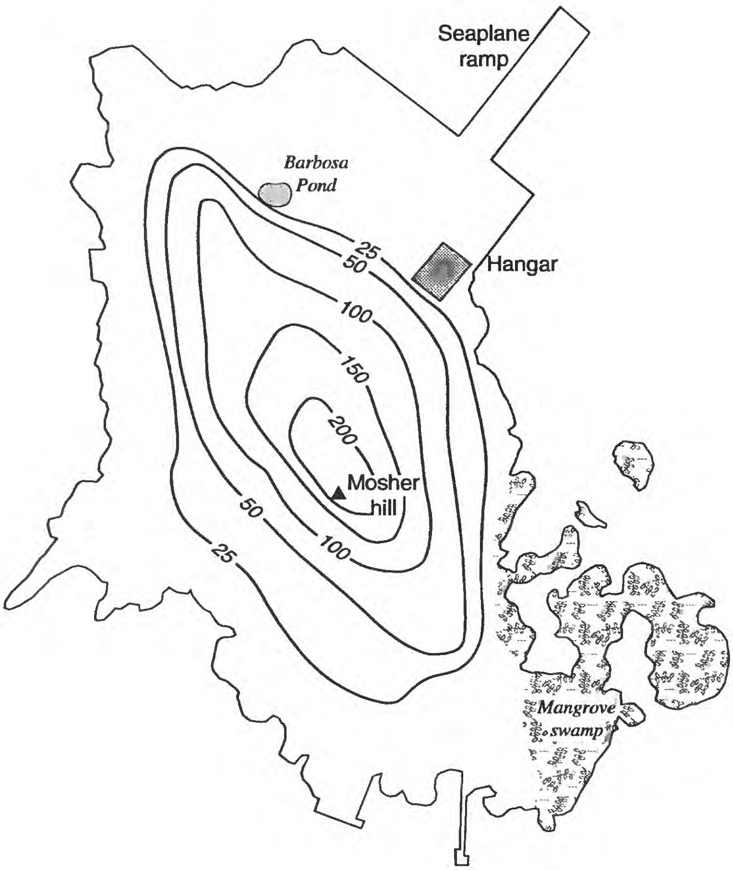
GEOLOGY AND WATER-RESOURCES RECONNAISSANCE OF LENGER ISLAND, STATE OF POHNPEI, FEDERATED STATES OF MICRONESIA, 1991

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 93-4217



Prepared in cooperation with the

STATE OF POHNPEI,
DEPARTMENT OF CONSERVATION AND
RESOURCE SURVEILLANCE

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By Stephen S. Anthony and Steven R. Spengler

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Honolulu, Hawaii
1996

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
acre	4,047	square meter
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.06308	cubic decimeter per minute
gallon per day (gal/d)	0.003785	cubic meter per day
inch (in.)	25.4	millimeter
inch per year (in/yr)	2.54	centimeter per year
mile (mi)	1.609	kilometer
million gallons (Mgal)	3,785	cubic meter
million gallons per day (Mgal/d)	0.04381	cubic meter per second
million gallons per day per square mile [(Mgal/d)/mi^2]	1,460	cubic meter per day per square kilometer
ounce (oz)	28.35	gram
square foot (ft^2)	0.09294	square meter
square mile (mi^2)	2.590	square kilometer

Abbreviations used: meq/L, milliequivalents per liter; mg/L, milligrams per liter.

Specific conductance is given in microsiemens per centimeter (µS/cm) at 25° Celsius, which is numerically equal to micromhos per centimeter (µmho/cm)

Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by using the equation:

$$1.8 \times {}^{\circ}C + 32 = {}^{\circ}F$$

Geology and Water-Resources Reconnaissance of Lenger Island, State of Pohnpei, Federated States of Micronesia, 1991

By Stephen S. Anthony and Steven R. Spengler

Abstract

Lenger is a small (less than 0.2 square miles) volcanic island located within the lagoon of Pohnpei Island. Ground water on Lenger moves as shallow subsurface flow through weathered bedrock slopes into low-lying areas near the coast before discharging into the surrounding lagoon. Estimated ground-water recharge to the island from rainfall is 506,000 gallons per day on the basis of a mean annual rainfall of 140 inches. The basal part of Lenger is composed of a relatively low-permeability post-shield-building lava flow. This flow is overlain by a more permeable conglomerate of stream deposits which is in turn overlain by a relatively low-permeability columnar-jointed lava flow. The limited land mass and relatively low-permeability lava flows that form the bedrock of Lenger are not favorable to the formation of well-defined drainage basins or large basal ground-water bodies.

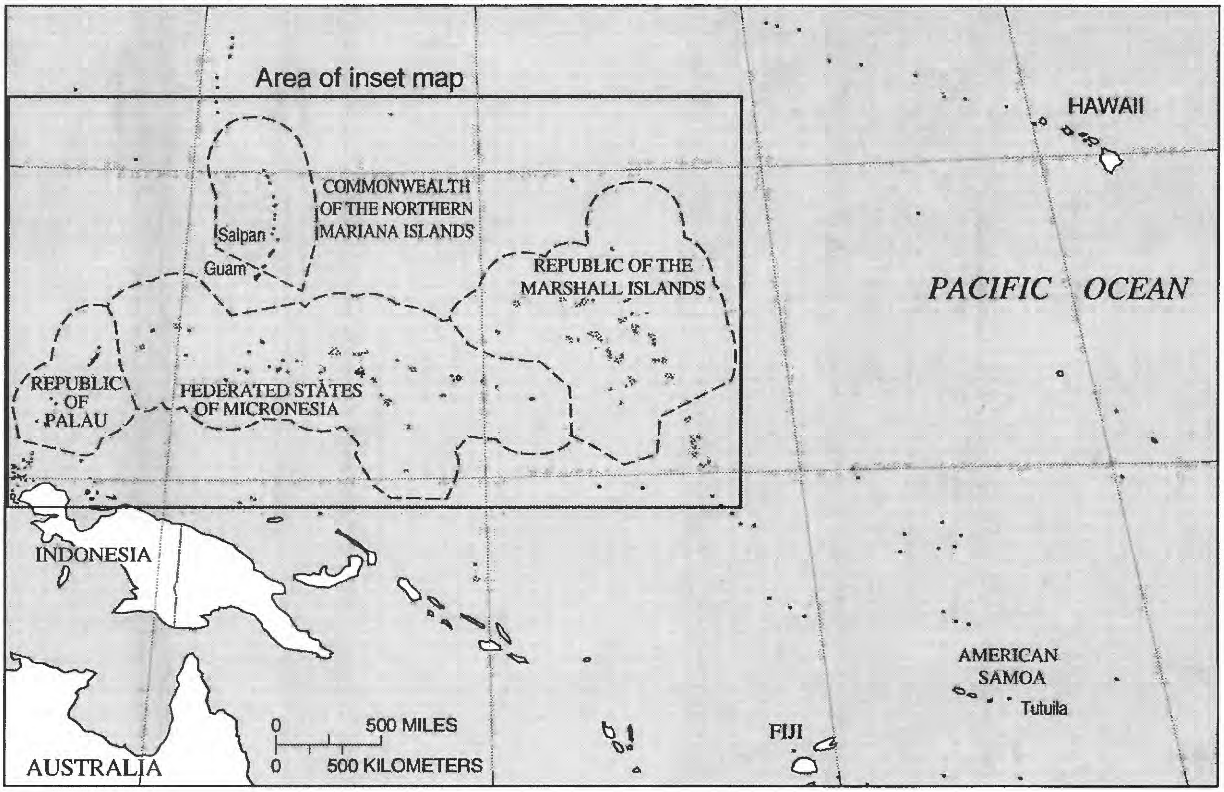
Numerous springs and seeps discharge shallow subsurface flow at the contact between water-bearing weathered bedrock and underlying less-permeable bedrock. Because the amount of water stored in these shallow subsurface ground-water bodies is limited, springflow and seepflow rates are directly related to rainfall. Barbosa Pond, the largest surface-water body on Lenger, contained 162,000 gallons of water on June 19, 1991. On June 20, 1991, springflow into the pond increased from 0.6 gallons per minute during base-flow conditions to 21 gallons per minute during a 4-hour period of rain that totaled 0.74 inches. The water from Barbosa Pond contains iron and manganese in concentrations that may cause problems in a water-supply system.

