THE 1983 DROUGHT IN THE WESTERN PACIFIC

By Otto van der Brug

U.S. GEOLOGICAL SURVEY

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CONVERSION TABLE

The following table may be used to convert measurements in the inch-pound system to the International System of Units (SI).

Multiply	By	To obtain
Length		
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile, statute (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m^2)
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
acre-foot (acre-ft)	1,233	cubic meter (m^3)
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
Volume Per Unit Time (includes Flow)		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	cubic decimeter per second (dm^3/s)
gallon per day (gal/d)	90.85	cubic decimeter per second (dm^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
Miscellaneous		
micromho per centimeter at 25° Celsius (µmho/cm at 25°C).	1.000	microsiemens per centimeter at 25° Celsius (µS/cm at 25°C).

DEFINITION OF TERMS

Cubic foot per second (ft^3/s) is the rate of discharge representing a volume of one cubic foot passing a given point during one second and is equivalent to 7.48 gallons per second or 448.8 gallons per minute.

Discharge is the volume of water that passes a given point within a given period of time.

Mean discharge (mean) is the arithmetic average of individual daily mean discharges during a specified period.

Instantaneous discharge is the discharge at a particular instant of time. If this discharge is reported instead of the daily mean, the heading of the discharge column in the table is "Discharge".

Dissolved is that material in a representative water sample which passes through a 0.45-µm membrane filter.

Drainage area of a stream at a specific location is that area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream above the specified point.

Gaging station is a particular site on a stream where systematic observations of hydrologic data are obtained.

Hardness of water is a physical-chemical characteristic that is commonly recognized by the increased quantity of soap required to produce lather, due to the presence of alkaline earths (principally calcium and magnesium) and is expressed as equivalent calcium carbonate ($CaCO_3$).

Milligrams per liter (mg/L) is a unit expressing the concentration of chemical constituents in solution as mass (milligrams) of solute per unit volume (liter) of water.

Partial-record station is a particular site where limited streamflow and/or water-quality data are collected systematically over a period of years for use in hydrologic analyses.

Recurrence interval is the average interval of time within which an event will be equaled or exceeded once.

Specific conductance is a measure of the ability of water to conduct an electrical current. It is expressed in micromhos per centimeter at 25°C. Specific conductance is related to the type and concentration of ions in solution and can be used for approximating the dissolved-solids content of the water. Commonly, the concentration of dissolved solids (in milligrams per liter) is about 65 percent of the specific conductance (in micromhos). This relation is not constant from stream to stream, and it may vary in the same source with changes in the composition of the water.

Streamflow is the discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" as streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

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ABSTRACT

A severe drought, from late 1982 until mid-1983, on many islands in the Western Pacific Ocean is attributed to the El Niño effect, a change in oceanic circulation that is typically associated with the Eastern South Pacific Ocean. Because of a lessening of the trade winds, warm Western Pacific seawater flowed abnormally to the west coast of the Americas, inducing an El Niño effect that was possibly the strongest in 100 years. Of the values for total monthly rainfall recorded January through May 1983 at long-term rainfall stations in the Western Pacific, half were the lowest of record. West of longitude 155° E., total rainfall for the five-month period was 28 percent of normal; east of this longitude, 13 percent of normal. In islands of the Caroline and the Marshall groups, recurrence interval of the drought is estimated at 125 years for Koror (Palau Islands), Yap Island, and Majuro (Marshall Islands); and at 250 years for Pohnpei and Kosrae. For most streams in the Caroline Islands, average monthly streamflow for January through May 1983 was the lowest of record each month. On Pohnpei, the streamflow for January through May was 4 to 7 percent of normal; on Moen (Truk Islands), 8 percent; on Kosrae for January through April, 3 to 7 percent of normal. On Moen, the average chloride concentration of ground water (the main source of water for the island) increased from 78 milligrams per liter on February 10 to 410 milligrams per liter on April 20, 1983. On Saipan, chloride concentration increased by a third, to a value of 878 milligrams per liter.

Water-conservation measures were imposed on islands affected by the drought. On Guam, conservation was voluntary; on Majuro, water was available for only one hour every third day; and on Jaluit Atoll (Marshall Islands), one gallon per person per day was allowed. Losses of staple food crops (taro, coconut, and breadfruit) were severe, especially on Pohnpei, Kosrae, and in the Marshall Islands. At least half the population of the Caroline and Marshall Islands received U.S. Department of Agriculture food supplements.

INTRODUCTION

Severe droughts or floods occurred at many places worldwide in 1982-83. In Australia, drought in the fall of 1982 was possibly the most severe in 200 years (Science News, 1983). In islands of the Western Pacific, rainfall for the first four to six months of 1983 was the lowest recorded of the past 80 years. The recurrence intervals for low streamflows on islands of the Western Pacific could not be determined accurately because gaging-station records were too short, but flows at many stations were the lowest in 10 to 15 years of record. Available flow-frequency curves (Van der Brug, 1983a-b; 1984a-c; 1985) were extended to 25 years and indicate low-flow recurrence intervals much greater than 25 years. By contrast, severe floods and rainstorms caused much property damage in California and along the coast of South America.

These droughts and floods are attributed to a temporary change in oceanic circulation, called El Niño (The Child) because it commonly occurs off the coast of Peru near Christmas. Technically, the term El Niño is applied only when the effect reaches catastrophic proportions (Wyrtki, 1979). It is attributed to a decrease or cessation of the easterly trade winds, which normally blow across the Pacific and cause a build-up of water in the Western Pacific. The easterly winds are replaced by westerly winds, which move warm water to the South American coast. In 1982, El Niño arrived in mid-year and lasted for more than 12 months. Sea-surface temperatures rose 2°C per month near Peru through the last third of 1982 (Cane, 1983), probably the most rapid rise in 100 years. Total property damage attributed to this intensive El Niño is estimated at 8.7 billion dollars, and loss of life, at 1,100 persons (National Geographic, 1984).

Factors that contributed to the intensity of the 1982 to 1983 El Niño remain uncertain. A major factor may have been dust thrown into the atmosphere from the 1982 eruption of El Chichon volcano in Mexico (Mitchell, 1982). This dust may have caused warming of the upper atmosphere over the Pacific, thus influencing the trade wind patterns.

