Pakein Atoll

FRESHWATER RESOURCES AND THEIR USAGE, STATE, AND INFRASTRUCTURE

USP Library Cataloguing-in-Publication Data

Taborosi, Danko
Pakein Atoll : freshwater resources and their usage, state, and infrastructure /
D. Taborosi and M. Martin. – Palikir, Pohnpei : Islands Research & Education Initiative, 2009.

95 p. ; 23 cm.

978-982-98023-5-4

Water-supply—Micronesia (Federated States)—Pakein 2. Fresh water—Micronesia (Federated States)—Pakein 3. Water use—Micronesia (Federated States)—Pakein 4. Water utilities—Micronesia (Federated States)—Pakein I. Martin, M. II. Title.

TD324.P7T262 2009 628.1

This publication was prepared by
Dr. Danko Taboroši and Matthew Martin
Island Research & Education Initiative (IREI) * PO Box PS 303 * Palikir, Pohnpei State, FM 96941 * ***www.islandresearch.org***

In collaboration with
Dr. John W. Jenson
Water and Environmental Research Institute of the Western Pacific (WERI) * University of Guam Station * Mangilao, GU 96923 * ***www.weriguam.org***

With funding by
United States Geological Survey (USGS)
FY 2008 USGS Water Institute Program 104(B) grant **** www.usgs.org***

Download a PDF version of this report from *www.islandresearch.org/books*
For additional information please contact *irei@islandresearch.org*

Pakein Atoll

FRESHWATER RESOURCES AND THEIR USAGE, STATE, AND INFRASTRUCTURE

Danko Taboroši, Ph.D.
Matthew Martin

October, 2009

Island Research &
Education Initiative

Water and Environmental Research
Institute of the Western Pacific

Dedicated to the people of Micronesia.

Acknowledgments

The authors wish to extend sincere gratitude to all the people who have helped during various stages of this project. We thank the entire Pakein community on the atoll itself and in Sokehs Municipality of Pohnpei, and would like to individually acknowledge:

Pius Siten, Pakein's traditional leader; Samuel Wenio, *kaniki* of Pakein; Jonathan Carred and his wife Kiki, Liberto Linge, and Selino Taiwelyar, teachers at Pakein Elementary School; Richard Susaia, former Mayor of Sokehs Municipality; Melson Syne, Sikio Wenio, and the other police officers of Sokehs Municipality; Mackanzie (Makan), resident of Pakein; Emerson Odango, Peace Corps Volunteer; and all others who were kind and helpful to us during field work.

We are also indebted to the following persons and organizations on Pohnpei and in Guam:

Milan Kamber and Marko Kamber, Caroline Fisheries Corporation; Joyce Anson, Peterson Anson, Jacqueline Hazen, and other IREI members; Shelten Neth; Dr. Gary Denton and Dr. John W. Jenson, Water and Environmental Research Institute of the Western Pacific, University of Guam; and Ben Namakin, Conservation Society of Pohnpei. We also wish to single out the research by Robert S. MacCracken *et al*. among the many reports and publications we consulted during the implementation of this project. Their work on Fais was a much relied-upon reference over the course of this project.

Contents

List of figures

List of maps

List of tables

List of appendices

Background

Introduction

This study is a fact-finding operation to document the current state of freshwater resources on Pakein Atoll.

This document is the result of a comprehensive baseline survey of the current condition, infrastructure, and use of freshwater resources on Pakein Atoll, in the Federated States of Micronesia. Using a combined hydrologic and sociological fieldwork approach, we have evaluated all hydrologically significant infrastructure; described practices of water production, distribution, and consumption; and recorded people's perceptions and concerns related to freshwater resources on their island. The infrastructure survey component included the inventory of all collection and storage elements of rainwater catchment systems, all wells utilizing groundwater supply, and all other relevant features. People-oriented component was based on direct observations and interviews of residents and leaders regarding the lifestyle practices, notions, and opinions pertaining to freshwater resources. The purpose of the project has been to collect up-to-date information in order to understand availability of and threats to fresh water resources on the island, support their future sustainable management, and avoid emergencies.

Federated States of Micronesia

There are 38 low islands – coral atolls and lone coral islets – in the Federated States of Micronesia.

The Federated States of Micronesia (FSM) is a small island developing state (SIDS) in the Western Pacific. It consists of 4 high island units (Yap, Chuuk, Pohnpei, and Kosrae) and 38 low island units. High islands are of volcanic origin and have relatively large land areas. They are centers of socioeconomic and political life of the country and home to the majority of its population. Low islands are of carbonate origin and include atolls and solitary coral isles, all of which have extremely limited land area and reach only a few meters above the sea level. They are collectively known as the "Outer

Islands," and have relatively small populations.

Outer Islands and limited resources

Except for Kosrae, each high island in the FSM has its own constellation of "Outer Islands." Pakein Atoll - the subject of this study - is one of the "Outer Islands of Pohnpei". The appellation 'outer' is somewhat of a misnomer considering the fact that low islands are not mere adjuncts of high islands – they are homes to distinct societies with unique histories, traditions, cultures, and languages. The cultural background and identity of "outer" islanders are clearly differentiated from those indigenous to high islands. Their lifestyle remains largely traditional and based on time-honored agroforestry and fishing methods. Such a way of life is shaped by unique geography of restricted low island environments and is defined principally by two attributes: extreme scarcity of natural resources and

Fig 1
Typical low island landscape, as seen on Pakein.

utmost dependence on natural conditions.

Climate and rainfall

Micronesia is tropical, its islands having a fairly uniform annual temperature range (26~27°C / 79~81°F) and relative humidity over 80%. Rainfall varies with geographic position and island size (from 180 cm / 70 in. in the driest islands to 960 cm / 380 in. in the mountains of the wettest island of Pohnpei). Probably because of its location near Pohnpei, the annual rainfall on Pakein is somewhat above the low islands' average. Most of the rainfall falls within the wet season (June to October), but this seasonal variation is less pronounced on Pohnpei, which is wet throughout the year and sees only a slight reduction in rainfall from January

Fig 2
Path through atoll forest.

through March. Micronesian climate is characterized by occasional typhoons and droughts, which can be severe and very damaging to quality of life and infrastructure.

Fresh water needs and issues

Availability of fresh water is a major problem in low islands.

Despite the small numbers of residents, the pressure on resources in the low islands can be quite high due to their extremely limited land areas. The FSM is the fourth most densely populated Pacific island nation based on the national average, and population densities of individual low islets are some of the highest in the world. Their residents have access only to the most basic amenities and infrastructure. Availability of fresh water is a major problem.

Thanks to their traditional lifestyle and subsistence economy, the residents of Pakein exert no unreasonable demands on their water resources. They have no technology-related demands for water and forgo many forms of water usage that are commonplace in communities accustomed to municipal water and power supplies and relatively lavish lifestyle. There are no conveniences that require plumbing and pressurization.

Water usage	Importance	Notes
Cooking	High	Necessity
Drinking	High	Coconuts are alternate source
Washing dishes	High	Health related need
Washing clothes	Medium	Health related need
Watering pigs	Medium	Agricultural need
Rinsing after bathing	Medium	Health related need
Showering / bathing	Low	Ocean is alternate source

Table 1
Overview of water usage on Pakein.

The islanders' demand for water, therefore, does not extend beyond the basic needs for drinking, cooking, dishwashing, laundry, and showering. Table 1 outlines the basic needs in order of relative importance.

Residents of low islands catch and store rain for their potable water needs.

However, the fact that the islanders' requirements are relatively low also means that they are based on fundamental needs. Therefore, any restriction or interruption of water supply immediately affects comfort and quality of life. If unmitigated, it can result in threats to well-being and health, and necessitates emergency intervention from outside sources.

Residents of Pakein and other low islands in Micronesia rely almost exclusively on catchment of rainwater to meet their potable water needs. Such water is more often than not unsafe for drinking due to a number of factors, including the prolific microbial growth in a tropical climate, limited possibilities for hygienic conditions, ease of contamination, lack of physical and chemical treatment of water, and imperfect service and upkeep. Estimates made in the neighboring Republic of the Marshall Islands state that less than 2% of low island population have access to safe drinking water.

Droughts and typhoons disrupt supply and cause water shortages.

Difficult weather conditions are a major threat. The use of rainwater for all potable water needs is a precarious arrangement characterized by a tight relationship between supply and demand. The system tends to break down during natural disasters, when emergency assistance from the outside becomes a matter of survival. During prolonged droughts, especially following El Niño events, catchment systems generally fail to collect and store sufficient water to meet even basic needs. They are also quite vulnerable to typhoons and other severe storms, which can render them inoperable for extended periods of time. Gutters and any associated hardware can be blown away by strong

winds. Roofs can also be damaged by gusts of wind, and plastic tanks can be broken by flying debris. That reduces an island's total catchment and storage capacity in the aftermath and creates shortages that profoundly affect the local people's health and quality of life.

At least a third of disease outbreaks in Micronesia result from the lack of safe water supplies.

Waterborne contagious diseases also represent a major concern. Health surveys in the FSM have shown that at least a third of disease outbreaks in the nation are a direct result of the lack of safe water supplies. In one of the more dramatic recent incidents, contaminated water was the identified as the source of the 2000 cholera epidemic in Pohnpei when 21 person died and more than 3000 were treated.

Availability of safe and ample fresh water remains one of the greatest challenges of life in the low islands, and a priority for sustainable development in Micronesia. It depends on numerous factors, including sufficient and appropriate catchment and storage infrastructure, backup systems, appropriate maintenance and periodic rehabilitation, and preparedness for emergencies. The critical tool necessary for planning of such sustainable development strategies is, of course, accurate and up-to-date information. We have carried out this research and prepared this publication in order to help with fulfilling that need. Part of a series dealing individually with select low islands in Micronesia, this report focuses on Pakein Atoll and provides baseline data regarding the current state of its freshwater resources. The information contained within is based on extensive fieldwork and comprehensive inventorying of features and facts relevant to the usage, state, and infrastructure of freshwater resources on Pakein Atoll.

We hope that it will become a useful reference for resource managers, planners, government authorities, and researchers who wish to improve the well-being of people in Pakein and other low islands in Micronesia.

Key concepts

Low islands are small carbonate bodies unable to support surface water flow and accumulation. For all practical purposes, their freshwater resources belong in two categories only: rainwater and groundwater.

Rainwater

Water vapor contained in the atmosphere precipitates and falls as rain. In the low islands, small total area and permeable coral rock mean that the little water that does fall on the land surface there is quickly lost into the ground and the surrounding ocean. People must capture and store the rainwater in order to use it. Typically, that is achieved using catchment systems consisting of an impermeable area that receives the rain (ie., roof), a series of conduits that transfer it (ie., gutter), and a storage component (ie., water tank) that keeps the water until it is used.

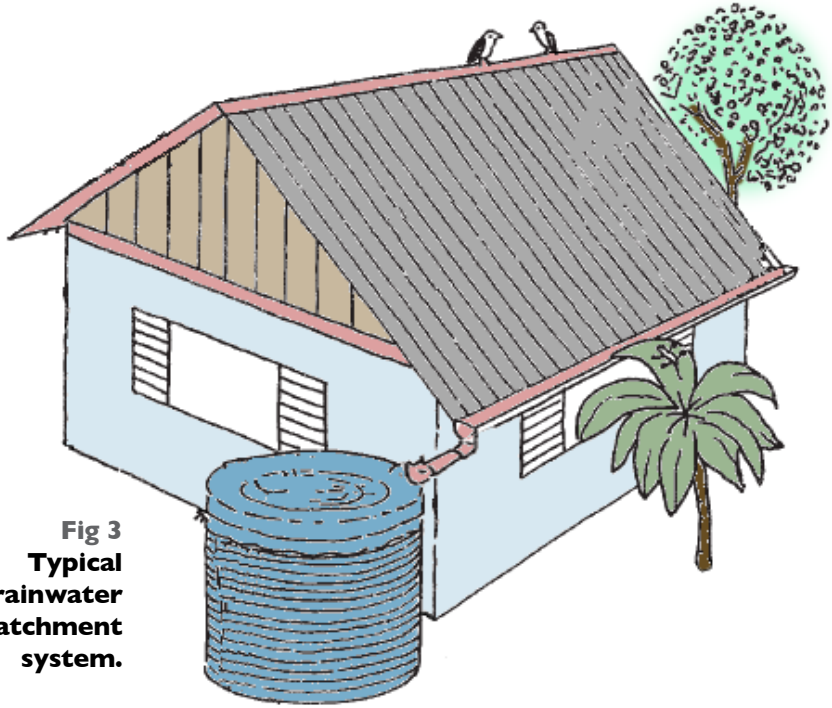


Fig 3
Typical rainwater catchment system.