Small-scale development of ground water, such as was done at Barbosa Pond by the Japanese, is possible by tapping water stored in colluvial talus deposits that flank the base of Mosher hill. The source of water in these deposits is from seeps and springs that have low base flows; however, additional quantities of water could be obtained from these deposits by widening or deepening the capture area of wells used to develop these deposits. If sufficient storage facilities are built, water from these deposits would be available during drought conditions.

INTRODUCTION

The demand for water on the island of Lenger is increasing as a result of a desire to construct a centralized water system for the residents. Lenger is a small volcanic island in the State of Pohnpei, Federated States of Micronesia (fig. 1). Water supplies on Lenger are presently obtained from individual rainwater-catchment systems and two small springs. During extended dry periods, the demand for potable water commonly exceeds the supply.

The water-supply problem on Lenger was accentuated during a drought in 1983 when rainfall was only 13 percent of normal for 5 consecutive months in the nearby town of Kolonia on the island of Pohnpei (fig. 2) (van der Brug, 1986). The subnormal rainfall created a severe problem because most of the potable water on Lenger comes from rainwater-catchment systems. Water was strictly rationed, and water from a shallow dug well and water that collected in a World War II cave shelter were used as supplementary sources of drinking water. One way to alleviate the occasional water-supply



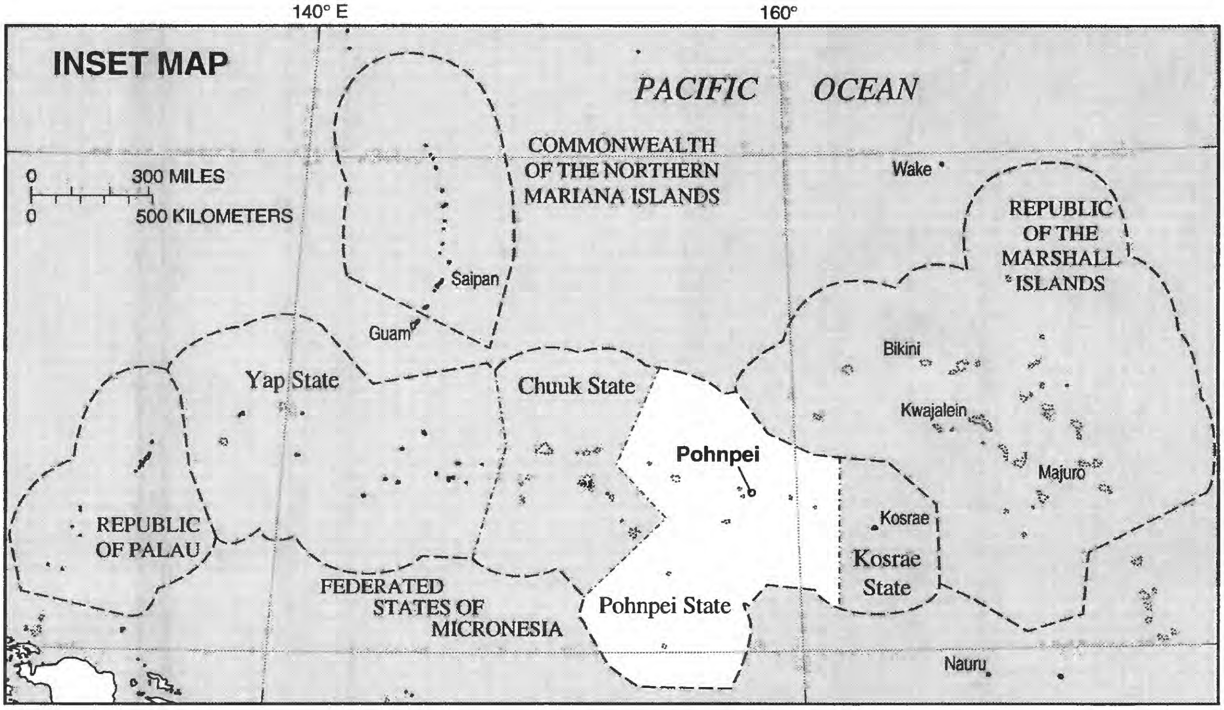


Figure 1. Location of Pohnpei Island, State of Pohnpei, Federated States of Micronesia.

