibility for the accomplishment of assigned objectives. Although the social structure on Fais discourages the dominance of any individual, the chiefs and their liaisons must exercise their influence and hold individuals responsible for the success of a self-sufficient water supply on Fais.

6.4 Future Studies

A definitive study to determine the properties of Fais' aquifer and the size and location of its fresh water lens should be conducted. To accomplish this, a precise survey of Fais Island is vital and needs to be conducted in advance, so that the exact elevation of the water table at different locations and therefore the lens thickness can be measured. Pump-tests should be conducted and analyzed to determine the hydraulic conductivity, transmissivity, and storativity to ultimately, more accurately estimate the potential productivity of the aquifer. Specifically, a pump-test using at least one observation well each between 100 ft (30 m) and 200 ft (60m) away is recommended. Sahagow Well is an obvious choice because it is presently a productive well. The Ruuche Well should be re-drilled and used as an observation well because it has been reported as providing salty water. A test well that uses Ruuche as an observation point could be placed within 130 feet (40 m) of the School Tank. An appropriate third location for a pump-test would be the previously successful Selibway Well, which is only 390 feet (120 m) from the School Tank. These three locations are well spread through the island's interior and are all close to the villages and their community tank.

REFERENCES

- Bouwer, H., 1989, The Bouwer and Rice slug test-an update: *Ground Water*, v. 27, no. 3, p. 304-309.
- Bouwer, H., and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: *Water Resources Research*, v. 12, p. 423-428.
- Dasher, G.R., 1994, On Station, National Speleological Society.
- Enfield, D.B., 2005, NOAA El Nino page, http://www.aoml.noaa.gov/general/enso/faq/#_Hlk419684448; Web site.
- Fetter, C.W., Jr., 1972, Position of the saline water interface beneath oceanic islands: *Water Resources Research*, v. 8, p. 1307-1314.
- Heitz, L.F., 2003, Users guide for RoofRain: Water and Environmental Research Institute of the Western Pacific, University of Guam.
- Internet, 2005a, Dive into the heart of exotic Micronesia, <http://www.visit-fsm.org/>, website.
- 2005b, Visit Yap, <http://www.visit Yap.org/>; web site.
- Interviews, 2005, Water Resources Survey: Fais Island.
- Intoh, M., 1997, Human dispersals into Micronesia: *Anthropological Science*, v. 105, no. 1, p. 15-28.
- Keating, B.H., Matthey, D.p., Helsley, C.E., Naughton, J.J., Epp, D., Lazarewicz, A., and Schwank, D., 1984, Evidence for a hot spot origin of the Caroline Islands: *Journal of Geophysics*, v. 89, p. 9937-9948.
- Kotake, Y., 2000, Study on the tectonics of western Pacific region derived from GPS data analysis: *Earthquake Res. Inst.*, v. 75, p. 229-334.
- Lander, M.A., 2006, Personal Communication at the University of Guam with Robert MacCracken, Techniques for estimating recurrence intervals for tropical cyclone-related high winds in the tropics: Results for Yap.
- Lee, S.-M., 2004, Deformation from the convergence of oceanic lithosphere into Yap trench and its implications for early-stage subduction: *Journal of Geodynamics*, v. 37, no. 2004, p. 83-102.
- Levin, M.J., 1976, Eauripik population structure, University of Michigan, Ph.D. Dissertation.
- MacCracken, R.S., 2006, Water Resources Analysis of Fais Island, Yap State, FSM, University of Guam, M.S. Thesis.
- Meeting, 2004, Fais community leadership meeting: Fais Island.
- Ourlroie, J.E., and Carew, J.L., 1995, Karst development on carbonate islands, *in* Budd, D.A., Harris, P.M., and Saller, A., ed., *Unconformities and Porosity in Carbonate Strata*, American Association of Petroleum Geologists, p. 55-76.
- Nugent, L.E., Jr., 1944, Photographic Intelligence Report 76.
- Rejcek, P., 2002, It's official: El Nino to return, *The Kwajalein Hourglass* (Volume 42, Number 56), p. 1 and 5.
- U.S. Congress, 1986, Compact of Free Association Act of 1985, Public Law 99-239: 99th Congress.
- Zheng, K., 1996, Implementation of Fais Well Drilling Programme and Well Driller's Training: FSM/United Nations Water Resources Assessment and Development Project.

Appendix A

Water Usage Survey

Water Resources of Fais Island WERwe & MARC

- 1) If your tank was full and then it stopped raining how long would it take for the level to drop to half-full?
- 2)
 - a. What did you do in the past when your tank got low?
 - b. What did you tell your family to do? How low was the tank when you did that?
 - c. [If they actually did change water usage] How long did the water last until the tank was empty?
- 3)
 - a. How many coconuts do the adults and children in your household drink per day?
 - b. Can you remember any droughts in the past when the island's supply of drinking coconuts was entirely used up? How many months did it take for that to happen? During a drought, after how many months do you notice a change in the coconut trees? What happens?
- 4)
 - a. If your household storage tanks were empty, where is the first place you would try to get water? Where is the second place?
 - b. Are there any rules for how much water can be used from the school tank when people are out of water at home?
- 5) If all storage tanks were empty and you had to go to the "Old Well" at Peyechich for water how many five-gallon buckets would you need per day?
- 6) Has the water on Fais ever made anybody sick?

Appendix B

GIS Development Procedures

- **Create Base Maps**
 - Import aerial images into ArcMap®
 - Set coordinate system to UTM zone 54N
 - Create an XY Table from known coordinates on aerial photos
 - Georeference photos to grid
 - Mosaic photos
 - Duplicate procedures for topo maps
- **Rectify Base Maps**
 - Import GPS points to map
 - Update georeferencing of aerial and topo maps to match GPS points
- **Develop Digital Elevation Model (DEM)**
 - Digitize topo lines assigning elevation values in attribute table
 - Create Triangular Irregular Network (TIN)
 - Edit the TIN to input digitized topo map
 - Modify the display properties for visual clarity
 - Save modified TIN as a layer file