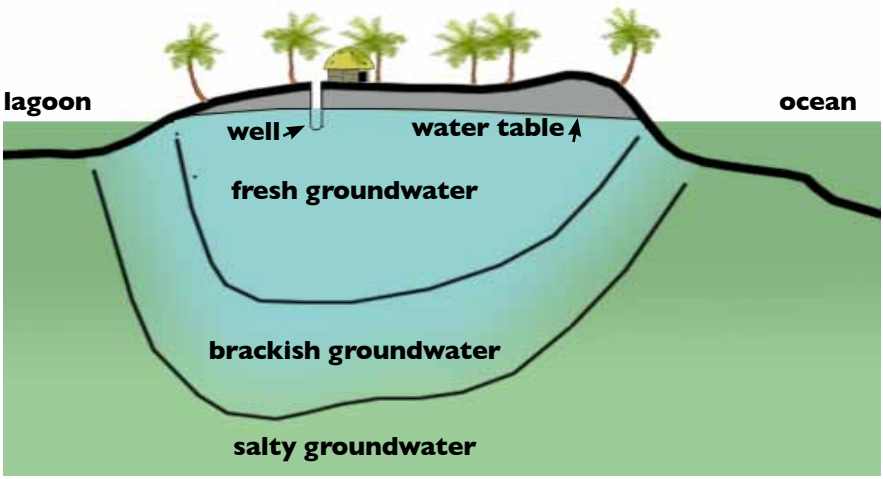
Groundwater

Rain that falls on an island quickly sinks into the ground and continues to percolate downward through porous coral rock. It reaches the water table, below which rocks are saturated with fresh groundwater. All that water originated as rain and is contained within the island because it is slightly less dense than seawater -- which also percolates into the porous island rocks and provides a base on which the fresh water rests. The fresh groundwater body is the thickest in the island's interior and thinnest around the perimeter, which gives it an overall shape reminiscent of a biconvex lens. The thickness of a groundwater lens and the amount of fresh water within it depend on island's size, amount of rainfall, and properties of rock that holds it.

Fresh and salty groundwaters do not blend because of their density differences (much like oil floating on top of water in a glass). They mix somewhat along the zone where they are in contact. Such mixed water is known as brackish - neither very salty nor sufficiently fresh.

Freshwater wells are excavated by people in order to allow extraction of water from the freshwater lens.

Fig 4
Cross-section of a low island showing its groundwater.



Rationale

Freshwater resources on low islands are under threat by unsustainable practices.

Freshwater resources on coral atolls and other low islands in the Federated States of Micronesia (FSM) are under threat of overuse due to changing lifestyles and increasing population pressures, damage by pollution and unsustainable development, and obliteration by the global climate change. The extent of specific problems are different on various islands, but cannot be evaluated at present due to the lack of most basic field data. Despite the rapid socioeconomic and environmental changes being experienced by the low islands in the FSM, there has been no comprehensive study to examine the current condition, infrastructure, and utilization patterns of their freshwater resources. The lack of such information represents a huge obstacle to government planners, resource managers, engineers, educators, environmental scientists, and others dedicated to the sustainable development and use of freshwater resources in Micronesia.

Historically, people on low islands have coped with the enormous restrictions of their natural environment by means of cultural and technological adaptations such as traditional conservation practices and resource management, specialized agriculture and distinctive land use systems, advanced fishing and navigational methods, etc. In the second half of the 20th century, however, as these societies gradually changed from those based on subsistence economy and traditional authority to those based on cash economy and individual freedoms, and improved transportation and communication links reduced their levels of self-reliance, much of the balance they had previously enjoyed with their environment has been lost. As a consequence, their limited natural resources have come under threat. For example, acquired desires for consumer goods are causing unprecedented amounts of non-biodegradable materials to be imported to the

islands, which creates ever increasing solid waste disposal problems; abandonment of indigenous religion has meant the replacement of traditional sea burials with interment practices that threaten the quality of atoll islets' exceedingly small groundwater bodies; the use of diesel, motor oil, soap, bleach, detergents, and other fuels and chemicals has introduced the threat of pollution; and more frequent travel and movement of goods between the islands pose new risks of introduction of plant diseases, agricultural pests, and other invasive species. In addition, the reduction of chiefly authority has lessened the strength of traditional regulations and taboos aimed at controlling population growth, which has lead to very high birth rates and extreme population densities. The increases in population are reflected in greater amounts of human and animal waste, greater pressure on the islands' limited resources, and greater likelihoods of environmental and health problems.

Similarly, the dichotomy between "old" and "new" can also be extended to the atolls' vulnerability to changing natural conditions. Over the centuries, people indigenous to atolls and low islands have developed response mechanisms and complex strategies to survive natural disasters, including destructive typhoons, giant swells, saltwater intrusion, and rapid erosion, as well as famines and epidemics that come with them. However, it is possible that the global climate change, irrespective of its actual cause, intensity and pace, is triggering events that have previously not been experienced by the atolls' current populations. If extreme weather conditions are striking with increased frequency and intensity, they could overwhelm the islands' vegetation and populations and even the islands themselves. The most terrifying threat, of course, is the possibility of a global sea level rise, which would obliterate the low islands' thin groundwater lenses and end the human ability to inhabit atolls at all.

Problems are exacerbated by erosion, saltwater intrusion, and extreme weather.

Considering how the changing socioeconomic and environmental circumstances described above are threatening atoll populations with resource shortages and reduced environmental quality, it is critical to evaluate the local people's current relationship with their most precious and sensitive resource of all: fresh water. Regrettably, up-to-date and detailed information on the state and usage of fresh water on low islands of Pohnpei State and other parts of the FSM is not easily accessible. This includes the data on water resources' current condition (e.g., salinity of groundwater and its suitability for an emergency supply of drinking water), infrastructure (e.g., size of rainwater catchment and storage facilities available on different islands), and lifestyle practices (e.g., water utilization patterns, solid and human waste disposal, animal husbandry, etc.).

Fig 5
Schoolchildren having class at Pakein Elementary School.

We have attempted to alleviate this problem in Pohnpei State by carrying out a comprehensive study of its atolls to document the current condition of their freshwater resources and related infrastructure, as well as the local people's relationship with those resources. Such information needs to be available not only to improve our understanding of the water resources in the low islands, but also to support their sustained use.

Finally, data collected as part of this project will help avoid or better respond to fresh water emergencies, agricultural difficulties, food shortages, health problems and other environmental crises that may arise due to lack of knowledge, awareness or preparation.

This report provides baseline data to support resource management, sustainable development, and emergency preparedness.

Objectives

The fundamental objective of research behind this project is to obtain baseline data on the freshwater resources on Pakein Atoll. The purpose of this report itself if to provide a comprehensive description of those resources and relevant information regarding their current state, usage, and associated infrastructure.

Specific tasks carried out include the following:

- Describe the atoll's physical and human environment (e.g., depict geographic, social, and cultural characteristics; highlight significant natural and man-made features; provide relevant maps; list major points of contact; etc.)

- Inventory, assess, and map hydrologically significant infrastructure (e.g., rainwater catchment systems, storage tanks, shallow wells, etc.)

- Examine the state of freshwater resources and their usage patterns on each island (e.g., relate specific water sources and infrastructure to daily water use for drinking, bathing, washing, etc.)

- Investigate other relevant lifestyle features (e.g., waste disposal, burial practices, animal husbandry and agroforestry patterns, etc.)

- Record island residents' attitudes and relevant cultural norms, perceptions, behavior and opinions related to freshwater resources (e.g., people's habits, concerns, and beliefs about their water, etc.)

- Identify and report any critical problems related to freshwater resources (e.g., historical or current shortages, health problems, agricultural problems, etc.)

The research objectives were identified as to fill data gaps in knowledge of the current situation in Micronesian low islands and their freshwater resources. They were pursued in order to provide information that is vital for improved usage, monitoring, management, and protection of the freshwater resources in Pakein Atoll.

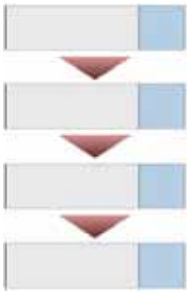
In addition, it is hoped that research and data presented here will provide not only specific information relevant to Pakein Atoll, but also criteria for similar surveys on other low islands in Micronesia and small island developing states elsewhere, as well as provide a basis for systematic comparisons.

Fig 6
Traveling to Pakein by outboard

Methods

The work presented here was carried out by Micronesia-based non-governmental organization Island Research & Education Initiative (IREI), with funding from the United States Geological Survey (GIS) received from the Water and Environmental Research Institute of the Western Pacific (WERI). Methodology employed has incorporated hydrogeological fieldwork, engineering studies, and sociological inquiry.

Project structure



Prior to project implementation, we have gathered and examined all extant relevant information in the form of scientific papers, maps, on-line resources, etc. about the island to be surveyed. We have conveyed our plans to the local points of contact, requested feedback from elected leaders and community members, and modified the research plan according to received input.

After thorough preparatory work, we undertook intensive data collection trips to the atoll. We met with island leaders and elders to explain the nature of our visit project and its objectives. We visually examined the island and coastal areas, performed comprehensive surveys of infrastructure, interviewed local leaders and residents, carried out GPS and GIS mapping, acquired numerous photographs, and finally worked on data processing and dissemination.

Fieldwork

Fieldwork comprised of three separate research trips to the atoll. Each trip included a hydrogeologic component comprising of field observations and mapping; an engineering component comprising of infrastructure

measurements and evaluations; and "people-oriented" component comprising of standardized surveys and freeform interviews of local residents. The data produced encompasses 1) hydrogeologic observations (e.g., descriptions of coastal discharge, taro patches, etc.), 2) technical particulars (e.g., size and shape of rainwater catchment tanks, condition of wells, etc.); 3) GIS data (e.g., locations of wells and water catchment systems); 4) lifestyle and sociological information (e.g., usage patterns of groundwater, perceptions of its quality, etc.); 5) images (e.g., photographs of infrastructure and daily life); and 6) other relevant data.

During the first visit to the atoll, we carried out an informal inspection and photographing of the island, its settlement, vegetation, buildings and other infrastructure, and any other distinguishing features. During the second visit, we carried out a systematic survey by visiting individual households and public facilities and assessing rainwater catchment systems, wells, and other relevant features. The third visit was used to verify previously collected data and fill in any information that may have been missing.

For data collection, researchers used sets of checklists to help them note all information previously identified as significant (or deemed so at the time of surveying). See Appendix 1 for the detailed list of information, attributes, and topics that were sought, examined, and recorded by researchers in the field.

Survey of infrastructure

The core of this project is a comprehensive survey of rainwater catchment systems and groundwater wells. Households were visited systematically and each had all of its water-related infrastructure examined. We recorded the size and state of repair of each component of existing rainwater catchment systems. We measured

dimensions of all individual catchment systems, storage tanks, and groundwater wells using a tape measure, noted their engineering characteristics, and recorded geographic coordinates by a hand-held GPS unit. See Appendices 2 and 3 for data collection sheets used by researchers during interviews.

In addition, we examined and documented other relevant features, such as solid and human waste disposal sites, weather data collecting stations, cemeteries and other burial sites, etc. Finally, we made observations of agricultural and coastal areas, paying special attention to anomalies such as saltwater damage to vegetation or unusual erosion features.

GPS and GIS

This study is the first to represent Pakein using GIS datasets and layered maps. We began by scanning and georeferencing the only available large scale map of Pakein (1960, US Army Corps of Engineers, 1:50000, series W756, sheet 5742 I). Vector data were derived by digitizing individual features off the scanned image. The information was updated using remote sensing imagery and corrected by ground control points collected in the field (by making GPS placemarks of prominent features visible in remote sensing imagery). Following base map preparation, we proceeded to build original data relevant to the project. We used a GPS-based mobile mapping unit (Thales MobileMapper CE) capable of creating GIS shapefiles to map important linear, areal, and point features on site. In addition to recording the locations of all water-related infrastructure, we mapped household sites, municipal and public buildings, main pathways, seawalls, taro patches, and other prominent features. GIS coverages generated in field were exported into ArcGIS® software and processed to create detailed maps.