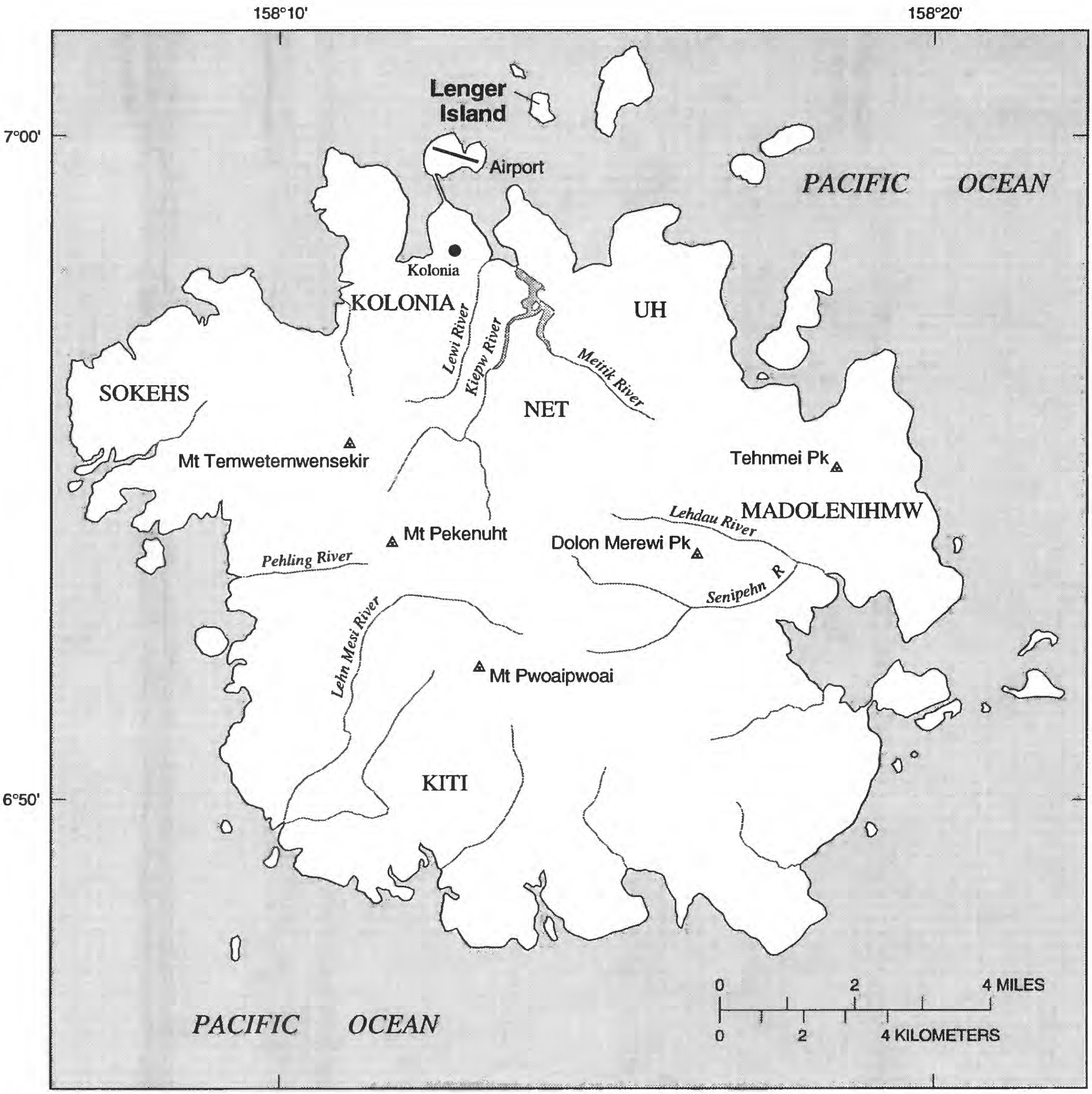


Figure 2. Pohnpei Island and location of Lenger Island.

shortage would be to further develop ground-water resources.

Because of concern over water-supply shortages on the island of Lenger and interest in developing ground-water resources, the State of Pohnpei, Department of Conservation and Resource Surveillance entered into a cooperative agreement with the U.S. Geological Survey to assess the water resources of Lenger. Information from this study could be useful for investigating the water resources of other small volcanic islands.

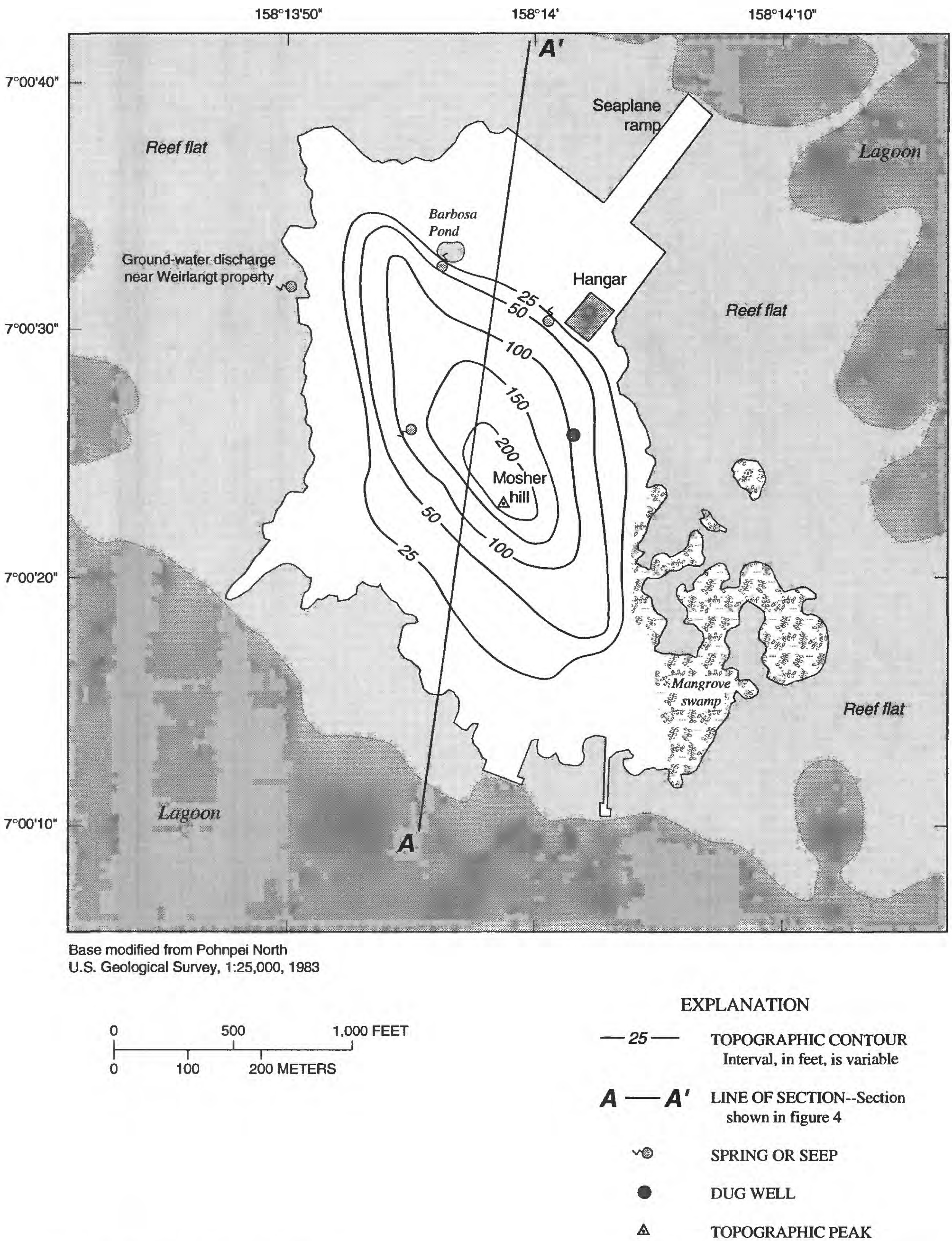


Figure 3. Lenger Island, Pohnpei.

Purpose and Scope

This report documents a reconnaissance of the hydrogeology of Lenger Island. Included are descriptions of the geology of the island, the occurrence of ground water, and the quality of water in Barbosa Pond. Also included are calculations of a water balance for the island, and of the discharge from seeps above Barbosa Pond. The field work for this study was completed December 3, 1990 and June 18–20, 1991. Much of the water-balance information in this report is based on data collected at the weather station in the town of Kolonia on the island of Pohnpei.

Setting

Lenger is a small volcanic island located within the lagoon that surrounds the island of Pohnpei. Lenger is about 0.5 mi from north to south, about 0.3 mi from east to west, and less than 0.18 mi^2 in area (fig. 3). Near the center of the island, Mosher hill rises 253 ft above mean sea level. A 100 ft cliff is exposed on the western side of Mosher hill and mangrove forest lines the southeastern shore. Lenger is about 500 mi north of the equator at latitude 7°00' N. and longitude 158°14' E.