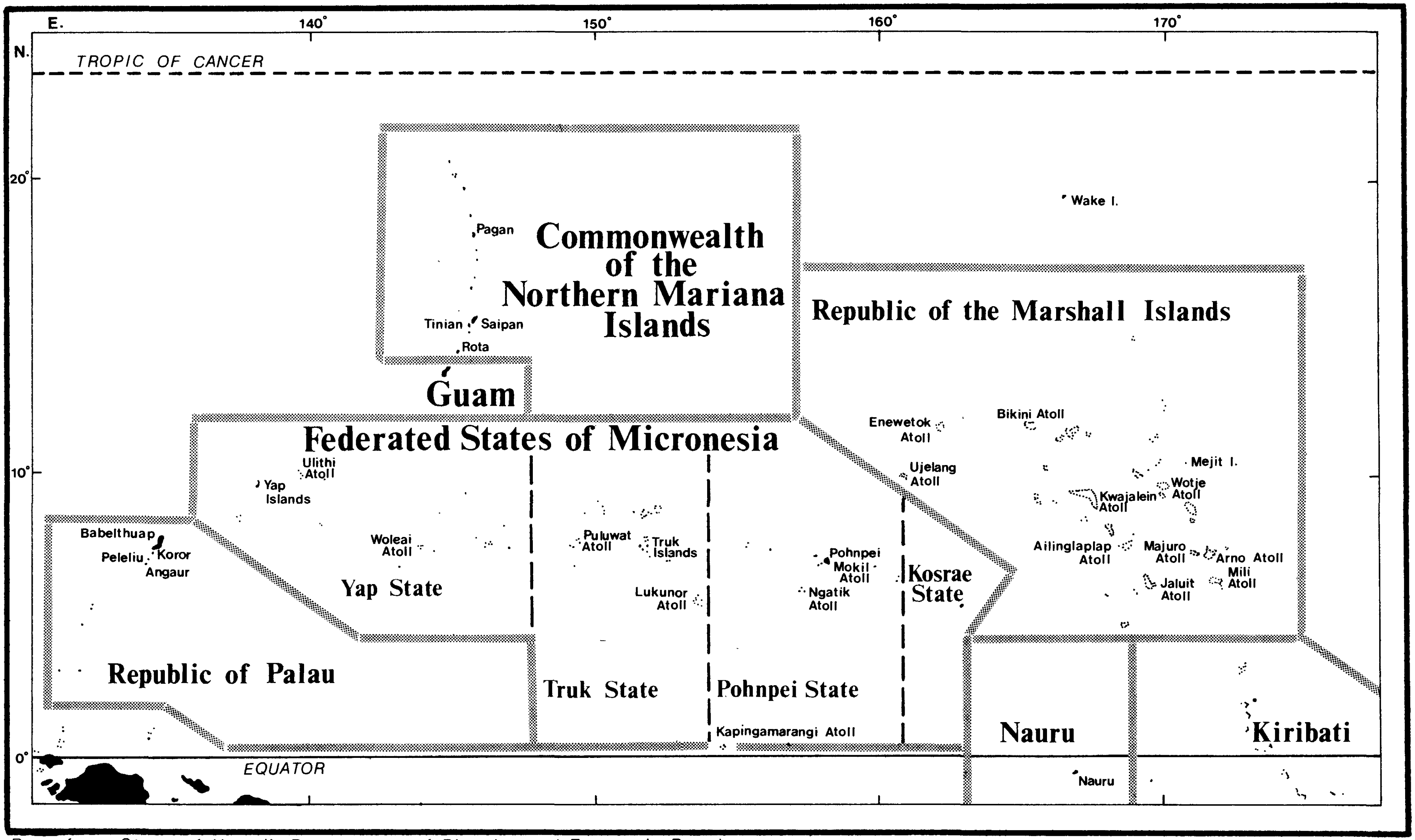
The purpose of this report is to document the severity of the drought, its effect on water resources, and its impact on people of island groups in the Western Pacific: the Mariana Islands, the Caroline Islands, and the Marshall Islands. Major islands in each group are treated separately. Rainfall recorded during the drought is compared with long-term records; and streamflow deficiencies are documented, as are the lowering of ground-water levels, the depletion of ground-water storage, and the effects of the drought on food crops. For several of the islands, hydrologic conditions before the drought have been described by Van der Brug (1983a,b; 1984a,b,c; 1985).

These island groups lie in latitude between the equator and the Tropic of Cancer (23°30'N.); in longitude, between 130°E. and 180°E. (fig. 1). Political entities of the island groups are the Commonwealth of the Northern Mariana Islands; the Federated States of Micronesia; the Republics of Palau and of the Marshall Islands (all formerly in the U.S. Trust Territory of the Pacific Islands); and the Island of Guam (a U.S. Territory).

Of the more than 2,000 islands in these groups, fewer than 100 are inhabited. The islands range in area from less than 100 ft^2 to 212 mi^2 (Guam). In relief they range from low coral islets, almost inundated at high tide, to mountainous Pohnpei, which has peaks above 2,000 feet. Almost half of the total population (250,000) of the islands is on Guam. Except for commercial production of copra, mainly on some of the smaller islands, agriculture is mostly subsistence farming.

Mean annual rainfall tends to be high on most islands of the Western Pacific, ranging from 80 inches in the Northern Mariana Islands to 200 inches on Pohnpei and Kosrae. During the drought, rainfall for January through June 1983 was about 28 percent of normal in the Mariana Islands, and for January through May 1983 also about 28 percent of normal on Yap, Koror (Palau), and Moen (Truk), all west of longitude 155°E. For the same period, January through May, rainfall was about 13 percent of normal on Pohnpei, Kosrae, and the Marshall Islands, all east of longitude 155°E. (table 1).

Although rainfall was deficient on most islands in the Western Pacific during the last quarter of 1982, the effects of the drought began to be felt mainly in January 1983, to different degrees on different islands. Where ground water was used for public supply, the effects were less than where surface water was used. Inhabitants on islands having annual dry periods adjusted more readily to the drought than those on islands without periodic dry periods. The most severe effects were felt on islands where surface water is normally abundant and is relied upon almost entirely, as on Palau, Pohnpei, and Kosrae; or where rain catchments are used, as on Majuro.



Base from State of Hawaii, Department of Planning and Economic Development, Geography and Map Division, Bernice P. Bishop Museum and the Pacific Basin Development Council

Figure 1. The Western Pacific Islands.

All streamflow data, much of the ground water information, and some of the rainfall records used in this report were collected by the U.S. Geological Survey as part of cooperative programs with governments of the Commonwealth of the Northern Mariana Islands, of Guam, of the Republic of Palau, and of the Federated States of Micronesia. This report was prepared as an extension of the programs.