Throughout the fieldwork, we used a secondary GPS unit (Qstarz BT-Q1200) capable of automatic logging to record researchers' position in 10 second intervals. That data was used to digitially geotag photographs taken by cameras whose internal clocks were previously synchronized with the GPS logger.

Interviews

Key aspects of the project were to evaluate the state of freshwater resources on a given island as perceived by local residents and to record their usage patterns of those resources. We made concerted efforts to have as many as possible informal conversations and formal interviews with local officials, community leaders, and average residents. We asked a range of questions designed to (1) record exact information (e.g., regarding specifics of catchment systems and wells), (2) determine customary behavior (e.g., regarding common and uncommon use of well water), (3) note people's impressions and perceptions (e.g., opinion of water quality and overall fresh water situation on the island), and (4) document past incidents (e.g., cases of water shortages or food shortages, epidemics, and weather-related crises in the island's past). The information was noted on previously prepared standardized interview data sheets, which were referred to during conversations in order not to omit any important questions, and used to note down responses until they could be transcribed and organized. An Olympus digital voice recorder was also used to record everything as an audio backup and for future reference.

In addition, over the course of our stay on the island we nearly continuously interacted with local people and made informal observations regarding drinking of water, cooking, dish washing, laundry washing, bathing, waste disposal, and other day-to-day activities.

Photography and geotagging

As many as possible features, landscapes, and photographs of people and their daily life were made using high-resolution digital SLR cameras and saved as uncompressed JPG files. The cameras' clocks were synchronized with the GPS logger used in the field, thus allowing straightforward geotagging (georeferencing) of acquired images.

GPS data was saved in GPX file format and imported into Houdah Geo software for Mac OS X operating system. That software was used to process photographs taken by camera and combine them with the GPX file, so that coordinates where the camera-coupled GPS logger was located at the moment when each photo was taken became embedded within each particular image JPG file.

Viewable in GoogleEarth® and other geospatial applications, geotagged images are a unique ground truth evidence and and a useful reference tool.

Data processing and dissemination

Upon completion of data acquiry portion of the project, we processed all information and prepared final reports and products. Results of work are presented in this report (and comparable ones for other islands), which contain most data and metadata acquired and observations made on each island, including technical information, geographic coordinates, informers' names, interview dates, photodocumentation, etc. The reports are available to government agencies, resource managers, engineers, educators, and others interested in natural resources in FSM's low islands.

In addition, digital media version of the report (PDF file) is made available for free download from IREI and

WERI websites, along with photographic collection labeled and organized by topic and location, GIS shapefiles generated as part of the project, audio files of interviews, and other supporting files. This approach ensures quick and easy information dissemination and access to raw data useful to various interested parties.

Fig 7
Screenshot of WERI's homepage

Fig 8
Screenshot of this project's main webpage

Pakein Atoll

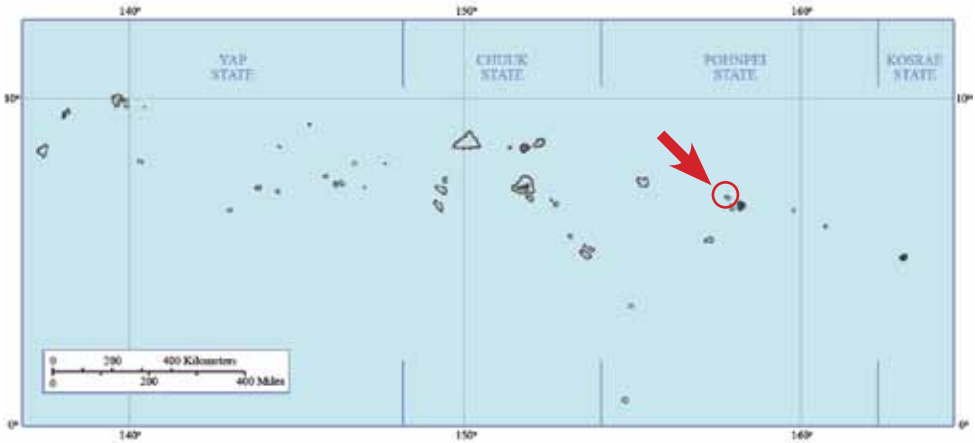
Geography and history

Among FSM's inhabitted atolls, Pakein is the closest to a high island.

Pakein is a small coral atoll located in the eastern part of the Caroline Islands. It is one of the "Outer Islands" of Pohnpei State, of the Federated States of Micronesia (see Map 1). Located just 18 miles northwest of Pohnpei, it is closer to its nearest high island than any other inhabitted Outer Island in the country. It is also the 2nd closest atoll to Pohnpei (after uninhabited Ahnd Atoll) and consists of about 16 islets (see Map 2).

Pakein is part of Pohnpei's Sokehs Municipality, and it is said that it can be seen from the top of Pohnpei's Sokehs Rock on a particularly clear day. This close proximity is reflected in both islands' culture and history. In ancient times, Pakein was considered an integral part of Pohnpei and one of the island's six northern areas according to land divisions in pre-Saudeleur times, and a part of Pwapwalik division of Pohnpei during Saudeleur times. According to a Pohnpeian legend, Pakein was the place of voluntary exile for the Luhk en Sed, on of the ocean gods, who got angry and left Pohnpei after his chief priest stopped worshipping him.

The first European to sight Pakein was Quiros in 1595, although Alvaro de Saavedra may have noticed



Map 1 Location of Pakein Atoll in the Federated States of Micronesia

Fig 9
An aerial view of Pakein Atoll, as seen from the southeast

it in 1529. Pakein was actually visited by Lütke in 1828, who named it one of the three Senyavin Islands (Pohnpei, Pakein, and Ahnd). When Irish castaway James F. O'Connell lived in Pohnpei in late 1820s, he described residents of Pakein as very close to Pohnpeians in terms of culture and language. Pakein provided a temporary refuge to insurgents of the failed Sokehs Rebellion (1910-1911) until the German colonial authorities found them and exiled them to Palau. Their lands in Sokehs and Pakein were confiscated by the colonial administration as a punishment, and given to the islanders brought from the Mortlock Islands some years earlier after their home islands were struck by a devastating typhoon in 1907.

Today's population of Pakein has descended from those relocated Mortlockese. They are culturally closer to Chuukese than Pohnpeians and continue to use their Mortlockese language in daily life (although many are bilingual in Pohnpeian). Only one islet, Nikahlap, is permanently inhabited (see Map 3). Some of the other islets are sporadically resided on by a few individuals at a time.

People of Pakein are ethnic Mortlockese.

The people of Pakein engage in taro farming, agroforestry, copra harvesting, and fishing on a subsistence level. Occasional sale of reef and pelagic

fish as well as copra to Pohnpei are the main sources of cash. Children attend elementary school on Nikahlap. After graduation, many move to Pohnpei to continue education. Except for the school and a Catholic church next to it, there are no concrete buildings on Pakein. Dwellings, cookhouses, and other related structures are all made of traditional materials (primarily wood and thatch) with concrete foundations and corrugated iron roofs in some instances. Residences are concentrated on the lagoon-facing side of the island. They are surrounded by coconut groves and agroforest. Further inland are *Pisonia* and *Terminalia* forests and brush, as well as taro patches. The ocean-facing side is vegetated mostly with coconut palms, *Pandanus*, and saltwater-resistant scrub.

Despite its proximity to Pohnpei, life on Pakein remains largely traditional.

Small boats that make more or less regular trips between Pohnpei and Pakein usually arrive at the beach in front of the school. The two-hour trip is made in open boats with outboard engines. It can be dangerous due to unpredictable weather and large open ocean distance that must be crossed. The island sees

relatively few visitors, some probably discouraged by the lack of a channel entrance into the lagoon. The locals usually enter and exit the lagoon at a specific point carefully at high tide, or actually pull the boat across the reef at other times. This is a necessity because Pakein's lagoon is completely enclosed by an uninterrupted reef and has no passes or channels connecting it with the ocean. The northwestern part of the reef rim is characterized by numerous dry patches at low tides.

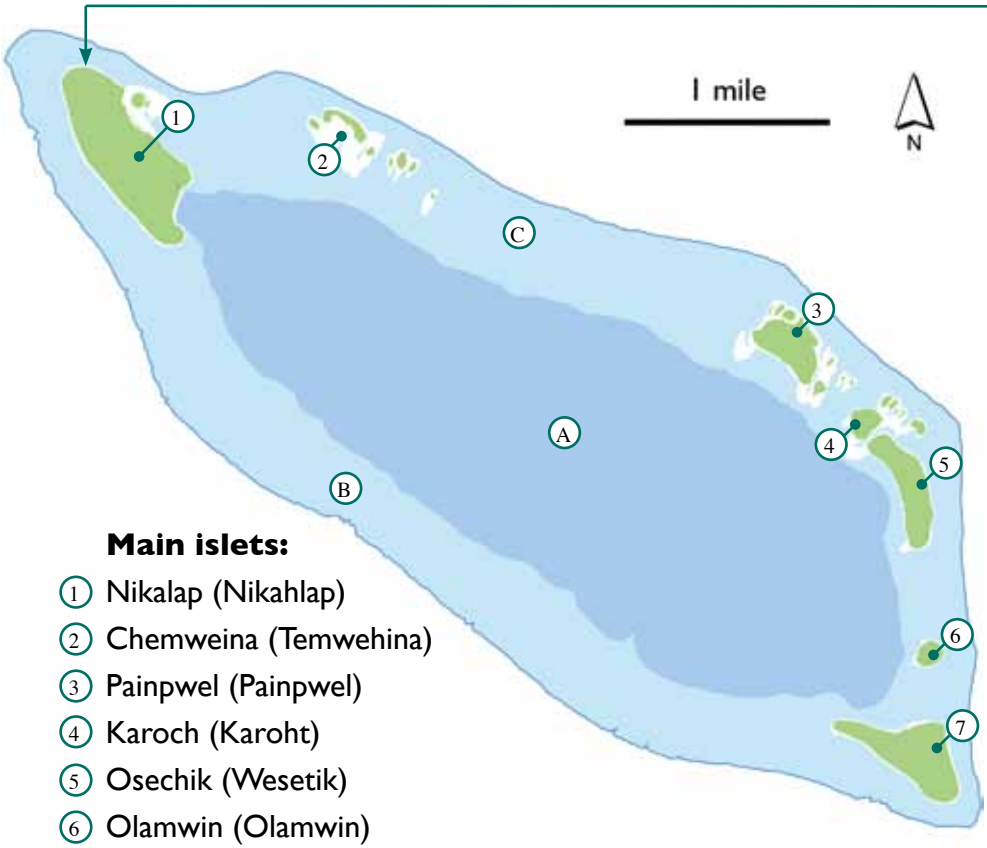
There are no reef channels permitting boats an entry to Pakein's lagoon

Possibly partly owing to the lack of any reef passes, the lagoon is graced with unparalleled water clarity, with visibility consistently over 100 feet. The atoll's outer edge of the reef is absolutely spectacular, with large fish and sharks patrolling the reef walls covered by corals, gorgonians, and hosts of other invertebrates. As in most FSM atolls, the outer reef wall is quite steep and quickly plummets to deep blue. Some Pohnpei-based dive companies advertise SCUBA trips to the atoll, but these rarely materialize due to weather and logistical problems.

Fig 10
A view of Pakein's lagoon and islets on the eastern stretch of the reef.