The main island of Pohnpei is a nearly circular volcanic island that covers about 129 mi^2 in area and rises 2,595 ft above mean sea level. Pohnpei is surrounded by about 40 small islands of both coral and volcanic origin and by a barrier reef averaging 2 mi in width that encloses a relatively narrow and shallow lagoon.

The climate of Pohnpei and Lenger is humid and warm: the average relative humidity is 85 percent. The temperature is relatively uniform throughout the year; high temperatures normally range in the mid to upper 80's and lows in the low to middle 70's. Light trade winds from the northeast prevail from November to June. The rest of the year is characterized by the doldrums, during which time the regional climate is dominated by the Intertropical Convergence Zone. The high rainfall, which averages 140 in/yr, results in extremely lush and dense vegetation.

During World War II the Japanese fortified Lenger with artillery and installed a small seaplane base (Ashby, 1987). The seaplane base contained a hangar with a repair shop, a seaplane ramp, and a seaplane parking area. The installation included underground fuel storage tanks of 3,300-ton capacity and six 1,000-gal water tanks. The source of water was rain catchment and two springs. The fortifications were destroyed by bombs and naval gunfire in early 1944. The island was used later as a seaplane facility until a runway on a nearby island (fig. 2) was completed in 1970. The seaplane ramp on Lenger is still in excellent condition.

The island is a popular spot for day or weekend outings, and is home to about 30 residents. Bomb craters, cave shelters, a 6-in. British Armstrong Whitworth rifle, and the skeleton of the seaplane hangar provide tourist attractions. Development of Lenger is limited by a lack of electrical, water, or sewer infrastructure.

Acknowledgments

Interest in and support for the project by the State of Pohnpei is gratefully acknowledged. Tony Actouka and Daniel Lehben of the State of Pohnpei, Department of Conservation and Resource Surveillance, and Higgino Weirlangt, the Chief Magistrate of Lenger, provided assistance that facilitated the completion of this project.

GEOLOGY

The island of Pohnpei is the eroded remnant of a large shield volcano composed of mildly alkalic lava (Spengler, 1990). Volcanic activity began about 9 million years ago and was centered in the northern part of the Net municipality (fig. 2). Flows capping an erosional unconformity above the shield-building lavas are as thick as 50 ft. Eruptive activity during the post-shield-building stage was episodic as indicated by conglomerate and stream deposits as much as 50 ft thick between individual flow units. Lava flows of this stage commonly ponded within the deeply dissected valleys of the original shield volcano, producing thick, low-permeability columnar-jointed flows that are resistant to erosion. As erosion of the island continued, the surrounding valley walls composed of less-resistant shield-building lavas eroded away, leaving elongate, near-vertical ridges composed of these valley-filling lavas.

Lenger is one of several volcanic islands located within the lagoon of Pohnpei. The generalized geologic

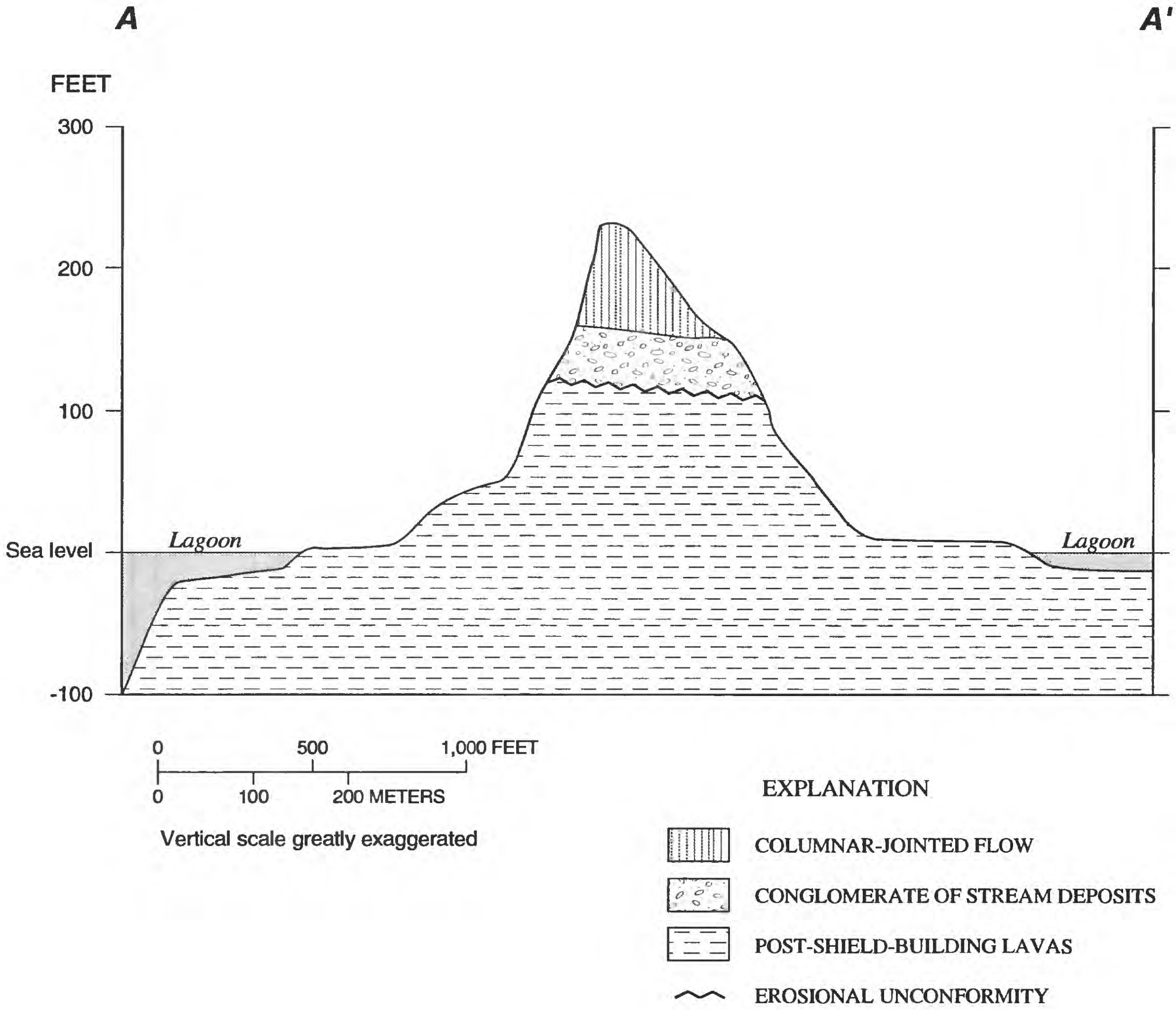


Figure 4. Generalized geologic section of Lenger Island, Pohnpei.

section of Lenger (fig. 4) is based on the mapping of the 100-ft cliff exposure on the western side of the island. The basal part of the section is composed of a low-permeability nephelinite flow that is not cut by dikes despite being located near the eruptive center of the shield-building lava flows. The absence of dikes indicates that this flow post-dates the vigorous intrusive activity associated with the main constructional phase of Pohnpei. Keating and others (1984) determined a potassium-argon age of 7 million years for this flow unit. This basal flow is overlain by a 25-ft-thick conglomerate of stream deposits composed of boulders up to 10 ft in diameter. The contact between the nephelinite flow and the conglomerate is about 120 ft above mean sea level. The conglomerate is overlain by a low-permeability columnar-jointed mugearite flow that is about 40 ft thick and quite resistant to erosion.