Table 1. Rainfall during the 1983 drought in inches and in percentage of normal

[Rainfall totals for 1983 from U.S. Geological Survey stations (Saipan, Kosrae) and National Weather Service stations]

	Years of record	Annual rainfall	January		February		March		April		May		June		Jan.-May		Jan.-June	
			Rainfall	Percent	Rainfall	Percent	Rainfall	Percent	Rainfall	Percent	Rainfall	Percent	Rainfall	Percent	Rainfall	Percent	Rainfall	Percent
Saipan 1/	51-56	81	0.86	22	0.90	27	1.62	50	1.14	36	0.91	26	0.53	11	--	--	5.96	27
Guam	26	102	1.31*	23	1.21	25	3.34	75	1.83	41	1.10	15	.80*	13	--	--	9.59	29
Koror, Palau Islands	57-58	148	3.44	30	.64*	8	1.71*	21	3.12	34	5.73	42	--	--	14.64	29	--	--
Yap, Yap Islands	73-75	122	1.25*	17	.27*	5	2.76	48	1.36	23	3.59	38	--	--	9.23	27	--	--
Moen, Truk Islands	33	144	5.16	62	.56*	9	1.95*	22	3.28*	27	3.80*	25	--	--	14.75	29	--	--
Pohnpei (Kolonia)	57-59	191	1.89*	16	1.72	17	1.52*	11	2.03*	11	2.21*	11	--	--	9.37	13	--	--
Kosrae (Lelu)	27-32	201	1.74*	12	1.32*	8	1.02*	5	4.43*	20	--	--	--	--	--	12 2/	--	--
Majuro	28	136	.83	11	.98	15	.66*	7	1.97*	17	1.49*	12	--	--	5.93	13	--	--
Kwajalein	38	103	.89	21	.68	25	.36	7	.20*	3	1.76	17	--	--	3.89	13	--	--

1/ Rainfall at 9-Mgal (million gallons) reservoir is compared to longer-term rainfall on the west coast (at several locations).

2/ January to April only; May rainfall figures are incomplete.

* New minimum rainfall for the period of record.

Note: Average monthly rainfall figures are given in the rainfall tables of each island.

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Republic of Palau

Koichi Wong, Minister of National Resources

Marcelino Melarei, Director of Public Works

Herman Francisco, Chief Agriculturist

Tokiwo Sumang, Area Sanitarian and Environmental Health Coordinator

Federated States of Micronesia

Ehson D. Johnson, Disaster Control Officer, Federated States of Micronesia

Yap State

Eusebio Taleng, Director Utilities and Contracts

Clayton Anderson, State Agriculturist

Joe Xavier, Safe drinking water specialist

Gabriel Flalay, Pollution control specialist

Felix Yinuk, Assistant Manager State Telecommunications

Truk State

Charles D. Boddy, Director of Public Works

David Ivra, State Agriculturist

Ermes Siales, Community Development Officer

George Ifenuk, Laboratory Technician Public Works

Pohnpei State

Bermin F. Weilbacher, Director Department of Community Services

Rogerlio R. Vega, State Agriculturist

Kurt W. Kushner, Community Planner, Community Action Agency

Kosrae State

Moses Mackwelung, Lt. Governor

Nena Palsis, Director of Environmental Health

Critin Philip, State Agriculturist

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Phillip Kabua, Deputy Chief Secretary

James A. Abernathy, Special Projects Coordinator

Michael Capelle, Secretary, and Bernard Reiher, Operations and Maintenance Superintendent, Ministery of Public Works

Bryant S. Zebedy, Administrative Officer, and Lomodro Jonathan, Statistics Specialist, Ministery of Resources and Development

Bujen Jacob, Chief Environmental Health and Sanitation, and Harvey Milong, Safe Drinking Water Specialist

NORTHERN MARIANA ISLANDS

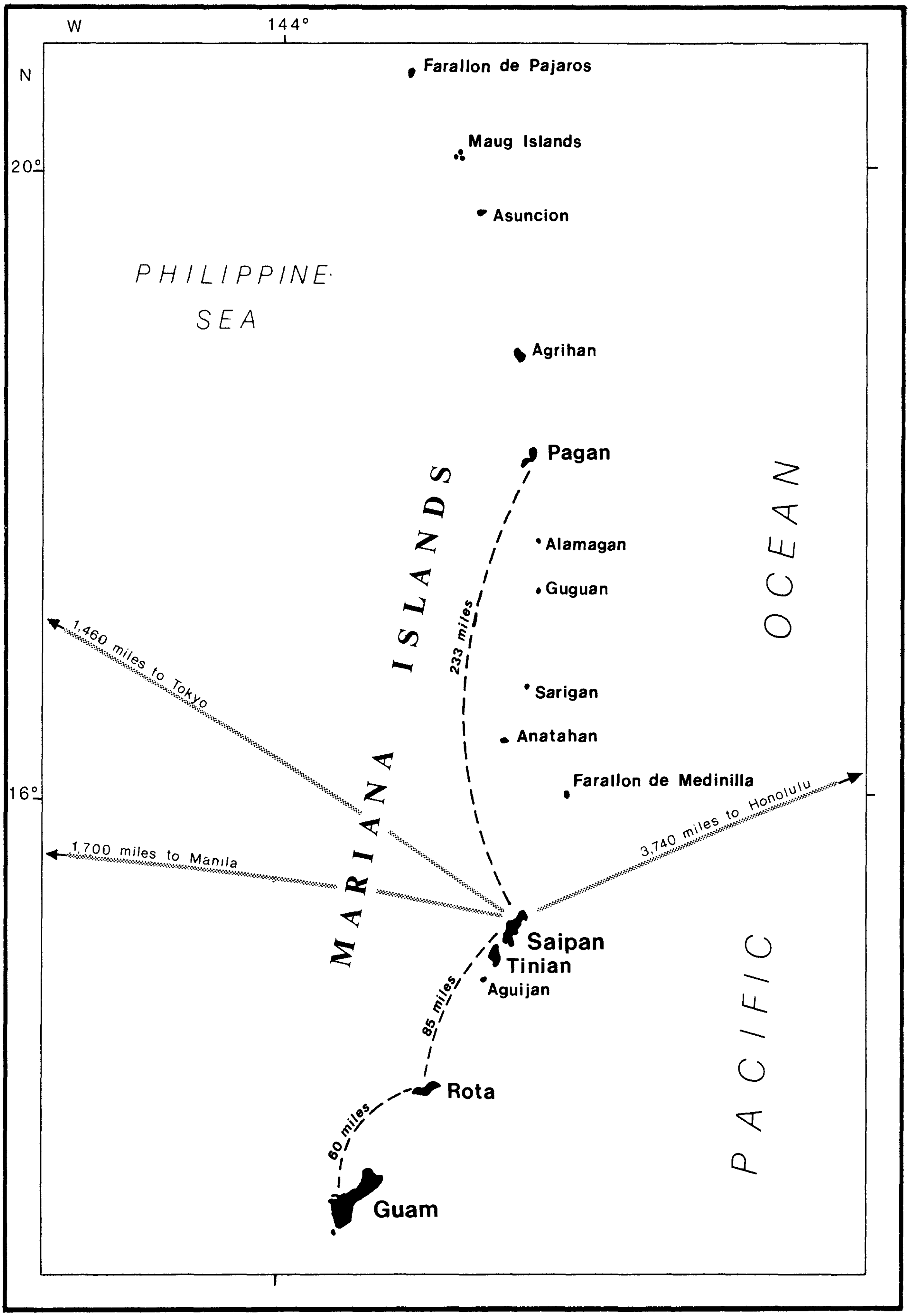
Physical and Cultural Setting

The Northern Mariana Islands are a chain of 14 islands north of Guam (fig. 2). The three main islands (Saipan, Tinian, and Rota) comprise about three fourths of the total land area and support practically the entire population. Saipan is the center of population, commerce, and education and the seat of government. It is 1,460 statute miles south-southeast of Tokyo, 1,700 statute miles east of Manila, and 3,740 statute miles west of Honolulu. Geologically, it consists of limestone overlying an old volcanic core. Because of the porosity of the limestone, there are few streams on Saipan.