General maps

Map of Pakein Atoll



Main islets:

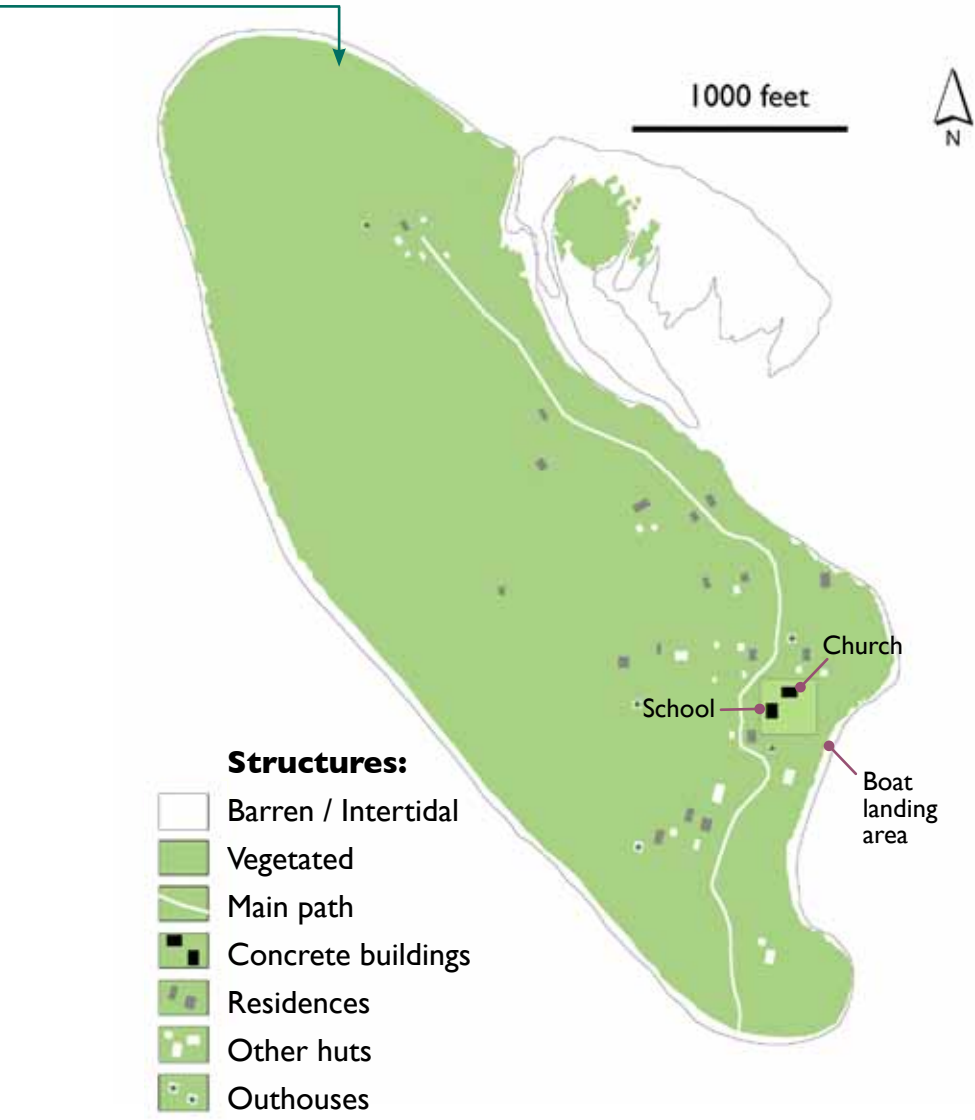
1. Nikalap (Nikahlap)
2. Chemweina (Temwehina)
3. Painpwel (Painpwel)
4. Karoch (Karoht)
5. Osechik (Wesetik)
6. Olamwin (Olamwin)
7. Mwanit (Mwanid)

Other features:

A. Lagoon
B. Entry point for small boats
C. Rocky area exposed at low tide

Map 2 Pakein Atoll. Map based on a US Army Corps of Engineers map corrected using ground control points in May 2007. Place names were recorded in interviews with residents and are spelled here in Mortlockese orthography (with Pohnpeian equivalents).

Map of Nikahlap islet



Map 3 Nikahlap, Pakein's main islet. Map based on field mapping completed in May 2008 by M. Martin and D. Taborosi.

Basic facts

Table 2 **Geography**

Standard name:	Pakein
Other spellings:	Pakin, Pakaein, Pakeen
Historical names:	Paguenema
Location:	NW of Pohnpei
Coordinates:	7° 04' 30" N, 157° 46' 30" E
Island type:	atoll
State:	Pohnpei State
Political status:	part of Pohnpei's Sokehs Municipality
Ownership:	Mortlockese clans residing on Pakein and Pohnpei
Closest high island:	Pohnpei
Distance to Pohnpei:	18 miles [reef to reef], 30 miles [Nikahlap to Kolonia]
Closest low island:	Ahnd Atoll
Number of islets:	~16
Total land area:	1.2 km^2
Reef area:	11.8 km^2
Reef outer perimeter:	23.0 km
Reef inner perimeter:	15.8 km
Reef passes:	none
Lagoon area:	11.2 km^2
Lagoon max. depth:	55 m
Distinctive features:	no reef passage into the lagoon
Rainfall:	450 cm/yr

Table 3 **Population**

Population:	~90 people in ~12 households
Inhabited islets:	one permanently, three sporadically
Permanently inhabited:	Nikahlap (~90)
Sporadically inhabited:	Mwand (~2), Wesetik (~10), Peinpwil (~4) [05/2007]
Ethnic group:	Mortlockese
Language:	Mortlockese
Dialect:	Pohnpei Mortlockese
Population origin:	Migrated in the early 20th century from the Mortlock Islands to Sokehs and then to Pakein

Table 4 **Infrastructure**

Atoll accessibility:	by sea only, 2-4 hours from Kolonia, Pohnpei
Lagoon accessibility:	to small boats only, difficult at low tide
Lagoon entry points:	N 07.04940° E 157.79208° (small boat passage)
Concrete buildings:	two
School:	N 07.07703° E 157.77637°
Church:	N 07.07716° E 157.77653°
Other buildings:	residences, outdoor kitchens, sheds; built of local materials, with thatched roofs, some with corrugated metal roofs
School:	elementary
Clinic:	none
Commercial activities:	small scale fishing, copra production, and pig husbandry
Ongoing research:	none known
Government projects:	black pearl production in lagoon (Land Grant)
Coastal engineering:	none (no seawalls, piers, dredging, etc.)
Electric power:	sporadic (solar power and generator)
Internet access:	none
Cell phone reception:	may be available in the vicinity of the atoll
Weather station:	none

Table 5 **GPS control points**

SE tip of Nikahlap:	N 07.07335° E 157.77676°
S tip of Wesetik:	N 07.05144° E 157.82849°
W tip of Mwand:	N 07.03883° E 157.82260°

Table 6 **Points of contact**

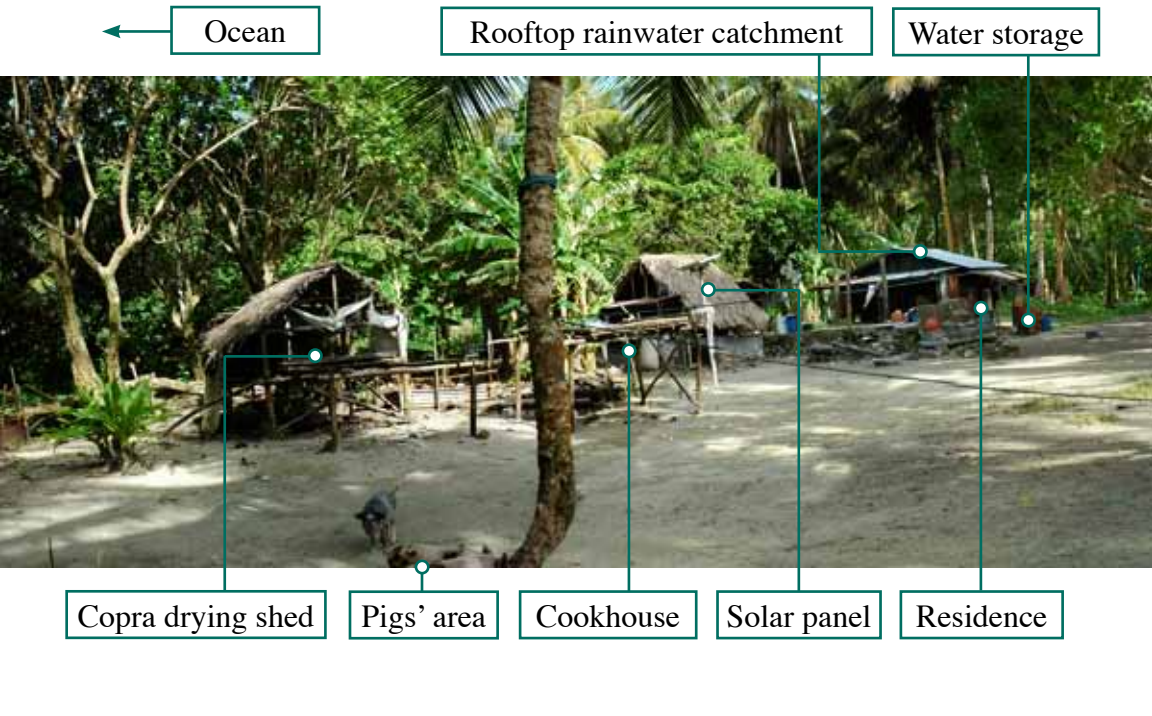
Traditional leader:	Pius Siten [*Sounirek Pakein*, resident on Sokehs Island, Pohnpei]
Traditional leader:	Samuel Wenio [*Kaniki*, resident of Pakein]
Mayor:	Michael Liemen [mayor of Sokehs Municipality, Pohnpei]
School teachers:	Jonathan Carred, Liberto Linge, Selino Taiwelyar
Catholic Church:	Roman Linge
Apostolic Church:	Elder Steve Mark
Recent PCV:	Emerson Odango [Peace Corps volunteer on Pakein 2007-2009]

Lifestyle

Pakein has a largely subsistence economy and almost no public infrastructure. Its residents are actively engaged in gardening, agroforestry, and fishing in order to produce food for themselves and their families.

Almost everyone on Pakein lives on the main island of Nikahlap, in residences concentrated on lagoon-facing side. Houses are not directly on the beach but scattered along the main path extending parallel to the shore a few dozen meters inland. A couple of households are further inland, connected by smaller paths. Constructions reflect traditional architecture and are made of local materials (wood and thatch); a few have elements of corrugated iron (for roofs) and concrete (for floors). In addition to homes where people sleep, each household typically has several additional structures. Usually there is a separate outdoor kitchen or cookhouse. There is a distinct and enclosed bathing/showering site. There may be additional objects, such as a shed for storing firewood or copra, etc.

Fig 11
A Pakein household and its elements



The center of the village is Pakein's elementary school, in front of which is the main landing area for arriving boats. The village is clean, and shaded by agroforest of coconut palms, breadfruit, and other useful trees. There is a small taro patch in the island's interior. Chickens and pigs forage freely in the vicinity of homes.

With no municipal facilities available on island, the people of Pakein solve water and energy needs on their own. Water for drinking, cooking, and dishwashing is usually obtained from the rain, which is captured by rooftop catchment systems and stored in concrete, or fiberglass water tanks. Water for washing laundry generally comes from the same source. Water for showering and bathing is usually taken from shallow hand-dug wells, one of which is typically available to each household. Surprisingly, some households have neither rainwater storage tanks nor wells of their own, but receive access to water from family and relations nearby. The community of Pakein is small and closely knit and families and neighbors customarily support each other.

Pakein lacks any municipal water and energy facilities.

Inventory of households

Infrastructure by household

This section presents data from the comprehensive inventory of households and associated water-related infrastructure on Pakein. The survey was carried out over the course of three visits in 2007 and 2008 and finalized in May 2008. Households are listed here in the order of their arbitrarily assigned ID numbers. Infrastructure is listed for each individual household in the following order: used water tanks, unused water tanks, groundwater wells, solar pannels, and miscellanea. For privacy reasons, names of individual households have been deleted from text hereon. IREI maintains an unaltered version of this document in confidentiality.