The dense and massive lava flows of Lenger Island have low permeability. The most permeable materials are the conglomerate deposits, the weathered lava flows on the slopes of Mosher hill, and the colluvial talus deposits that flank the base of Mosher hill. The conglomerate, which overlies the nephelinite flow, is capped by a mugearite flow composed of massive columnar joints. This capping flow has low permeability and therefore limits recharge to the conglomerate. Recharge to the conglomerate most likely occurs along the vertical joints in the columnar basalt.

WATER RESOURCES

Rainfall is the sole source of freshwater on Lenger. The rain that falls on the island is divided among surface runoff, evapotranspiration, and ground-water recharge. Individual rainwater-catchment systems capture surface runoff from the roofs of homes. These systems are unreliable during droughts because of their small catchment area and storage capacity. There are no streams on Lenger that discharge surface runoff to the surrounding lagoon. Evapotranspiration is a collective term for the evaporation of rainfall and the transpiration of soil moisture by plants. Water not lost to evapotranspiration or runoff recharges ground water, and eventually discharges to the surrounding lagoon. The occurrence of ground water on Lenger is controlled by the geologic structure of the island. Water stored as ground water on Lenger could provide additional sources of supply.

Rainfall

The mean annual rainfall on Lenger is estimated to be 140 in. on the basis of a map showing lines of equal mean annual rainfall on Pohnpei (Spengler, 1990). The mean annual rainfall on Pohnpei ranges from about 140 in. along the coastal areas to greater than 360 in. in the high mountainous interior (fig. 5). Although there are no climatological records for Lenger, a relatively complete record of historical data since 1900 is available for the town of Kolonia, located 2.7 mi to the southwest (fig. 2).

The mean annual rainfall for the Kolonia weather station is 190 in. for the period of record 1950–90, but the annual rainfall varies widely from year to year. A plot of the running 3-year mean annual rainfall reveals multi-year periods during which rainfall digresses significantly from the mean (fig. 6). Pohnpei receives abundant rainfall throughout the year (fig. 7). May is the wettest month with an average rainfall of 19.82 in. and February is the driest month with 10.96 in.

Evapotranspiration

Because rainfall is generally abundant throughout the year, the shallow soils on Lenger are almost always moist, and water is nearly always available to plants. Under these conditions, the actual evapotranspiration rate approaches its potential or maximum possible rate that can be estimated from pan-evaporation measurements.

Pan-evaporation measurements have not been made at the Kolonia weather station. In a study of the Chuuk (Truk) Islands, however, Takasaki (1989) showed that a strong correlation existed among measured pan evaporation rates, annual rainfall, and wind movement on the islands of Guam, Yap, and Johnston Atoll. Using these relations, the amount of evapotranspiration on Chuuk was estimated. Spengler (1990) expanded this relation to include data from American Samoa. Extrapolating the best-fit line through the data from these four islands to the mean annual rainfall of 140 in. estimated for Lenger yields a value of 72 in/yr for both pan evaporation and evapotranspiration.

This technique assumes that the reduction of sunlight at wetter stations is proportional to the annual rainfall. Implicit in this assumption is that the annual potential sunlight intensity, which is a function of the island's latitude, is similar for each island. The islands used in this relation lie between 7 and 17 degrees of the equator and thus the potential annual sunlight intensity on each station is similar.

Ground-Water Recharge

Ground-water recharge is equal to rainfall minus evapotranspiration and surface-runoff losses. Subtracting 72 in. of evapotranspiration and 0 in. of surface runoff from 140 in. of annual rainfall would leave an estimated 68 in. of water to recharge ground water on Lenger in an average climatic year. An annual recharge of 68 in. over a catchment area of about 100 acres yields an average annual recharge to Lenger of 506,000 gal/d. This is an average figure and actual values will vary with rainfall and evapotranspiration.

Ground-Water Discharge

Ground water on Lenger flows through shallow parts of weathered bedrock on the slopes of Mosher hill, through colluvial talus deposits flanking Mosher hill, and into low-lying areas near the coast before discharging into the surrounding lagoon (fig. 8). The low-permeability bedrock and the limited land area of the island are not favorable to the formation of large basal ground-water bodies.

Numerous springs and seeps discharge shallow subsurface flow at the contact between water-bearing