Tinian has a land area of 41 mi^2 and is located a few miles south-southwest of Saipan. The island is composed of coralline limestone on a volcanic foundation and rainwater percolates rapidly into the porous rock. Rota has a land area of 33 mi^2 and is located between Tinian and Guam. Most of the island consists of coralline limestone covering volcanic rocks, which crop out locally.

The population of the Northern Mariana Islands exceeds 15,000, most of which is on Saipan in the towns along the west coast. On Rota, almost the entire population (about 1,300) is in the town of Songsong. On Tinian, the majority of the 900 people live in the town of San Jose.

Employment on Saipan is provided by the government, the tourist industry, or local small businesses. A limited amount of farming is done, usually for family subsistence. The principal sources of income on Tinian are from cattle and small farms. On Rota, produce is grown for markets on Guam and Saipan.



Note: Distances are in statute miles (one statute mile is 0.868 nautical mile).

Figure 2. The Mariana Islands.

Rainfall

The two seasons in the Northern Mariana Islands are defined by the amount of rainfall. The dry season usually is from January through May and the rainy season, from July through November.

Only Saipan has long-term rainfall records. To obtain long-term monthly and annual mean rainfall, records at Garapan for 1901-12 (during the German administration) and for 1927-42 (during the Japanese administration) were combined with the rainfall data collected by the U.S. Navy (1954-63), U.S. Coast Guard (1963-76) and the U.S. Geological Survey (1977-82, at the 9-Mgal reservoir). All these rainfall data were collected near the west coast of the island. Comparison of rainfall data collected at different locations along the west coast has shown little variation in monthly totals.

During 1983, rainfall data were collected on Saipan at the 9-Mgal reservoir on the west coast, at Isley Field near the southern coast, and on the Hakmang peninsula on the east coast (fig. 3). Table 2 compares these data with the long-term west-coast means for the first 7 months of the calendar year. No recent rainfall data are available for Tinian and Rota.

Rainfall on Saipan was deficient each month from November 1982 through September 1983 and less than half the normal rainfall was recorded for the period. For January through June 1983, rainfall was 27 percent of the long-term average for those months.

Streamflow

Streamflow has been measured on Saipan by the U.S. Geological Survey from 1968 to the present. Springflow at Denni Spring was measured for 1952 to 1954 and from 1969 to the present (U.S. Geological Survey, 1971-82; 1977). For 1983, a continuous record is available for South Fork Talufofo Stream and Denni Spring. A comparison of average monthly discharges January through July 1969 to 1982 with discharges for the same months in 1983 (table 3) indicates that springflow declined to 69 percent of normal and streamflow to 13 percent of normal.

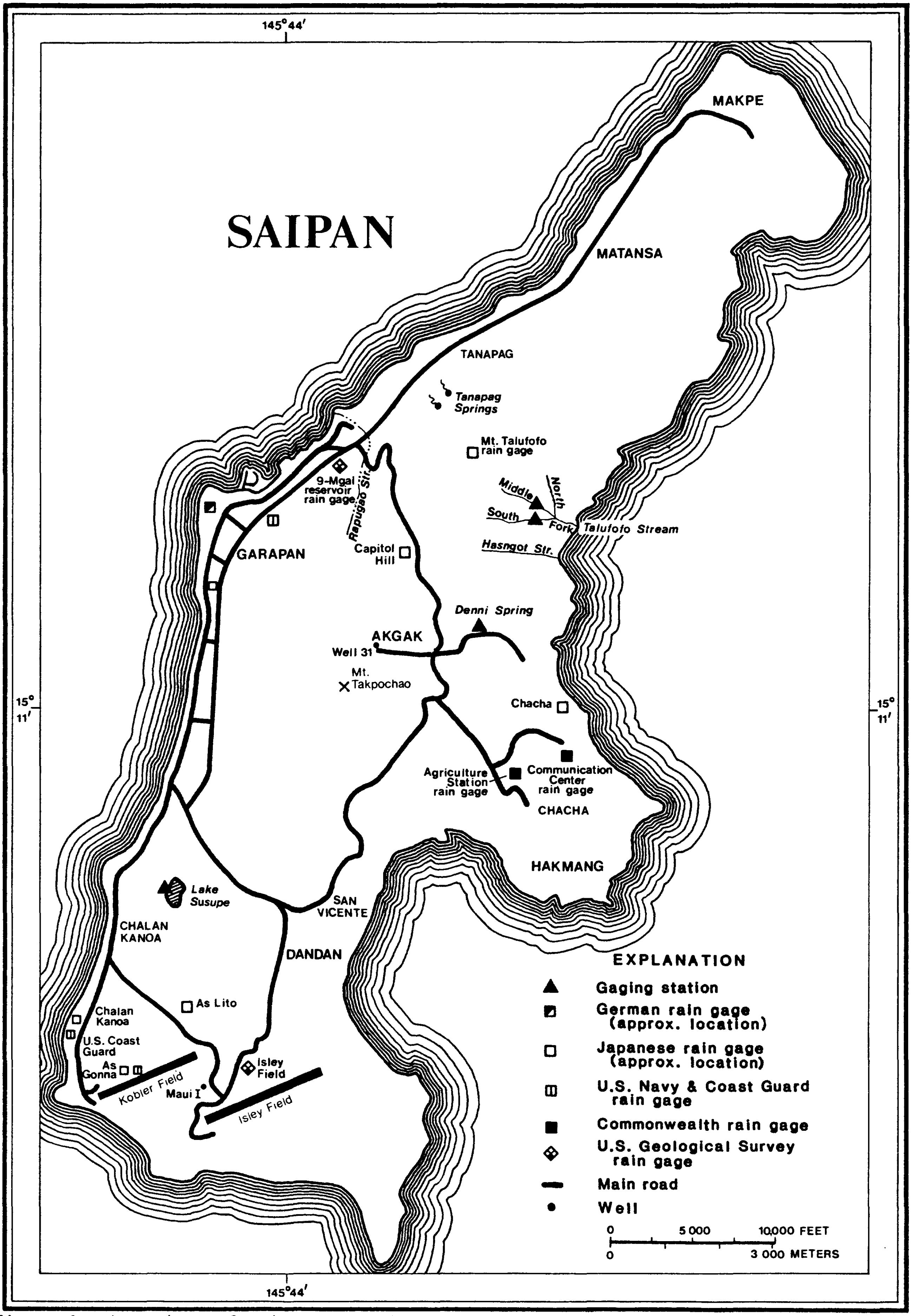


Figure 3. Locations of rain gages and water-resources data collection sites on Saipan.