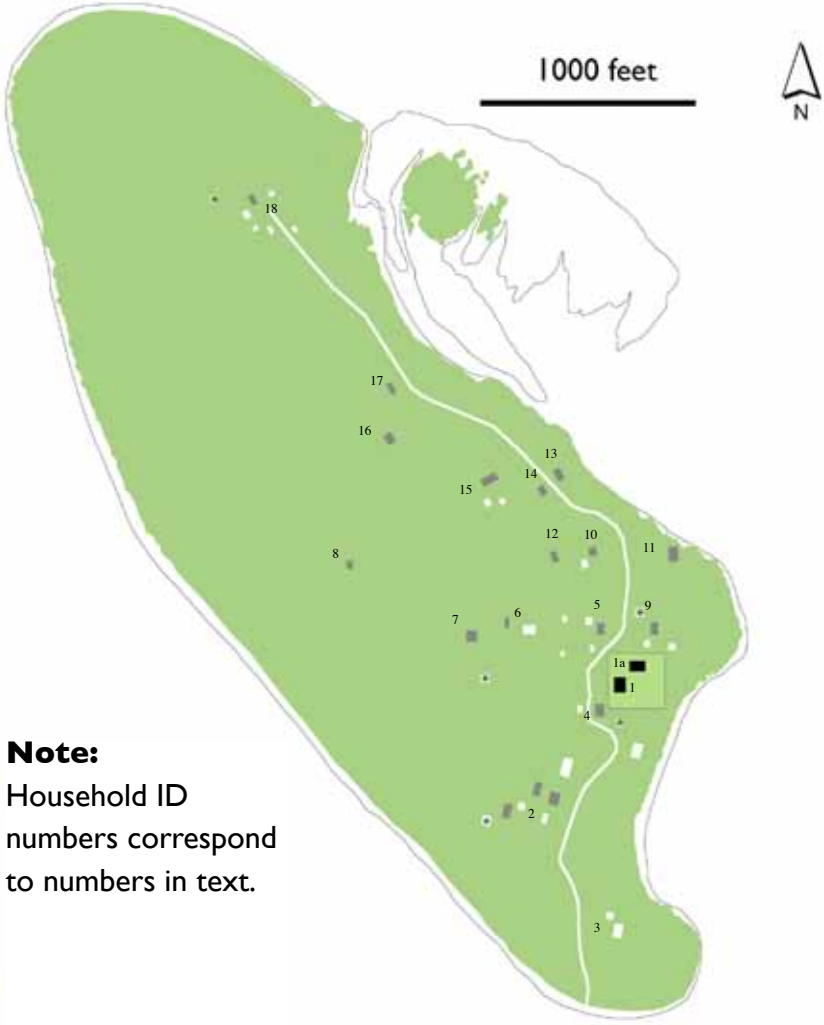
1. Pakein Elementary School

Community on Pakein is centered around the elementary school, located in the southeast part of the island. That area faces the lagoon and is where arriving boats usually come ashore. The following infrastructure belongs to the school and sees communal use.

School is community's center and has the only public water source.

- black PVC 1,200 gallon tank, with ~16 m^2 catchment on school roof (potential is ~12x more)
- blue fiberglass 700 gallon tank, school roof catchment (potential is shared with previous tank)
- public toilet, separate male and female, not in use, and is used instead as a shed and storage area
- concrete 3,500 gallon tank, with top, no catchment, unused, always empty
- drilled well, concrete lining, with pump
- a set of solar pannels, mounted on aluminum poles; dedicated for use with the well pump, but currently unused because the pump is broken

Locations of households on Nikahlap



Note:
Household ID numbers correspond to numbers in text.

Map 4 Locations of households on Nikahlap, Pakein's main islet. Map is based on a survey completed in May 2008. ID numbers are assigned arbitrarily to each household or a separate living area.

Fig 12
Elementary school (left) and church (back). Well site and solar pannels in the foreground.

- white fiberglass 150 gallon tank, elevated, connected to the well, should be fed by pump and used to flush public toilet; but is currently unused, as the toilet itself

1a. Catholic Church

The church building is located right next to the school. It has no own water sources.

2. //Name removed for reasons of privacy//

- smaller plastic barrels and buckets used to store water from a small part of ~40 m^2 tin roof
- unused concrete 1,500 gallon tank, no top, no catchment, unused
- excellent concrete-lined well, very clear water, level reported high even at low tide
- three solar pannels, apparently one in use and connected to a functioning battery

3. //Name removed for reasons of privacy//

This house is not used but has a functioning fiberglass tank, so it is the first place residents turn to when they run out of water at their own household.

- blue fiberglass 700 gallon tank, rusty and leaky
- catchment of 4m^2 (potential is ~6x more)
- unused concrete 1,500 gallon tank, no top, no catchment
- one solar pannel, dedicated for use with well pump, but not used due to the pump being broken
- solar pannel, unused

Homes on Pakein are made of wood, thatch, and corrugated iron.

4. //Name removed for reasons of privacy//

- no catchment and water storage tanks (residents use school tank nextdoor)
- one solar pannel, functioning, battery connected
- well, lined with flat brick-like stones, nice and clean, made during the Japanese period

5. //Name removed for reasons of privacy//

- concrete 1,500 gallon tank, rooftop catchment of ~20 m^2 (entire one side of the roof; potential 2x)
- concrete 1000 gallon tank, broken, no top, no catchment, unused
- well, with coral rubble wall, clean, shaded by tarp canopy, daily use

6. //Name removed for reasons of privacy//

- plastic barrels and buckets with rooftop catchment of about 15 m^2 (potential is 2x)

7. //Name removed for reasons of privacy//

There is a small taro patch just north of this house.

- one welded metal box with 250 gallon storage, with leaky catchment of ~12 m^2 (potential is 2x)
- well, with a burried 55 gallon drum and rubber lining at land surface, daily use

8. //Name removed for reasons of privacy//

- blue fiberglass 700 gallon tank, catchments by 17.5 m^2 roof of a pig shelter (potential is 2x)
- well, wall made of coral rubble, clean, used

9. //Name removed for reasons of privacy//

- one small metal container for roof catchment (only small part of potential 30 m^2 is used)
- well, wall of coral-rubble, filled with sand and vegetation, unused
- one solar pannel, unused because of no battery

10. //Name removed for reasons of privacy//

House is under construction.

- no catchment and water storage tanks
- well, good rock-walled, clean, used
- one solar pannel, unused because it lacks battery

11. //Name removed for reasons of privacy//

Just one thatch roof. Nobody lives here at present.

- no catchment and water storage tanks

12. //Name removed for reasons of privacy//

- no catchment and water storage at present

13. //Name removed for reasons of privacy//

- no catchment and water storage tanks
- well, flat-rock walled, filled with sand, dry except high tide, unused

14. //Name removed for reasons of privacy//

- 1,500 gallon concrete tank, no top, used with 10 m^2 catchment (potential is ~3x greater)

15. //Name removed for reasons of privacy//

- no catchment and water storage tanks
- well, different from the rest on island, wider than 2 m in diameter, coral rubble walls slanted not vertical, partly filled with sand
- second well, roofed, 1.3 m deep

16. //Name removed for reasons of privacy//

Several households have no own water catchment systems.

Fig 13 (opp.) **A house with various containers for rainwater catchment.**

- no catchment and water storage tanks
- well, wall of coral rubble, clean, used

17. //Name removed for reasons of privacy//

Just one thatch roof. Nobody lives here at present.

18. //Name removed for reasons of privacy//

- black PVC 55 gallon drum, with 20 m^2 catchment (potential ~2x)
- white PVC 55 gallon drum with roof catchment of 3 m^2
- 1,500 gallon concrete tank, no catchment, unused
- remains of a destroyed concrete tank
- well, coral rock wall, used, clean, sand bottom
- one solar pannel, unused due to lack of battery

Fig 14
Household at the north end of the island.

Fig 15
A well-aired traditional cookhouse.

Rainwater catchments

Summary of conditions

Catchment

Rain is typically captured by rooftops made of corrugated iron, or less commonly, thatch. The size of catchment areas vary widely. Their upper limit is defined by the total roof area of a house and availability of suitable material. The catchments can be as small as a few square meters. During the survey, we have observed that only limited portions of available areas (roofs, etc.) are guttered, which diminishes their effectiveness to capture water.

Transfer

From the roof (or another catchment), water flows down slope across the surface and reaches metal, or rarely plastic, gutters at the roofs' lower edges. It continues to flow down gradient within the gutters. The gutters transfer the water into storage tanks. The condition of gutters varies, but most are quite leaky and rusty and prone to water loss. For that reason, tanks are usually placed as close as possible to the catchment to minimize water loss due to gutter leakage.

Storage

Water storage tanks on Pakein are made of fiberglass or ferro-concrete, with one community tank made of PVC, and one private tank made of stainless steel. The volumes of privately owned tanks vary between the largest with 1500 gallon capacity and 55 gallon drums, which are the smallest meaningful containers. Most households have no more than one small tank. Surprisingly, some homes have no catchments and rely on water sources maintained by their family relations in other households.

Fig 16 (opp.) **Examples of water catchment systems on Pakein.**

a

b

c

d

e

f

g

h

Summary of sites

Public rainwater catchment sites

The only public water source on the island is at the elementary school, which has its own well and rainwater catchment system. Here is one of the best water tanks on the island, holding about 1200 gallons when full. It normally satisfies the needs of children during school time, but also provides water for any residents in need. Schoolmaster restricts use for non-school purposes when water level in the tank is low.

Other major rainwater catchment sites

Individual households maintain their own water tanks. On the main island, Nikahlap, there are four significant private rainwater storage sites with large-volume tanks; and there are a dozen or so smaller sites. Among them are several fiberglass tanks, which were provided by the FSM government in 1997 or 1998, after an El Niño-related drought. Families with large tanks usually provide a part of their stored water to relatives and heighbors from other households.

Minor rainwater catchment sites

In addition to permanent rainwater catchment sites, residents of Pakein rely on numerous small containers to make impromptu catchments as they are needed. These utilize 55-gallon drums, pots and smaller containers for storage. Fresh water for domestic animals is usually captured in this way, with roofs of animals' own enclosures providing catchment areas.

Abandoned sites

Quite a few storage tanks appear to have been abandoned. In addition to remains of destroyed

i

j

k

l

Fig 16 (cont.) **Examples of water catchment systems on Pakein.**

concerete tanks, with missing top parts or gaping holes, we have also obsereved apparently undamaged tanks that have fallen into disuse for no apparent reason. One household, for example, has a large (~1000 gal) concrete tank located in its immediate vicinity but remaining unconnected to any catchment area. Another large concrete tank stands at an abandoned household at the south end of the island, but it does see use by residents from elsewhere at times of low or no rainfall.

Other places

Comprehensive survey was carried out only on Nikahlap, which is the only permanently inhabited islet on the atoll. However, Wesetik, Mwand, Peinpwil, and Olamwin islets each have at least one living area with sporadically occupied thatch huts. Each of the four locations has one minor water catchment site.

Household	Ownership	Use	Volume (gal)	Material
Nikahlap				
1 (school)	communal	not used	<3500>	concrete
1 (school)	communal	interrupted	150	fiberglass
1 (school)	communal	daily	1200	PVC
1 (school)	communal	daily	700	fiberglass
2	private	not used	<1500>	concrete
3	private	sporadic	700	fiberglass
3	private	not used	<1500>	concrete
5	private	not used	<1000>	concrete
5	private	daily	1500	concrete
7	private	daily	250	stainless steel
8	private	daily	700	fiberglass
14	private	daily	1500	concrete
18	private	not used	<1500>	concrete
Mwand	private	sporadic	500	fiberglass
Peinpwil	private	sporadic	minor	
Olamwin	private	sporadic	minor	
Wesetik	private	sporadic	few hundred	

Table 7 Summary and specifications of rainwater catchment and storage systems on Pakein. The table includes only features with storage capacities larger than 55 gallon drums. Smaller features are mentioned in the household inventory. Any features significant enough to be noted but out of commission for various reasons stored no water at the time of survey. They have their total volumes shown in <brackets>.

Catchment	Catchment area	Potential area	Gutter
no	none		n/a
yes	well with pump	n/a	n/a
yes	school roof - 16 m^2	~ 12 x	excellent
yes	school roof	~ 12 x	excellent
no	none	~40 m^2	n/a
yes	roof, 4 m^2	~ 6 x	very leaky
no	none		n/a
no	none		n/a
yes	roof - 20 m^2	~ 2 x	leaky
yes	roof, 12 m^2	~ 2 x	leaky
yes	piggery - 17 m^2	~ 2 x	good
yes	roof -10 m^2	~ 3 x	bit leaky
no	none		n/a
yes			
yes			
yes			
yes	metal sheet		

Wells and groundwater

Summary of conditions

Residents of Pakein rely on groundwater as their source of non-potable fresh water.

Summary of conditions

a) Appearance

There are about a dozen wells on Nikahlap. Another well is found on Wesetik islet. Other islets apparently have no wells. The wells are shallow and hand-dug, and quite variable in appearance. They may or may not be covered. If covered, it is by wood, metal sheets, or thatch, apparently to keep water cool on sunny days. Also, they may or may not be surrounded by a protective barrier in order to prevent small children and animals from falling in. The barrier is usually made of rocks, wood, metal sheet, metal mesh, tarp, etc.

b) Lining

Wells themselves are differently constructed and maintained. The simplest ones are lined by piles of small coral heads. Such walls permit soil and sand to enter a well from its sides, and do not make the structure lasting. Abandoned and destroyed wells we observed had this type of lining. A better and more common way uses fitted rocks (also coral in origin). Such wells are constructed with more care, as the rocks are cut and fitted to create a tight and stable wall. Concrete may be added to strengthen the structure, especially in the topmost parts. Finally, two wells (one communal and one private) have fully concrete linings.