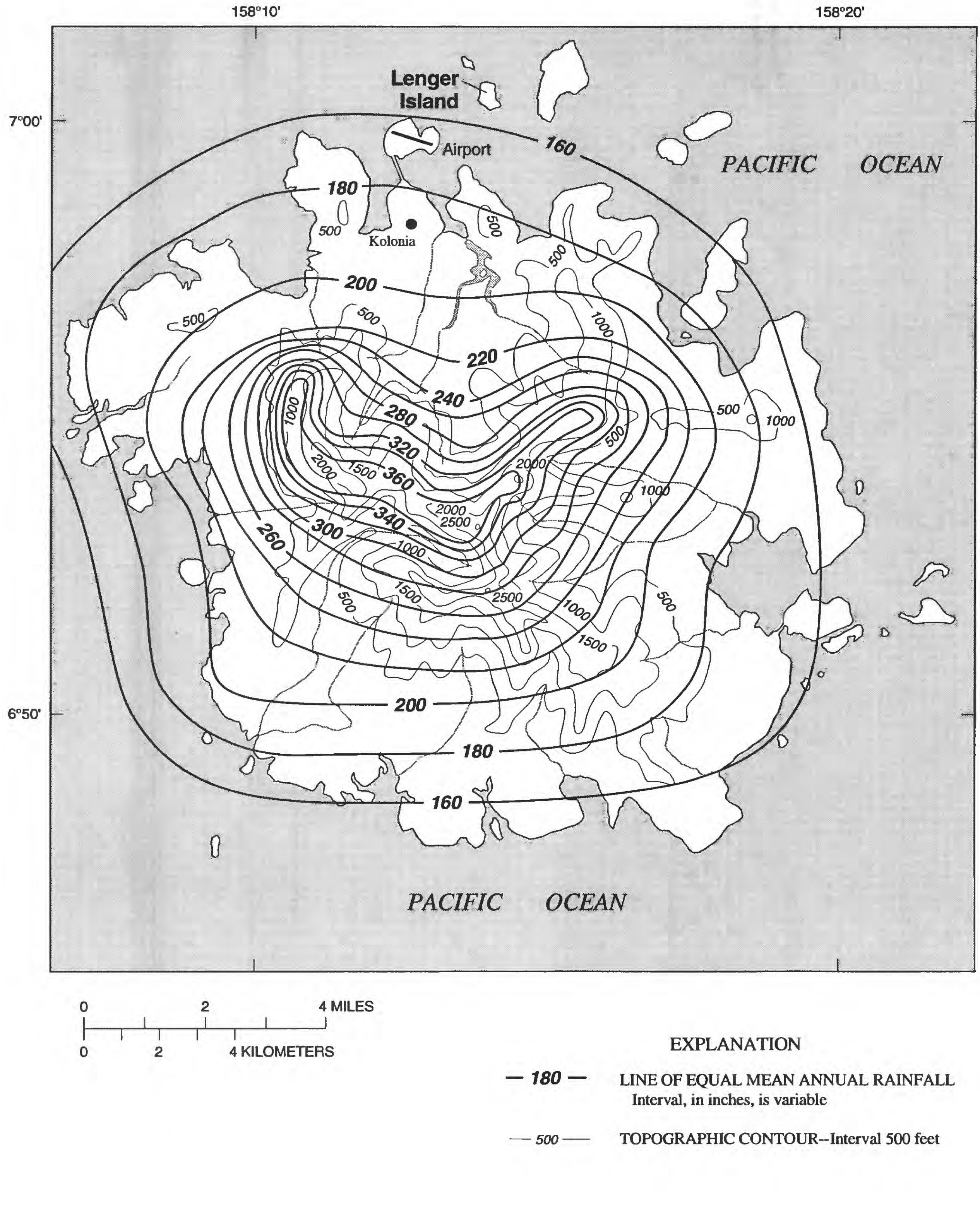


Figure 5. Equal mean annual rainfall for the island of Pohnpei (modified from Spengler, 1990).

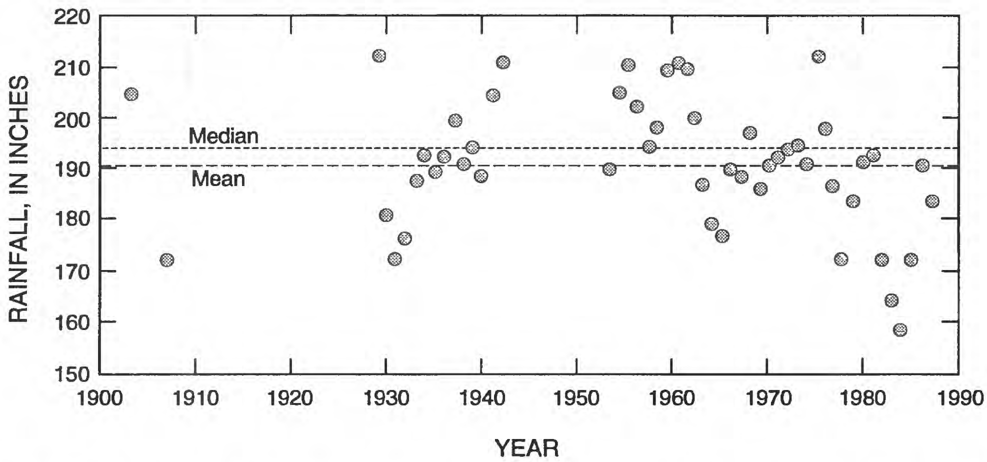


Figure 6. Variations in 3-year running mean of annual rainfall, Kolonia, Pohnpei (from Spengler, 1990).

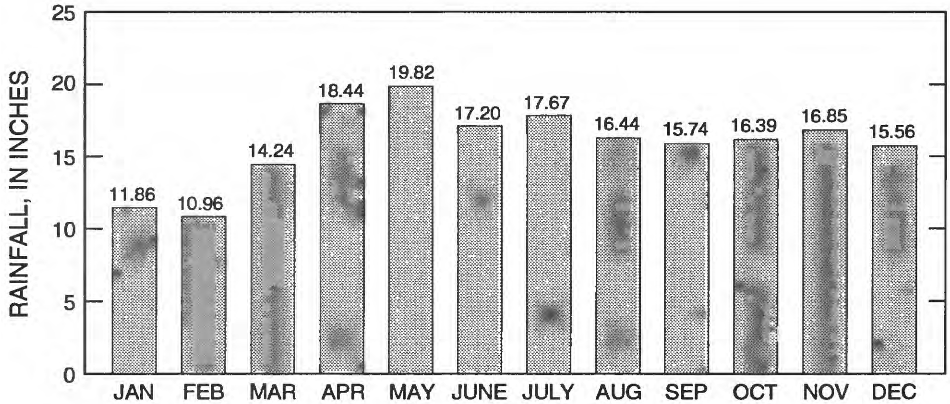


Figure 7. Mean monthly rainfall, 1950–89, Kolonia, Pohnpei (from Spengler, 1990).

weathered bedrock and underlying less-permeable unweathered bedrock on the slopes of Mosher hill. Because storage of water in these ground-water bodies generally is small, the flow at most of the springs and seeps is directly related to rainfall. Water from one of these springs is piped to the Weirlangt home (fig. 3); however, the yield is often less than 1 gal/min.

Water discharging from seeps near the base of Mosher hill recharge colluvial talus deposits flanking the hill. A shallow dug well, located at the base of the hill on the east side of Lenger, yields ground water stored in colluvial talus deposits (fig. 3). The yield and quality of water from this abandoned well is not known. During World War II, the Japanese excavated a pit in the colluvial talus deposits to capture water discharging from three seeps located inland from the seaplane ramp.

Water discharging from seeps and colluvial talus deposits near the base of the hill recharge a low-lying area along the coast of the island. Natural discharge of ground water in the low-lying areas is mostly by plant uptake (transpiration) and evaporation from the wet soil, ponded water in bomb craters, and freshwater marshes. Ground water not discharged to the atmosphere and plants by evapotranspiration discharges to the surrounding lagoon.

The majority of the ground-water discharge at the shore is diffuse flow. During low tide, however, conduit flow is observed to be discharging into the lagoon at several locations along the west coast of the island near the Weirlangt property (fig. 3). This flow, which probably represents water discharging from fractures in the bedrock, has a specific conductance of about 5,000 µS/cm and is therefore nonpotable.