Table 2. Monthly January through July rainfall, in inches, for Saipan

[USGS, U.S. Geological Survey; NWS, National Weather Service; CNMI, Commonwealth of the Northern Mariana Islands]

	Jan.	Feb.	Mar.	Apr.	May	June	Total of Jan.-June	July	Total of Jan.-July
West coast (1901-82)*:									
Number of years	55	55	56	55	51	53	--	52	--
Mean	3.97	3.37	3.27	3.19	3.53	4.96	22.29	9.45	31.74
Minimum monthly	.31	.77	.35	.59	.74	1.63	--	1.54	--
Year of minimum	1978	1936	1978	1912	1967, 1977.	1973	--	1957	--
9-Mgal reservoir:									
1983 rainfall	.86	.90	1.62	1.14	.91	.53	5.96	2.79	8.75
Percent of mean	22	27	50	36	26	11	27	30	28
Departure from mean.	-3.11	-2.47	-1.65	-2.05	-2.62	-4.43	-16.33	-6.66	-22.99
Other 1983 rainfall:									
Isley Field (USGS)	1.28	1.15	1.57	.82	1.15	.23	6.20	1.80	8.00
Communication Center, Hakmang (NWS).	3.06	1.91	1.43	1.94	1.17	1.32	10.83	3.29	14.12
Agriculture Station, Hakmang (CNMI).	2.20	2.14	1.90	1.85	1.27	1.61	10.97	2.57	13.54

* Compiled from the following sources: "Mitt(h)eilungen von Forschungreisenden and Gelehrten ans den deutschen Schutzgebieten" 1903-13; Taylor, 1973; U.S. Weather Bureau, 1954-55, 1956-69; U.S. National Oceanic and Atmospheric Administration, 1970-76; U.S. Geological Survey data.

Table 3. Mean monthly discharges, January through July, at gaging stations on Saipan

[Discharge in cubic feet per second and in percentage]

Station number	16800000				16801000			
Station name	Denni Spring				South Fork Talufofo Stream			
Drainage area	--				0.69 mi^2			
Years of record	13-14				14			
	1969-82		1983		1969-82		1983	
	Average of monthly means	Lowest monthly mean	Mean	1/ Percent	Average of monthly means	2/ Lowest monthly mean	Mean	1/ Percent
January	0.57	0.20	0.44	77	0.53	0.12	0.14	26
February	.49	.18	.29	59	.43	.075	.084	20
March	.41	.12	.25	61	.29	.057	.064	22
April	.33	.10	.24	73	.17	.049	.043*	25
May	.34	.094	.16	47	.55	.035	.026*	4.7
June	.25	.069	.12	48	.12	.033	.022*	18
July	.34	.055	.11	32	1.08	.028	.016*	1.5
January to July.	.39	--	.27	69	.45	--	.057	13
Annual	.64	--	--	--	--	--	--	--

1/ Percentage of 1969-82 mean for the month.

2/ Low-flow records prior to May 31, 1971, collected at a downstream site, not included due to undetermined amount of underflow between sites.

* New minimum mean discharge.

Effects of Drought on Water Supply

In the Mariana Islands, except on Rota, the water supply is mostly from ground water. On Rota, water for Songsong comes from nearby Lupug Spring, a large high-level spring. The population of Saipan is served by a central water system that is supplied by water from wells and from Denni and Tanapag Springs. On Tinian, all water is obtained from wells. The Marianas have a dry season each year; therefore people are at least partially prepared to cope with dry conditions. The consequences of the 1983 drought on Saipan were small in comparison to those on other islands in the Western Pacific.

On Saipan, ground water is obtained mostly from a limestone aquifer which contains a basal lens of freshwater floating on saltwater near sea level. Most of the wells on Saipan are sited to obtain water from this lens without drawing in ocean water. The height of the water table in the basal lens is less than 2 feet above sea level (Mink, 1977) and the freshwater is easily contaminated with sea water.

During 1982, water in the distribution system was available at all hours in contrast to the previous practice of providing water only during the hours of greatest demand. This was achieved by drilling many new wells. Pumpage of ground water peaked in August 1982, when 3.9 Mgal a day were produced. The weighted average of chloride concentration in the water was about 700 mg/L; by mixing with spring water, the concentration was reduced to 600 mg/L, the maximum permissible by World Health Organization (1971) standards.

During the 1983 drought, water service could not be maintained on a 24-hour basis in the northern half of the island except where users were connected directly to the transmission lines. The reduction in water service was necessary to limit the loss of water; an estimated two-thirds of the water put into the system is lost through leakage and waste.

During the first six months of 1983, the pumpage of ground water dropped only by 15 to 20 percent. The result of the continued high draft was a sharp increase in chloride concentration in most wells tapping the basal lens of the island. At Isley Field the average chloride concentration of the water increased by 32 percent (to 327 mg/L) between Nov. 18, 1982 and June 30, 1983 (Van der Brug, 1985). At the adjacent Kobler well field, the average chloride concentration increased from 510 mg/L to more than 1,000 mg/L. The chloride concentration of water from most wells on the western side of the island increased by as much as 200 percent, to more than 1,000 mg/L; in three wells it increased to over 3,000 mg/L.

Wells at Akgak tap perched ground water with low chloride concentrations. Because of the high chloride content in most low altitude wells, the Akgak wells were pumped extensively. Soon, two of the pumps in the well field had to be turned off because of low water levels. A continuous record of water level for well 31 shows that the water level on Aug. 31, 1983 was 4.24 feet lower than on Aug. 31, 1982 and at the end of October 1983, the water level was 16.5 feet lower than in October of the previous year. The half foot decline in water levels from August to October 1983 was unusual because water levels generally rise in September and October, which are the wettest months of the year.