Fig 17 (opp.) **Examples of groundwater wells on Pakein.**

c) Extraction

Water is taken from wells by buckets tied to a rope and pulled by hand. Only the communal well on the

a

b

c

d

e

f

g

h

premises of elementary school is equipped with a solar-powered electric pump. The pump is intended to fill a dedicated concrete storage tank used for flushing the school toilet, but is currently malfunctioning.

d) Cleanliness and water quality

Water in all wells is reported to be of approximately the same quality. There are no wells that stand out as exceptionally good or bad. Residents have expressed no concerns regarding the island's groundwater. There are no problems with saltwater intrusion, no wells have ever been abandoned for being saline. In addition, bad smell, bad taste, obvious microbial contamination, and other complaints have not been reported.

Summary of sites

a) Public well

One well belongs to community. Located at the elementary school, it is maintained but unused.

b) Private wells

We were able to locate 11 private wells on Nikahlap, of which all but two experience daily use.

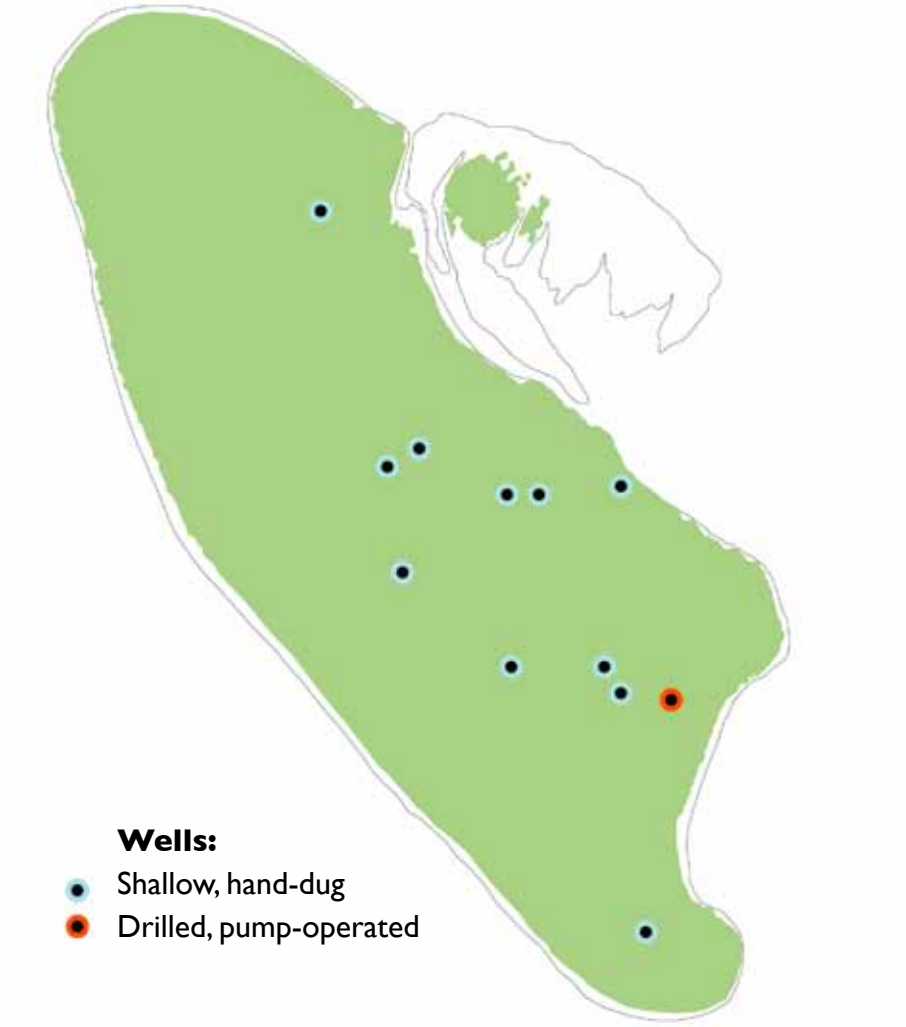
c) Abandoned wells

One collapsed and abandoned well was seen. There could be others at overgrown sites in the island interior.

d) Wells on sporadically inhabited islets

There is one well on Wesetik. We were told that Mwand, Peinpwil, and Olamwin also have one well each, for use be the occassional residents there.

Locations of wells on Nikahlap



Map 5 Locations of wells on Nikahlap, Pakein's main islet. Map is based on a survey completed in May 2008.

Household	Ownership	Use	Type	Depth to water
Nikahlap				
1 (school)	communal	interrupted	SDR	<2 m
2	private	daily	SHD	<2 m
4	private	daily	SHD	<2 m
5	private	daily	SHD	<2 m
8	private	daily	SHD	<2 m
9	private	not used	SHD	<2 m
10	private	daily	SHD	<2 m
13	private	not used	SHD	dry except high tide
15	private	occasional	SHD	<2 m
15	private	daily	SHD	<2 m
16	private	daily	SHD	<2 m
18	private	daily	SHD	<2 m
Wesetik				
21	private	sporadic	SHD	<2 m

Table 8 Summary and specifications of wells on Pakein. Type key: SHD-shallow hand-dug well, SDR-shallow drilled well. Condition key: E-excellent, outstanding well lining, exceptionally maintained, very clean water, no debris; VG-very good, quality well lining, well maintained, clean water, no or little debris; G-good, reasonable well lining, maintained, usable water, some debris; B-bad, unsuitable or decaying well lining, not maintained, water not usable, filled with debris and/or sand.

a

b

Wall lining	Cover	Extraction	Condition
		solar power pump	
concrete	wooden board	hand-pulled bucket	VG
concrete	none	hand-pulled bucket	E
good rock wall	none	hand-pulled bucket	G
coral pile	thatch frame	hand-pulled bucket	G
rock wall, concrete	none	hand-pulled bucket	G
collapsing coral pile	none	none	B
good rock wall	none	hand-pulled bucket	G
good rock wall	none	none	B
sloping coral pile	none	hand-pulled bucket	G
rock wall, concrete	thatch frame	hand-pulled bucket	G
coral pile	none	hand-pulled bucket	G
coral pile	none	hand-pulled bucket	G
coral pile	plant growth	hand-pulled bucket	G

Natural discharge

Natural freshwater discharge along the coast is unfamiliar to the residents. We have not observed any seeps or springs along the coast even at very low tide. This is consistent with the general pattern observed on Micronesian atoll islets, where visible discharge of fresh water from the coast is extremely rare.

Surface water

Surface water is regularly seen only within taro patches. They are excavated and maintained as to have water accumulations required for cultivation of wetland taro (*Cyrtosperma* and *Colocasia*). Other than the taro patches, there are no real surface water bodies. Ephemeral puddles form during heavy rainfall. A few small intermittent ponds were seen in depressions in May 2007, but were absent during other visits.

Fig 18 (opp.) **Examples of surface water ephemera on Pakein.**

Water and way of life

Water usage patterns

Drinking and cooking

Captured rain is almost exclusive source of water for drinking, cooking, and dishwashing. Groundwater is almost never used for such purposes. It may be boiled and consumed only during emergencies when stored rainwater runs out during droughts.

Cooking typically takes place in an outdoor kitchen or kitchen house located next to, or as part of, the residence. It is carried out on open fire. The same area or an adjacent place is also used for washing dishes.

Residents report that two or more decades ago, groundwater was boiled and used for cooking and drinking. This is no longer practicable.

Other sources of hydration

Water content of fruits used in the local diet are significant sources of hydration. Coconuts are by far the most important. They grow year-round, bear abundant fruit, and contain around 300 ml (10 fl. oz.) of liquid that is an excellent source of water and electrolytes. Ample supply of coconuts can sustain proper hydration even if no other sources are available.

Coconuts are plentiful on Pakein and seem to be used for drinking at any time. Residents report consuming between one and two coconuts per individual on an average day. In general, however, people state that they primarily drink water when thirsty. (Water-based powdered drinks such as instant coffee and Tang® are the most popular, but rarely available).

Coconuts are used a lot in celebrations and meetings, and are readily brought to visitors.

Fig 19 *(opp.)*
A pretty house with its bathing area.

Nevertheless, although coconuts can be an important component of usual hydration and even coooking needs of islanders, it cannot be considered an alternative to safe drinking water and definitely not a reliable emergency source. This is because water shortages are typically caused by droughts and storms, which also affect coconuts. Prolonged droughts are known to gradually reduce quantity or quality of nuts. Major storms can virtually eliminate standing crop of coconuts in an instant.

In addition to coconuts, which are by far the most important, papayas, citrus, and other fruits also provide water and nutrients when regularly consumed.

Showering and laundry

Water for showering, bathing and washing laundry is taken from shallow open-surface wells. It is used directly and is not treated in any physical or chemical way. Occasionally, well water may be used for dishwashing as well.

Showering and bathing is usually done in a somewhat more detached section designated for that purpose. In general, the bath area is partly or well sheltered for privacy and is constructed of wood, tarp and/or metal sheeting. On Pakein there are no elevated tanks that are used as showers, so all bathing is done using buckets of water. The same area is typically used for washing of laundry, which is then dried on lines strung adjacent to homes or between trees.

Water for animals

Animals are watered using either rain or groundwater. Domestic and feral pigs also utilize ephemeral ponds after heavy rains as wallows.

Fig 20 (opp.) **Illustrations of lifestyle and water use by Pakein residents.**

a

b

c

d

e

f

g

h

Water shortages and issues

Residents report that they sense a risk of fresh water shortage when the level of water in their tanks drops to one-half full. At that time, residents respond to the situation by modifying certain daily water consumption practices. They reserve the stored rain water only for high priority needs and shift part of their demands to water stored in tanks of neighbors' and relatives' households or the public tank at the school. Rainwater becomes reserved only for drinking and cooking, and lower priority requirements are relegated to groundwater sources. Showering might be replaced by bathing in the seawater and rinsing with freshwater.

Modified behavior allows water crisis to be delayed somewhat, but not averted if absence of rainfall continues. If crisis level is reached, sharing of water between the compounds is increased and usage minimized for vital purposes only.

Despite change of behavior, sharing between households, and transfer of demand to community system at the school, many households do periodically run out of water completely.

Perceptions

Residents have not expressed serious concerns about water quality and availability on the island. They seem to accept unreliable supply as inevitable. The fact that some available storage tanks are not used seems to indicate that ample water is available most of the time.

Shortages

The current rainwater catchment system is insufficient to collect and store enough water to meet the needs of the local people during major droughts. Even during

regular times, families with lots of children or small water storage tanks partly rely on water from the school tank. The principal allows this practice, except when rainfall is reduced and water level in the tank is low.

At such times, people can walk to the southeast end of the island where there is a working tank at an unused homestead site. That tank is used only during real shortages and typically has the last remaining private water supply during droughts.

Health problems

No epidemics or significant health problems have been reported. At the time of research, the island did not appear to have a mosquito problem.

Bringing fresh water by ship

During the 1997/98 El Niño event, there was a major drought. As a result, the residents of Pakein compltely ran out of fresh water supplies. They report that when they became aware of the emergency, they acted to eliminate all but essential water use. Nevertheless, water stored in tanks was exhausted before there was any rain to replenish the supplies. The local pople had to boil groundwater obtained from wells and use it for drinking.

The FSM Government sent a relief ship from Pohnpei. Since Pakein's lagoon has no entry points for ship, the vessel stayed outside the reef and could not anchor. A long PVC pipe was extended from the ship and laid out across the reef and over land through the forest all the way to storage tanks in the village. Potable water was then pumped into the tanks. The long white PVC pipe is still visible meandering through the undergrowth in the island's interior.

Agriculture, animal husbandry, and fishing

Residents of Pakein engage in agriculture and keep animals for subsistence. Agriculture is not intensive and is based on sustained modification and maintenance of parts of the natural ecosystem. The key source of plant foods are 1) agroforest, which is a maintained garden of trees and useful plants in the vicinity of households; and 2) taro patches, which are natural or man-made depressions where wetland conditions allow cultivation of taro*. The rest of the island is covered by scrub vegetation. Main sources of animal foods are fish and other edible marine organisms and domestic animals.

Agroforestry

Areas in the vicinity of households is covered with agroforest. It consists of breadfruits and other large trees. Coconut groves are found on both lagoon side and ocean facing side of the islet.