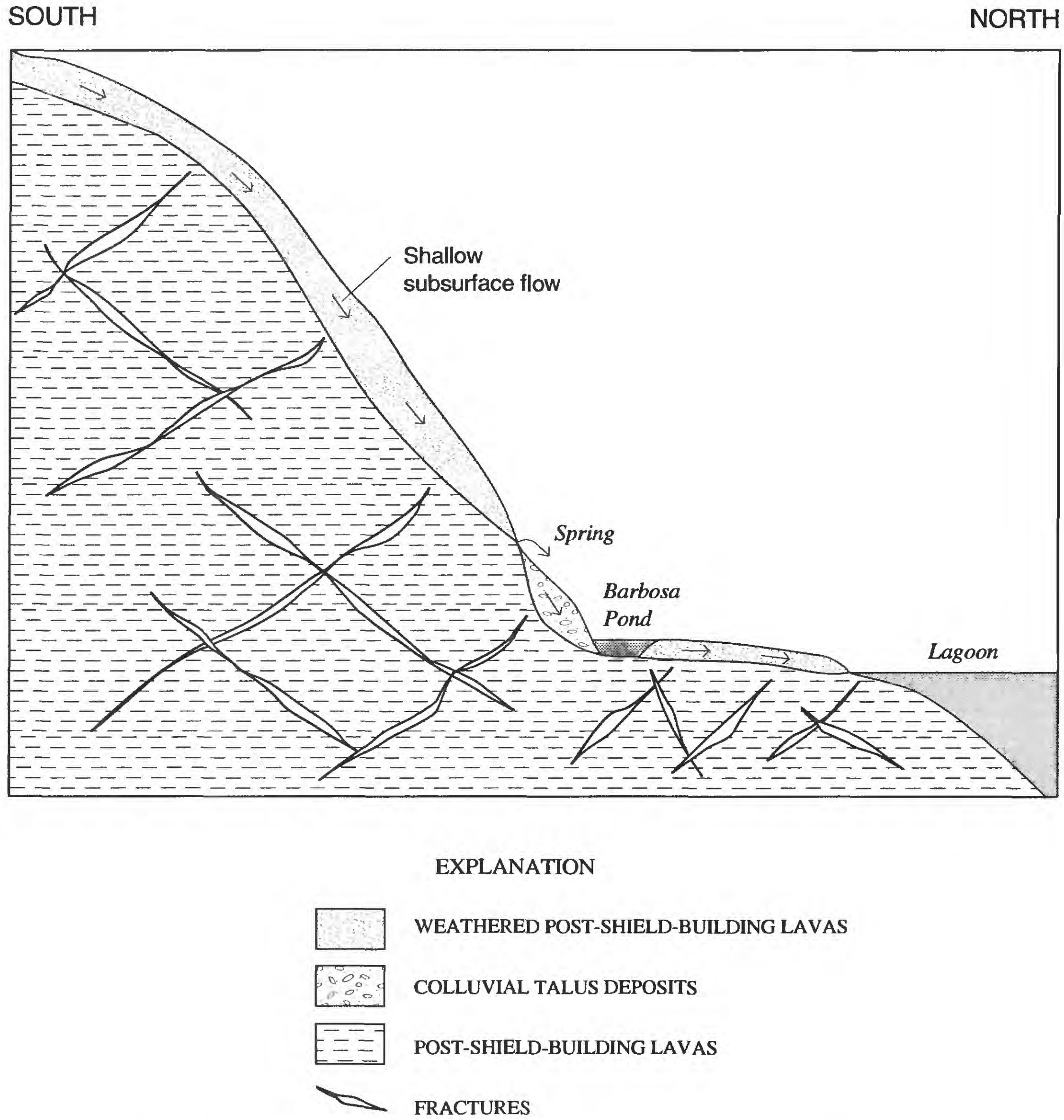


Figure 8. Generalized occurrence of ground water near Barbosa Pond, Lenger Island, Pohnpei.

Barbosa Pond

Barbosa Pond, the largest surface-water body on Lenger, is located inland of the seaplane ramp at the base of Mosher hill (fig. 3). The pond, which has an area of about 7,200 ft^2 extends along 80 ft of the hillside and about 90 ft outward from the hillside. The average depth of water on June 19, 1991, was 3 ft, which equates to about 162,000 gal of water.

Inflow and Outflow

The bottom of the pond seems to have extremely low permeability because nearby bomb craters of equal depth are dry. Inflow to the pond is from direct rainfall and three seeps that discharge at the contact between water-bearing weathered bedrock slopes and underlying less-permeable unweathered bedrock exposed just above the pond (fig. 8). Outflow from the pond is through a rock-lined overflow drainage ditch

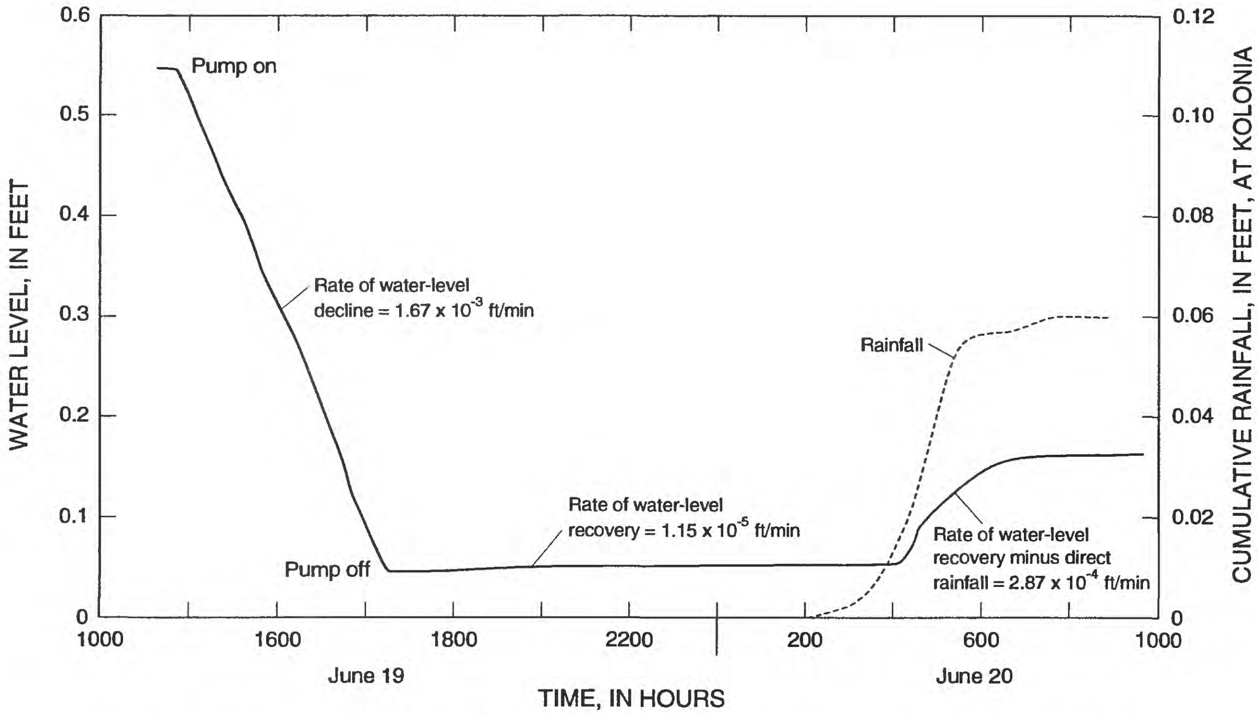


Figure 9. Water level in Barbosa Pond, Lenger Island, and cumulative rainfall at Kolonia, Pohnpei, June 19–20, 1991.

at the southeast corner of the pond. This pond was developed as a source of water for the Japanese seaplane base on Lenger during World War II.

The rate of inflow to the pond was determined from the rate of water-level recovery in the pond after 5 hours of pumping at a constant rate. This is possible because the rate of water-level decline over the pumping interval is linear, indicating that the relation between the volume of water withdrawn from the pond and stage height over the interval pumped is linear.