The largest producing well on Saipan has been Maui I, a shaft with infiltration tunnels. This well, constructed in 1945, has produced as much as 1 Mgal/d (million gallons per day) and averaged 1/2 Mgal/d until mid 1982. At that time, the water level in the tunnels began to decline and the well dried up in January 1983. At the height of the dry season in June 1983, the water level increased and limited pumping could resume. At the same time, wells on Tinian which had been dry, regained sufficient water to allow them to be pumped again.

The decline and subsequent increase in ground-water levels coincides with the start and the end of El Niño. In January 1983, ocean levels in the Western Pacific had declined by an average of 20 centimeters (2/3 ft) below normal at the equator (Wyrtki, 1984). After May 1983, the trade winds along the equator started to return and ocean levels returned slowly to normal. The tide gage of the U.S. Coast and Geodetic Survey at Apra Harbor on Guam registered a sea level of -1.0 foot from December 1982 to February 1983 and a gradual one-foot rise between February and July 1983.

Effects of Drought on Agriculture

Because farming on Saipan is mostly subsistence, losses of income due to the drought were not significant. On Rota, the growing of produce was not affected much because irrigation was done with spring water. Some loss of cattle on Rota were attributed to the drought. On Tinian, beef production decreased by 11 percent (Santos, G. R., Department of Natural Resources, oral commun., 1983).

GUAM

Geographic Setting

Guam, the largest island in the Western Pacific, has a land area of 212 mi^2. It is 30 miles long, and its width is about 8.5 miles in the north, 4 miles in the center, and 11.5 miles in the south. The population, largest of any Western Pacific island, exceeds 100,000; of these, half are native Chamorros and the others are either immigrants, U.S. military personnel, or transient residents from the United States. Most of the population is on the central part of the west coast.

Rainfall

Guam has two distinct seasons: July to November is rainy and January to May is dry. Rainfall records, mostly during short periods of time, have been obtained at more than 50 localities since 1906. The longest continuous periods of record (fig. 4) are for the U.S. Geological Survey rain gage at Umatac in southwest Guam (1950 to present) and for the National Weather Service station in northwest Guam (1957 to present). A comparison of monthly rainfall, January through June 1983, with long-term rainfall (table 4) indicates that rainfall during the first 6 months of 1983 was 29 percent of normal at the National Weather Service station.

Streamflow

Since 1950, the U.S. Geological Survey has collected streamflow data for most streams on Guam. In 1983, eight continuous-record stations were in operation. A recorder on the Fena Valley Reservoir recorded the water level of the reservoir, and the other seven stations recorded streamflow levels (table 5).

Although rainfall during the first 6 months of 1983 was the lowest on record, streamflow did not recede to the low levels of 1965 to 1966. The lowest mean monthly discharge of record for each month from November through May occurred in 1965 to 1966 because rainfall had been deficient during most of 1965. For January through July 1983, the discharges of two streams on Guam are compared with long-term mean discharges in table 6.

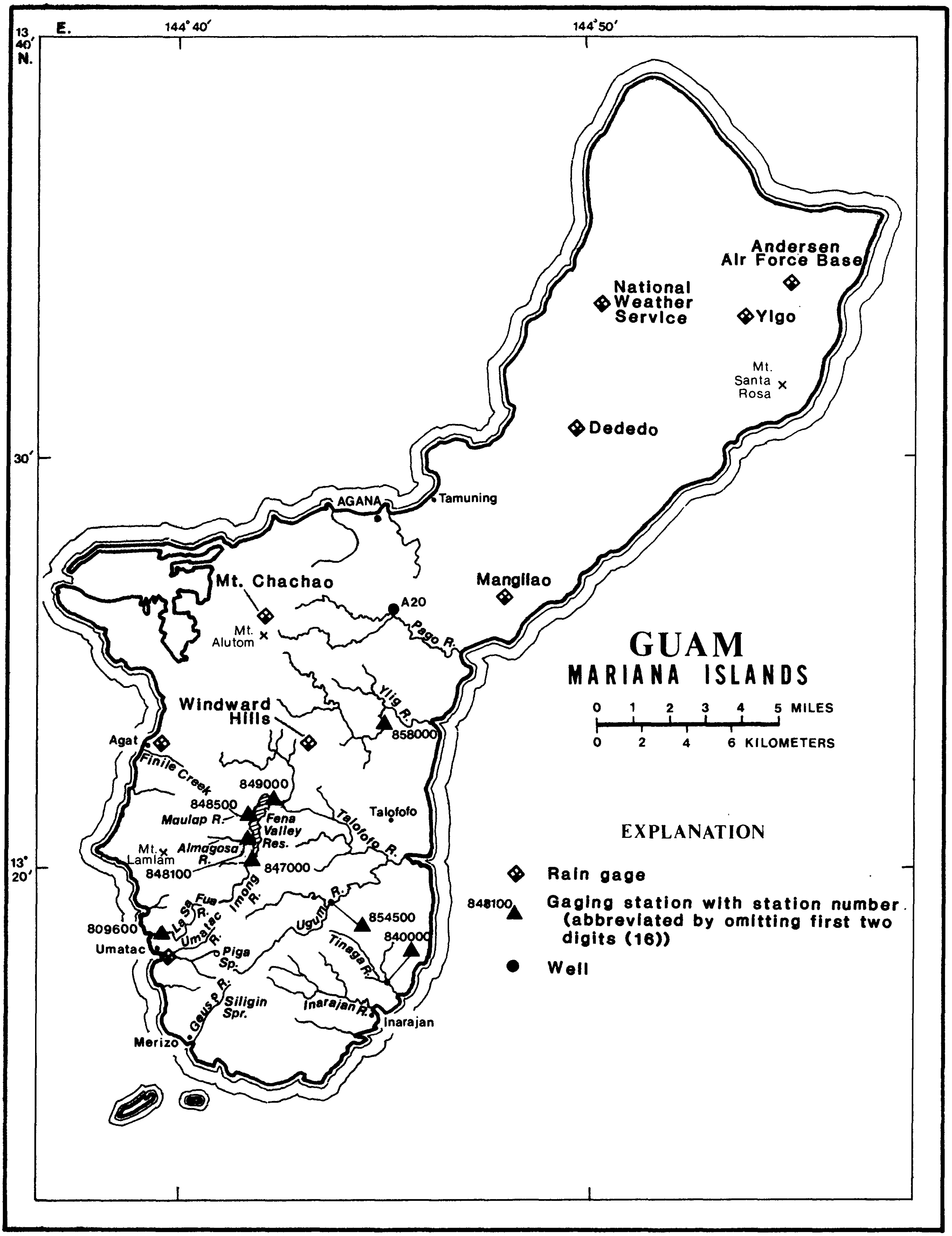


Figure 4. Locations of rain gages, gaging stations, and Well A20 on Guam.