Taro patches

Innermost parts of the island contain taro patches. They are water-filled depressions excavated and maintained by people in order to cultivate wetland taro, which requires ample water supply. The taro patches on Pakein are not nearly as extensive as on many other atolls in Micronesia.

---

* Taro is one of the few crops in the world (others being rice and lotus) that is grown in flooded conditions. Large air spaces in the petiole permit the submerged parts to maintain gaseous exchange with the atmosphere. However, surrounding water must have enough dissolved oxygen. If the water is too stagnant and warm, the high temperature and low oxygen content can cause the basal rotting and wilting of the taro.

Agricultural problems

Since ~2004, some coconuts, breadfruits, bananas and other trees have been dying. Their leaves turn brown and eventually fall off. This is caused by a small, white insect, known as *meninkau* in Pohnpeian. On Pakein, this problem was first seen on the breadfruit tree located by the church. This tree is one of the trees closest to the boat landing area.

No problems regarding taro patches have been reported.

Domestic animals

The only domestic animals on Pakein are chickens and pigs. They may be kept in the vicinity of a household, in a particular more secluded area, or allowed to freely forage around the island. Some of those pigs are feral and live in the uncultivated part of the island. Pigs do not create huge demands on the water supply. Roofs of pigsties can be set-up to catch their own rainwater supply, which is stored and used exclusively for watering the pigs. Alternatively, pigs can drink groundwater taken from the wells or the taro patch.

Fishing

Fish are caught on the reefs, in the lagoon, and in the open ocean using a variety of methods. Spearfishing is a popular way to catch something for a family meal. Trolling is done from small boats during trips to and fro the main island of Pohnpei. Thanks to the low population and relatively large size of the atoll, there appear to be no problems related to overfishing, but this may change as reef fish is now also caught commercially for sale at Pohnpei fish market. Sea turtles are hunted but do not nest on the atoll.

Energy and waste

The local community and individual residents of Pakein resolve their own energy and waste disposal needs. The municipal and state governments provide emergency assistance, but no regular service of any type.

Energy

Each residence on Nikahlap is equipped with a single solar panel for electric power. The school building has two single and one double pannel mounted on 3-m tall aluminum poles. Solar facilities were donated and installed by the government in late 1990s. However, many systems have fallen into disuse, leaving families without power again. The reason for this is that the batteries are quick to decay or lose capacity. There is at least one privately-owned gasoline/diesel powered generator on island.

a

b

c

d

Household waste

There is no single locale used for waste disposal. No area on Nikahlap is visibly polluted. Household trash is disposed of in pits that are covered with soil when filled up. Trash may or may not be burned prior to covering the pit. The island appears very clean, and areas around certain households are immaculate.

Human and animal waste

Toilets are outhouses. Each household has one, typically constructed of wood and metal sheets. Underlying pits are hand-dug and lined with rocks. At times, human waste is disposed elsewhere, on land or in the intertidal zone. There is one public toilet near the school. It is equipped with a flushing tank but is currently not in operation. The tank is supposed to be filled with water pumped from the school well. Residents place outhouses reasonably far from their wells but not in a particular direction.

Burial practices

There is no cemetery on Pakein. In the past, one inland site on Nikahlap was used for that purpose but has been abandoned. A few graves are still visible underneath dense brush. Nowadays deceased are buried near family homes. Single graves are observed right next to houses.

Other

The beach in front of the school is covered by thick accumulations of seaweed. It does not appear to cause any issues. Other than that, no major floating debris accumulations were observed in the lagoon or on the beaches. No noteworthy objects came floating in recent times. No shipwrecks have occurred in recent times.

Fig 21 (opp.) **Select illustrations of energy and waste features.**

Coastline and climate

During the field surveys on Pakein, we have made informal observations of the coastal areas. Special attention was paid to any distinctive or unusual features, and anything that may indicate problems related to climate change and/or sea level rise.

Meteorologic data

No meteorologic data is being collected on island.

Flooding

The island has not been flooded in recent memory. Typhoon-generated waves in 2001 or 2002 have reached the school building (~40 m from lagoon side) but saltwater has not entered taro patches or caused any damage.

Erosion and vegetation loss

No vegetation loss is observed in any particular area. No erosional features are apparent along the coast of Nikahlap.

Distinctive coastal features

There is one unusual natural feature on the ocean-facing reef of Nikahlap. It looks like a fracture cutting the entire width of the reef, extending from the beach to the reef margin at approximately 90° to the coast. Reef on one side of this feature is at least a few inches taller than the other side, which creates an interesting water cascade effect when the tide is going out. It is not clear whether this feature was created by primary deposition of carbonate or is a secondary feature related to some structural displacement. It exhibits luxuriant coral/algal growth (mostly smooth massive corals and calcareous

algae) along all of its length. The local people call it *ial*, which in Mortlockese means "path", and often use it to walk to the reef margin. It is located at N 07.07592° E 157.77245°.

There are some rock piles in shallow water on the lagoon-facing side of Nikahlap, on the beach in front of the school. These are remnants of a wall built in Japanese times to delineate evaporation pans used to produce salt.

a

b

c

d

Fig 22
Select coastal features of Nikahlap.

Addenda

Recommendations and conclusions

The availability of fresh water to Pakein's residents is a currently a function of the amount of rainfall, total catchment area, and total storage capacity. Shortages, therefore, should not be thought of as failures of rain to fall, but as failures to catch and store enough of the rain that did fall. In its current state, the system of rainwater catchments is not sufficient to provide enough water to all Pakein residents neither for routine use nor emergency supply.

Improvement of catchment systems

Rainwater catchment system on Pakein should be improved to a capacity consistent with past contingencies and likely events in the future. Catchment areas to capture rain should be increased, efficiency of gutters and pipes improved, and storage capacity adjusted so that reserves can last through extended periods of no rain. Since storage tanks are never connected to each other, setup of each individual household must satisfy such requirements separately in order to be considered appropriate. This would level out the current inequities between households and prevent certain families from reaching water crisis levels well before others. To minimize tank instability due to spillovers, catchments should not be disproportionately high for the size of coupled tanks either.

Improved effectiveness of catchment

Our survey has shown that only a small portion of available roof areas are used to catch rain, and the gutters are decayed and leaky. However, regardless of those limitations and loss in collection methods, the

patterns of seasonality and amounts of single-episode rainfall are such that available storage tanks get filled anyway during normal weather. That means, that the main limitation to the system is deficiency in storage capacity due to absence of enough actively used tanks.

Technical support and maintenance

Residents of Pakein are resourceful and hardworking, but could certainly benefit from technical assistance from persons experienced in development and maintenance of water catchment and storage systems. Recommendations should be made regarding the management of all components of rainwater catchment systems. Periodic evaluations should be made to ensure that the island is capable of managing future emergencies. If any outside entity donates new tanks or other parts of the water system, efforts should be made to remove old outdated equipment to prevent accumulations of waste and dirty water.

Worst-case scenario

If a major storm were to occur and severely damage Pakein's rainwater catchment network, the only portions likely to remain intact are concrete tanks. They could provide a small water reserve to last until the other components of the system are repaired. However, if a prolonged drought were to follow the event, water reserves could not be replenished and the island would run out of water. An unusually long drought, even without a preceding storm, would eventually cause the island's water supply to be exhausted. It would therefore be prudent to prepare for such contingencies by protecting and preparing the groundwater as a viable emergency water supply.

Well maintenance and inspection

It is clear that given the small size of the island, the freshwater lens contained within is very small and unsuitable for large-scale extraction of water. The hydrologic properties and productivity of the small aquifer are not known, and it would be dangerous to recommend it as a persistent water source. However, during emergencies, when water shortages are severe but short-lasting, the groundwater can act as a reliable backup source. Its ability to provide water during times of need are limited less by its size and properties, and more by the general behavior of island residents and ways they affect the groundwater.

Local authorities should develop and implement a recurring well inspection system, where each well on the island would be periodically checked and assessed. That would encourage residents to regularly clean and maintain their wells and prevent their abandonment -- making them readily available during emergencies.

Waste management

The following are specific recommendations designed to minimize pollution risk to the groundwater and facilitate its viability for daily use for washing and showering, and emergency drinking water source.

1) Piggeries should be located away from wells and household and limited to an area of the island where groundwater is never utilized. If possible, pigs should be allowed to range freely in such an area to minimize likelihood of point-input of concentrated organic waste.

2) Solid waste disposal in pits should not be performed in immediate vicinity of any wells. The pits should never be located up hydraulic gradient from the wells. Specifically, the spatial relationship between a well

and waste disposal pit should be such that 1) waste is disposed seaward from wells, or 2) waste is disposed at roughly the same distance from the coast as the location of the well but not close to the well. Such arrangement would ensure that groundwater percolating through any buried waste in the vadose zone recharges the aquifer in a location from where it is unlikely to afterward flow within the phreatic zone to the well.

3) Pit toilets should be constructed as to enhance filtering of waste water. Coralline sandy and gravelly soil and sediment typical of low islands are poorly consolidated and have fast percolation rates. Waste liquids entering a pit dug in this material pass through the unlined walls quickly and may seep into groundwater before microorganisms can remove contaminants. To prevent groundwater pollution, walls of the pits should be lined with a layer of absorptive organic material available locally -- for example, a thick mat of old thatch or dry foliage. This material will decompose and become part of the compost pile lining the pit, acting as a filter for percolating liquid. The locations of toilets with respect to wells should be chosen in fashion described in the previous point.

4) People should be informed of the dangerous effects of human burials right within the household compounds and encouraged to create a single cemetery. Considering the nature of groundwater flow, the location should not be in a site inland from the settlement, but in a place distant along lines parallel to the shore. Ideally, the communal cemetery would be created on an entirely separate islet on the atoll. The grave sites would thus not endanger health and well-being of the community, yet remain accessible for visits in a peaceful and quiet location. It should be noted that for many Micronesian communities this would constitute a reversal to a practice that already existed prior to current trend to bury the deceased within homesteads.

References and further reading

Interviews

Interviews with leaders and residents of Pakein Atoll, Personal communication, 2006-2008, Pohnpei.

Odango, E. [PeaceCorps Volunteer, 2007-2009], Personal communication, February, 2008, Pohnpei.

Further reading

Ayers J. F., Vacher H. L., Clayshulte R.N., Stout D. and Stebnisky, R., 1984, Hydrogeology of Deke Island, Pingelap Atoll, Eastern Caroline Islands. Technical Report **52**, Water and Environmental Research Institute of the Western Pacific, Mangilao, Guam, 366 pp.

Bailey, R. T., Jenson, J. W., Rubinstein, D. H., and Olsen, A. E. (2008) Groundwater Resources of Atoll Islands: Observations, Modeling, and Management. Technical Report **119**, Water and Environmental Research Institute of the Western Pacific, Mangilao, Guam, 84 pp.

Bailey, R. T., Jenson, and Olsen, A. E. (2008) An Atoll Freshwater Lens Algebraic Model for Groundwater Management in the Caroline Islands. Technical Report **120**, Water and Environmental Research Institute of the Western Pacific, Mangilao, Guam, 35 pp.

Falkland, A. C. (1993) Hydrology and water management on small tropical islands. In: Hydrology of Warm Humid Regions (Proceedings of the Yokohama Symposium, 1993), IAHS Publication no. **216**.

French, C. Farrell-Poe, K., Payne, W., Wu, L., Evensen, C., Castro, L., Walker, M., Houte-Howes, K., Duponcheel, L., Phillip, J., Kalemen, A., Franz, P., and Mahler, B. (2004) Public Perceptions of Water and Environmental Issues in the Southwest States and Pacific Islands, CSREES poster, 1 pp.

Jenson, J. W. and Rubinstein, D. (2006) Island Groundwater Resources Research - Federated States of Micronesia. PowerPoint presentation, unpublished.

Johannes, R. E. (1978) Traditional Marine Conservation Methods in Oceania and their Demise. Annual Review of Ecological Systems **9**: 349-364.

Khosrowpanah, S. (2009) Drinking Water: Challenging Issue for Tropical Islands in the Western Pacific. DevForum **31**, Council for International Development, Wellington, New Zealand.

MacCracken, R. S., Jenson, J. W., Heitz, L. F., Rubinstein, D. H., and Mylroie, J. E. (2007) Water Resources Analysis of Fais Island, Federated States of Micronesia. Technical Report **111**, Water and Environmental Research Institute of the Western Pacific, Mangilao, Guam, 41 pp.