A total of 24,670 gal of water was withdrawn from the pond at an average rate of 90 gal/min lowering the water level 0.5 ft. The pumping rate was measured with a 55-gal drum and timed with a stopwatch. Water was discharged into a bomb crater 200 ft away and assumed not to return to the pond. There was no outflow from the pond through the drainage ditch before or during the test. A continuous record of the water-level decline and recovery in the pond was obtained with a chart-float recorder (fig. 9). This record was used to calculate the base springflow and springflow during a period of rainfall. Because the pumping rate was much greater than the base springflow, no correction was made for spring inflow that occurred during pumping. Hourly rainfall recorded at the Kolonia weather station was assumed to equal that which fell on Barbosa Pond, because the 24-hour rainfall recorded at the Kolonia weather station on June 20, 1991 equaled that recorded on Lenger for the same time period.

The base springflow to the pond was estimated to be 0.6 gal/min. This base flow was determined by multiplying the rate of water-level recovery (1.15×10^{-5} ft/min) before the rainfall that began at about 0300 on June 20, 1991 by the area of the pond (7,200 ft^2).

The springflow to the pond increased to 21 gal/min between 0415 and 0700 on June 20, 1991. This springflow was determined by multiplying the rate of water-level recovery (3.8×10^{-4} ft/min) during the period of rainfall by the area of the pond (7,200 ft^2). The rate of water-level recovery was corrected for the 0.042 ft of direct rainfall to the surface of the pond between 0400 and 0700 hours. The springflow returned to base-flow conditions at 0800 on June 20, 1991.

Table 1. Results of chemical analysis of water collected, June 20, 1991, from Barbosa Pond, Lenger Island, Pohnpei

[All constituents reported in milligrams per liter unless otherwise noted. WHO, World Health Organization (1984); °C, degrees Celsius; ND, no data; --, no guidelines; µS/cm, microsiemens per centimeter at 25°C; meq/L, milliequivalents per liter; <, less than]

Property or constituent			WHO guidelines
Temperature, °C	26.8		--
Specific conductance, µS/cm	120		--
pH	6.69		--
	Total recoverable	**Dissolved**	
Total alkalinity, meq/L	ND	0.8	--
Calcium	9.43	8.98	--
Magnesium	3.24	3.19	--
Sodium	6.31	6.39	--
Potassium	4.11	3.98	--
Iron	1.2	0.16	0.3
Manganese	0.11	0.001	0.1
Chloride	9.3	9.4	250
Sulfate	4.0	<1.0	400

The source of the water in Barbosa Pond is direct rainfall and three hillside seeps that discharge shallow subsurface flow into the pond. Rainwater contains very small amounts of various dissolved species. Rainwater near the ocean, however, can acquire significant amounts of salts deposited from seaspray. As water from rainfall passes through the shallow subsurface, it reacts with inorganic material and organic matter, and various ions and compounds are taken into solution. Minerals contribute such cations as sodium, potassium, magnesium, and calcium, and such anions as chloride and bicarbonate. Organic matter affect the content of oxygen, carbon dioxide, and nutrients such as nitrogen and phosphorus.

Water Quality

A water sample was collected from the shore of Barbosa Pond on June 20, 1991 and analyzed for major constituent cations and anions to determine the chemical characteristic of the water in the pond (table 1). Temperature, pH, and specific conductance were determined in the field. Samples for major ion analysis were preserved for laboratory determination at the University of Hawaii.

The water analyzed from Barbosa Pond was calcium-magnesium-sodium-bicarbonate type water. Calcium and bicarbonate were the dominate dissolved cations and anions, respectively. All the dissolved constituents analyzed were within the World Health Organization (WHO) guidelines for drinking-water quality (World Health Organization, 1984).

Iron and manganese concentrations were 10- and 100-times higher in the total recoverable (unfiltered) sample compared with the dissolved (filtered) sample, respectively. Although iron and manganese pose no real health hazard, they can appreciably affect the taste of beverages and the flow of water through distribution systems, and can stain laundered clothes and plumbing fixtures. Iron can also promote the growth of bacteria. WHO (1984) recommends a drinking-water guideline of 0.3 and 0.1 mg/L for iron and manganese, respectively.

Although water might be safe for drinking on the basis of its chemical composition, it might not be safe bacteriologically. The microbiological quality of the water in Barbosa Pond was not determined. Because bacteria are a common surface-water contaminant, water from surface-water sources such Barbosa Pond commonly are filtered and disinfected with chlorine before drinking.

GROUND-WATER DEVELOPMENT

Small-scale development of ground water, such as that by the Japanese at Barbosa Pond, is possible from colluvial talus deposits that flank the base of Mosher hill. The source of water in these deposits is seeps and springs that have low base flows and slightly larger flows during periods of rainfall. The yield of water from these colluvial talus deposits can fluctuate greatly between periods of rain and drought. However, additional quantities of water can be obtained from these deposits by simply widening or deepening the capture area of wells used to develop these deposits.

Horizontal wells, also known as infiltration galleries, are well suited for the development of ground water from the colluvial talus deposits on Lenger. A horizontal well makes use of a water-tight pump sump into which water only can flow from horizontal infiltration pipes. Infiltration galleries used in the Cook Islands consist of porous pipes constructed of no-fines aggregate and cement at a ratio of 10:1 (Waterhouse and Petty, 1986). Each pipe is 3 ft long by 1.5 ft diameter, with walls 0.4 ft thick. The pipes are laid end-to-end over the length of the gallery intake area or trench with the distal ends plugged to prevent the entrance of fine-grained material. The trench is dug below the water table and parallel to the source of water, which in the case of Lenger is the hillside. The pipes are laid in the trench, with inspection chambers at each end, then back filled with coarse rock. A pipeline connects the pump sump in the gallery to the consumer or into storage tanks located at strategic points around the island. If sufficient storage tanks are built, water developed from the colluvial talus deposits with horizontal wells could be available during drought conditions.

SUMMARY AND CONCLUSIONS

Lenger is a small (less than 0.2 square miles) volcanic island located within the lagoon of Pohnpei. Ground water on Lenger occurs as shallow subsurface flow through weathered bedrock slopes and low-lying areas near the coast before discharging into the surrounding lagoon. The limited land mass and low-permeability bedrock of Lenger are not favorable to the formation of well-defined drainage basins or a large basal ground-water body.

Numerous springs and seeps discharge shallow subsurface flow at the contact between water-bearing weathered bedrock and underlying less-permeable bedrock. Because the storage of water in the shallow subsurface ground-water bodies is limited, the flow at most of the springs and seeps is directly related to rainfall. Barbosa Pond, the largest surface-water body on Lenger, contains 162,000 gallons of water. On June 20, 1991, springflow into the pond increased from 0.6 gallons per minute during base-flow conditions to 21 gallons per minute during a 4 hour period of rain that totaled 0.062 feet. The water from Barbosa Pond contains iron and manganese in concentrations that may cause problems in a water-supply system.

Small-scale development of ground water is possible from colluvial talus deposits that flank the base of Mosher hill. The source of water in these deposits is seeps and springs that have low base flows and slightly larger flows during rainfall. The yield of water from the colluvial talus deposits can fluctuate greatly between periods of rain and drought. However, additional quantities of water can be obtained from these deposits by simply widening or deepening the capture area of wells used to develop these deposits. If sufficient storage facilities are built, water from these deposits would be available during drought conditions.

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