Table 4. Monthly January through June rainfall, in inches, for Guam

[USGS, U.S. Geological Survey continuous-record rain gage; all other rainfall data from U.S. National Oceanic and Atmospheric Administration, 1957-72, 1973-83]

	Jan.	Feb.	Mar.	Apr.	May	June	Total
National Weather Service Station							
1957-82 (26 years):							
Mean	5.80	4.75	4.46	4.48	7.27	6.28	33.04
Percent of annual mean	5.7	4.6	4.4	4.4	7.1	6.1	32.3
Minimum monthly	1.99	.67	.59	.50	.90	1.52	--
Year of minimum	1964	1960	1965	1965	1959	1969	--
1983:							
Rainfall	1.31*	1.21	3.34	1.83	1.10	.80*	9.59
Percent of mean	23	25	75	41	15	13	29
Departure from mean	-4.49	-3.54	-1.12	-2.65	-6.17	-5.48	-23.45
Umatac (USGS)							
1950-82:							
Number of years	30	30	28	25	28	30	--
Mean	4.89	4.19	3.41	3.43	5.55	6.26	27.73
Minimum monthly	.90	.43	.17	.23	.61	.99	--
Year of minimum	1966	1972	1978	1950	1975	1975	--
1983:							
Rainfall	1.69	1.79	4.70	.51	2.54	1.35	12.58
Percent of mean	35	43	138	15	46	22	45
Departure from mean	-3.20	-2.40	+1.29	-2.92	-3.01	-4.91	-15.15
Other 1983 rainfall:							
Andersen Air Force Base	1.08	1.40	3.69	2.02	1.92	.55	10.66
Yigo	1.15	1.73	4.13	2.24	.92	1.93	12.10
Dededo	1.59	1.83	4.75	--	1.67	.53	--
Mangilao	.96	.74	2.75	.79	2.21	.67	8.12
Windward Hills (USGS).	.95	.53	2.30	.76	1.25	.45	6.24
Agat	--	1.14	2.65	1.50	1.92	1.59	--
Inarajan Ag. Station	.54	1.58	1.20	.46	3.81	--	--

* New minimum monthly total.

Table 5. Lowest discharge, in cubic feet per second, of rivers on Guam

Station number	Station name	Drainage area (mi^2)	Years of record	Lowest instantaneous discharge Prior to 1983	In 1983
16809600	La Sa Fua River near Umatac.	1.06	12	0.12 (1979)	0.16 (July 1)
16840000	Tinaga River near Inarajan.	1.89	30	.15 (1966, 1973)	1/ .36 (June 26-30)
16847000	Imong River near Agat.	1.95	21	.37 (1966)	1.2 (July 16, 17)
16848100	Almagosa River near Agat.	1.32	10	.13 (1979)	.15 (June 26 to July 1, July 7, 8).
16848500	Maulap River near Agat.	1.15	10	.33 (1975)	.31 (June 28 to July 1).
16854500	Ugum River above Talofofo Falls, near Talofofo.	5.76	5	3.4 (1979)	3.5 (June 29 to July 1).
16858000	Ylig River near Yona.	6.48	30	.07 (1973)	.10 (June 29 to July 1).

1/ Minimum daily.

Table 6. Mean monthly discharges, January through July, of two rivers on Guam prior to 1983 and in 1983

[Discharge in cubic feet per second]

Station number ---	16847000			16858000		
Station name -----	Imong River near Agat			Ylig River near Yona		
Drainage area ----	1.95 mi^2			6.48 mi^2		
Years of record --	21			30		
	1961-70, 1972-82		1983	1953-82		1983
	Average of monthly means	Lowest mean	Mean	Average of monthly means	Lowest mean	Mean
January	5.34	2.10	3.60	16.6	2.63	5.20
February	6.23	1.62	3.01	13.9	1.33	2.62
March	4.03	1.39	2.93	7.6	.71	2.07
April	3.89	1.00	2.20	7.0	.36	.83
May	5.52	.59	1.93	15.8	.15	.48
June	4.81	1.00	1.60	10.9	.38	.23*
July	8.70	1.71	2.48	29.2	.73	1.91
January to July.	6.45	--	2.97	14.5	--	2.24
Annual	10.3	--	--	28.7	--	--

* New minimum mean discharge.

Effects of Drought on Water Supply

Areas under civilian control, except for the towns of Umatac and Merizo, are served by a central water system, which receives most of the water from about 75 wells. With few exceptions, these wells tap the basal ground-water lens of the northern part of the island. A few wells in the center of the island take parabasal water from an aquifer not influenced by ocean water; at well A-20 (a U.S. Geological Survey recording well) the water level during the 1983 dry season was the lowest of record. Normally some water from the Ylig River is used to supplement the well water of the central water system, but this was halted during the drought because of low flow. Water from Piga and Siligin Springs and from La Sa Fua River is used in Umatac and Merizo. During the drought, a severe water shortage occurred in this area because of the low yield of springs and streams.

The 1983 drought had little immediate effect on the quality and the quantity of the ground water pumped. Chloride concentrations of the water, the most important limiting factor in the use of water from a basal lens, changed little during the drought. The amount of water pumped remained at about 30 Mgal/d.

Of all the islands in the Western Pacific, Guam was the least affected by the drought. The areas served by the central water system were subjected to only voluntary restrictions on water use. Navy installations receive water from the Fena Valley reservoir, which is in a military reservation. The reservoir provides about 9 Mgal daily. On August 4, 1983, the reservoir level dropped to a record low of 21.86 feet below the spillway. The previous low was 21.36 feet on Aug. 14, 1977. Users of Fena Valley Reservoir water were under strict water conservation measures imposed by the U.S. Navy at the beginning of 1983. For the first time since Fena Dam was constructed in 1950, the reservoir failed to fill during the next rainy season.

PALAU ISLANDS

Physical and Cultural Setting

The Palau Islands are a chain of about 350 islands, stretching for a distance of nearly 100 miles between latitude $6^\circ53'$ N. and $8^\circ12'$ N., and longitude $134^\circ07'$ E. and $134^\circ39'$ E. In size they range from very small islets to Babelthuap, the second largest island in the Western Pacific (fig. 5). Babelthuap, near the northern end of the chain, has an area of 153 mi^2, more than 80 percent of the total land area of the Palau Islands. Directly south of Babelthuap lies Koror (3.6 mi^2 in area), the center of administration, commerce and population; and the smaller islands of Ngerekebesang (0.9 mi^2 in area) and Malakal (0.3 mi^2 in area). The remaining inhabited islands, farther to the south, are Peleliu (4.5 mi^2 in area) and Angaur (3.2 mi^2 in area), where phosphate is mined. Between Babelthuap and Peleliu lie several hundred uninhabited limestone islands ranging in area from mere dots in a lagoon to Ngeruktabel, which has an area of 7.2 mi^2 and is the second largest island of Palau; these are called "rock islands".