Macomber, P. S.H. (2001) Guidelines on Rainwater Catchment System for Hawaii. College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa.

Maharaj, R. J. (1999) Coastal Erosion and Management in Federated States of Micronesia (FSM). SOPAC Miscelanneous Report **347**, 38 pp.

Meehl, G. A. (1996) Vulnerability of Freshwater Resources to Climate Change in the Tropical Pacific Region. Water, Air, and Soil Pollution **92**: 203-213.

Regional Water Program - Southwest States & Pacific Islands (2002) Franz, P. K. (Ed.) A Guide for Rainwater Catchment Systems in the Pacific. 20 pp.

Regional Water Program - Southwest States & Pacific Islands (2005) Drinking Water Trends in the Pacific. 2 pp.

Regional Water Program - Southwest States & Pacific Islands (2005) Water Issues are a High Priority in the Pacific. 2 pp.

Vacher, L. and Quinn, T., Geology and Hydrology of Carbonate Islands. Developments in Sedimentology, v. 54: Elsevier, New York.

Maps

US Army Corps of Engineers (1960) Map of Pakein Atoll, 1:50000, series W756, sheet 5742 I

Appendix 1

Detailed list of information sought by researchers and a guide for researchers during interviews with local leaders and officials

A) Background information: 1) Geographic location and description [island name and location, island type, number and size of islets, land area, lagoon area, coastal perimeter, highest point, description of vegetation, any distinctive features]; 2) Population information [names, size and location of populated islets, population size (adult population, total population), ethnolinguistic affinity, significant demographic events (immigrations, emigrations, evacuations), etc.]; 3) General infrastructure [island accessibility (air/sea), lagoon accessibility (shape, size, and number of channels), major traditional buildings (men's houses, meeting houses, women's houses, menstrual houses, canoe houses, residences), major concrete buildings (mayor's office, church, school, clinic, stores, residences]; 4) Points of contact [name and contact information of the mayor, traditional chief, schoolteachers, municipal officials, Peace Corps volunteers on island]

B) Meteoric water usage and infrastructure: 1) General description of rainwater catchment systems [Rainwater catchment systems present or not, what type (rooftop, dedicated), etc.]; 2) Catchment portion descriptions [material (metal sheet, corrugated iron, plastic), size of catchment area, gutter condition (good, leaky), etc.]; 3) Storage portion description [type of storage tanks, material (concrete, plastic, fiberglass), size (approximate average volumes, maximum volumes]; 4) number of catchment sites [approximate total number of catchments, number per household); 5) locations of catchment sites (approximate locations of catchment site clusters; exact locations of communal/public/major structures]; 6) Ownership [private, communal, or public]; 7) History [origin of rainwater catchment systems (self-made, purchased, donated, FEMA), significant events (destructive typhoons, relief operations, water shortages, other crises]; 8) Meteoric water use [inquire about primary and all other uses of rainwater].

C) Groundwater usage and infrastructure: 1) General description of wells [wells present or not; type of wells]; 2) Well engineering [general depth, walls (reinforced or not), material (rock wall, concrete, plastic, etc.), covering (none, partial, complete]; 3) Well condition [new, damaged, old, destroyed]; 4) Well state [active, partly used, inactive, abandoned]; 5) Number of wells [total number of wells; number per household]; 6) Locations of wells [approximate locations of well clusters; exact locations of significant wells]; 7) Well ownership [private, communal, or public]; 8) Water condition [how do residents perceive groundwater quality (any physical pollution, microbial pollution, bad taste)? Is groundwater fit for drinking or not, fit for cooking or not? Are there any exceptionally good wells, or any exceptionally bad wells?]; 8) Saltwater intrusion [any evidence of saltwater intrusion? What is the water condition like at low tide vs. high tide?]; 9) Groundwater use [what are the primary and other (emergency) uses of groundwater? If ever used for drinking, is the water treated in any way?]; 10) Natural discharge [are there any significant discharge points on the coastline of inhabited islands? Any identifiable springs and seeps? What is their morphology and estimated discharge and quality? Is there any evidence of nutrient-enriched groundwater discharge?]

D) Agriculture and animal husbandry: 1) General description [description and extent of managed vegetation on island, agroforest, taro patches, coconut groves, major crops]; 2) Agroforest [composition of agroforest, major plant species]; 3) Major trees [large breadfruit and/or other trees present or not? Any significant events that destroyed trees? Is lumber harvested

on island and what are its uses?]; 4) Taro patches [note extent of taro patches, describe their condition]; 5) Coconut groves [do people perceive that there are enough coconut palms on island? Do they produce enough? Are coconuts casually used for hydration or are they partly or strictly conserved?]; 6) Piggeries [how many pigs are there? Where and how are they kept?]

E) Waste disposal: 1) Solid waste disposal [note any landfill-type areas, contaminated land]; 2) Household waste disposal [is garbage disposed of in piles, pits, burned, buried, thrown to the lagoon, thrown to the ocean?]; 3) Human and animal waste disposal [fixed locations or not? Toilets or outhouses? Any flushing toilets? Any septic tanks? What size, construction and lining of the septic tanks? Any human and animal waste related problems?]; 4) Burials [any designated cemeteries? Any individual graves around households? Are locations of graves and cemeteries in/near village, on same/different island as the village? Any traditional (at sea) burials in living memory?]; 5) Pollution [any evidence of pollution on land? Any evidence of pollution along the coastline? Any evidence of pollution in the lagoon? Any evidence of unusual algal growth or coral decay?]; 6) Shipwrecks [any recent shipwrecks? Any ships still aground on the reef? What state are wrecked vessels in? Any cleanup operations? Any leaks or physical damage to reefs?]

F) Meteorologic data: 1) Meteorologic data collection [are data collected on island? Who is the local person in charge of data collection? What type of data? What instruments are available? Who is the collecting agency? How is the data reported and how often?]

G) Fresh water-related problems: 1) Water availability [do residents perceive that there is enough water on island? Is water use unrestrained or are there some conservation practices in place?]; 2) Water condition [do residents feel there are any specific water-related problems or issues? Is stored rainwater quality suitable for the way it is used? Is groundwater quality suitable for the way it is used?]; 3) Health [has island ever experienced any contagious disease outbreaks? Any unusual health problems? Any community-level health emergencies?]; 4) Water crises [has island ever run out of fresh water? What triggered the crisis? How did the residents respond? How was emergency resolved? Are there any contingency plans for the future?]

H) Sea water-related problems: 1) Flooding [has the island ever been subject to a major flood? What caused it (typhoon, swell, tide)? What was the damage? How did the residents respond? How was the situation remedied?]; 2) Loss of vegetation [are there any formerly well vegetated areas that are now poorly vegetated or barren? Is any natural vegetation or agricultural land damaged by tides, waves, sea-spray, or underground saltwater contamination?]; 3) Erosion [what is the state of coastal vegetation? Is there any evidence of eroded modern beaches, exhumed paleo-beaches, and undercut vegetation? Any evidence of coastal sediment accumulation? Is erosion or accumulation gradual/imperceptible or is it caused by rapid events? Any islets destroyed, created, split, connected, significantly reshaped in living memory?]; 4) Community perceptions [do people perceive any ocean encroachment or loss of land?]

I) Visual information (photographs): 1) Natural features [general landscape; coastal scenery (lagoon-side, oceanward side); inland scenery (natural vegetation, agroforest, taro patches, coconut groves), etc.]; 2) Infrastructure [settlements; households; general infrastructure; water-related infrastructure (rainwater catchment systems, rainwater storage objects, wells, toilets); other relevant sites (waste disposal locations, cemeteries]; 3) Cultural features [water use practices: washing of dishes, washing of clothes, showering, bathing, open fire cooking, outdoor kitchens, etc.]; 4) Problematic features [any features, structures, or areas identified as problematic by investigators or island residents]

Appendix 2

Data collection sheets used by researchers to obtain basic information about individual households (top), their water catchment systems (middle) and wells (bottom)

SECTION	Map #	Household name	GPS waypoint #	# adults	# kids	start photo#	end photo#	# of tanks	# of wells	COMMENT (no tank/well)

Map #	Ownership	Use	Purpose	Shape	W cm	L cm	Circ. cm	H cm	Material	Catch w cm	Catch l cm	Potential	Gutter

Map #	Ownership	Use	Purpose	Type	Lining	Cover	Extraction	Condition	Quality	Depth cm

Appendix 3

Checklist and interview sheet used by researchers to obtain information from individual households

HOUSEHOLD AND INFRASTRUCTURE SURVEY INVESTIGATOR CHECKLIST

Household name: _____

Number of people: _____ adults _____ children

GPS location: _____ N _____ E

Photo numbers: _____ (start) _____ (end)

___ Check water storage tanks: types, size, state, water quality, water use

___ Check catchment area: total used and potential

___ Check wells: type, state, depth, water quality, water use

If no tanks or no wells, ask residents where do they get the water?

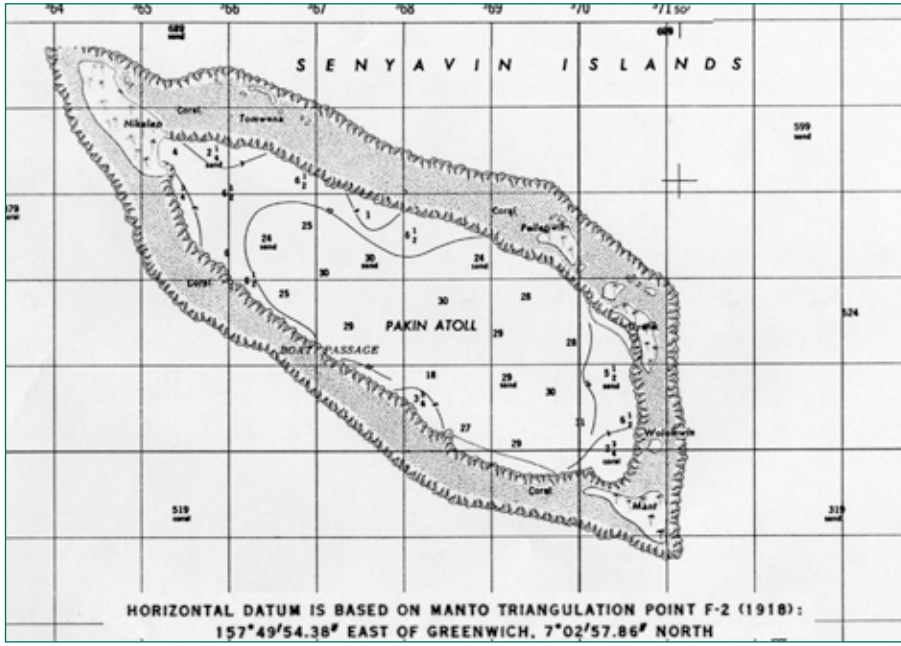
Thank the residents for cooperation.

HOUSEHOLD AND INFRASTRUCTURE SURVEY RESIDENT QUESTIONNAIRE

0) Household name?
1) What do you drink when you are thirsty? What kind of fruits to you eat regularly?
2) Where do you bathe? Ever bathe in the ocean and just rinse with fresh water?
3) Can you drink water out of any tank, or are there differences in quality between tanks?
   What kind of tanks are the best or most popular? Why?
4) How many coconuts do adults and children in your household drink per day?
   Can you remember any events in the past when coconut supply was used up?
   How long did it take for that to happen?
   Do you notice any changes in coconut trees or nuts during droughts?
5) If your tank was full and it stopped raining, how long would it take for the level to drop to half?
6) At what level of water in your tank do you become worried?
   At what level of water in your tank would you say that the water is running out?
   What did you do in the past when the water level in your tank got that low?
   What did you tell your family to do?
   How long did it take for the tank to become empty?
   Did yours and other households ever run out of water?
7) If your tank was empty, where is the 1st place you would try to get water? And 2nd place?
   Are there any rules on how much water can be taken from community tanks?
8) Did it ever happen that no tank on the island had water in it? What did you do then?
9) Has water on the island ever made anyone sick?
10) Where do you go for human waste disposal?
    Where do you throw away your garbage?

Appendix 4

Satellite image (from Google Earth®) and scan of a 1:50000 paper map (US Army Corps of Engineers, 1960) of Pakein Atoll.



Appendix 5

Small subset of geotagged photographs taken over the course of this project, each displayed at coordinates where it was taken.

Geotagged images
on this map are reduced
in size and resolution.