The highest point on Babelthuap is almost 800 feet. Like most other volcanic islands in the group, Babelthuap is fringed by dense mangrove swamps. Eighty percent of the length of its coastline is occupied by these swamps, covering a total area of approximately 13 mi^2. Many streams on Babelthuap are perennial and the largest of these, the Ngerdorch River, drains an area of 18 mi^2 on the eastern part of the island. The smaller streams tend to be intermittent.

According to the 1980 census (U.S. Department of Commerce, 1982), the population of the Palau Islands is 11,963 of which 9,000 (75 percent) live on Koror. Except for Koror and Ngerekebesang, the other inhabited islands are thinly populated. The interior of Babelthuap is nearly uninhabited.

Rainfall

Since 1901, rainfall records have been collected at various locations on the islands. A comparison of these records show that there is normally little variation in total rainfall among the islands of Palau. Most of the records were collected for short periods; but on Koror, rainfall data are available for 57

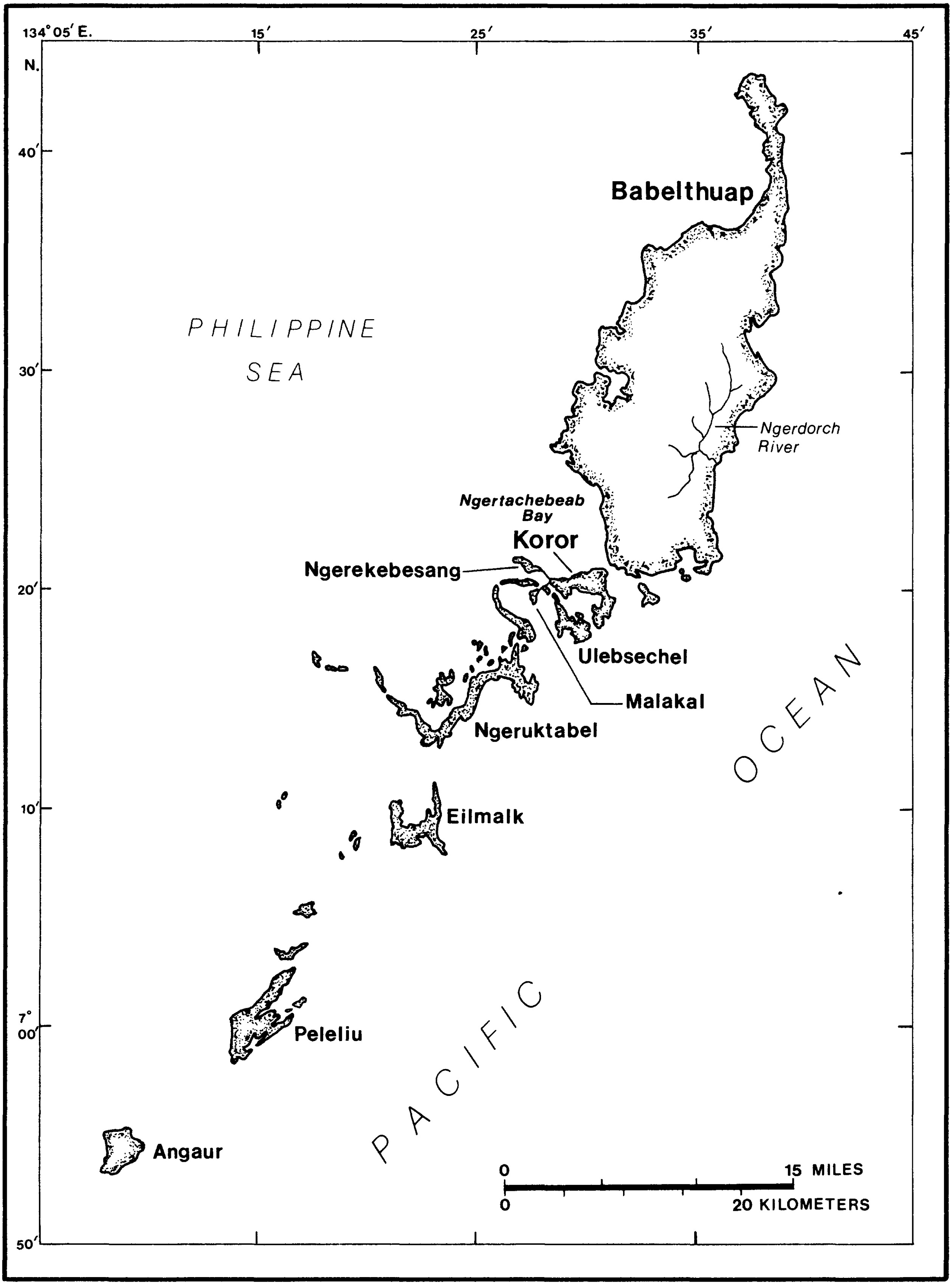


Figure 5. Palau Islands.

years at about the same location from German (1905-12), Japanese (1924-41), and American (since 1947) sources. The data were combined to provide a long-term record. This record shows that February, March, and April are the driest months of the year; the combined rainfall during these months account for one-sixth of the average rainfall of 148 inches. During the 1983 drought, rainfall records were collected by the National Weather Service on Koror, the U.S. Geological Survey at the Diongradid River in northern Babelthuap, and at Airai in southern Babelthuap (fig. 6).

Rainfall during the period January through May 1983 was deficient by 36 inches, less than 30 percent of normal (table 7). Rainfall for February and March 1983 was the lowest on record. Figure 7 shows a comparison of the average rainfall with the 1983 rainfall for Koror.

The severity of the drought can be measured in terms of its recurrence interval. Frequency relations were compared for the lowest 5 consecutive months during each 12-month period beginning in August. Use of the August through July year reduces the likelihood of a computational year ending during a low rainfall period; July is generally the wettest month of the year. The resultant frequency distribution is presented as the lower curve in figure 8. The curve shows a recurrence interval for the 1983 drought of about 125 years. The upper curve presents the recurrence interval based on rainfall for January through May and shows a recurrence interval of about 200 years.

The points of figure 8 and of all subsequent recurrence interval figures in this report are plotted by using the formula $T = \frac{n + 1}{m}$, where

T = recurrence interval in years

n = number of items in the sample

m = order number of the individual item in the sample array with the smallest as No. 1 (Riggs, 1968). The curves are based on a log Pearson Type III distribution.

The months of February and March 1983 were the driest on record. Figure 9 shows the probability of a similar event recurring in February to be about once in 125 years and in March about once in 55 years. For the first time in memory, the dense vegetation of the uninhabited limestone islands (the "rock islands") turned yellow from lack of moisture.

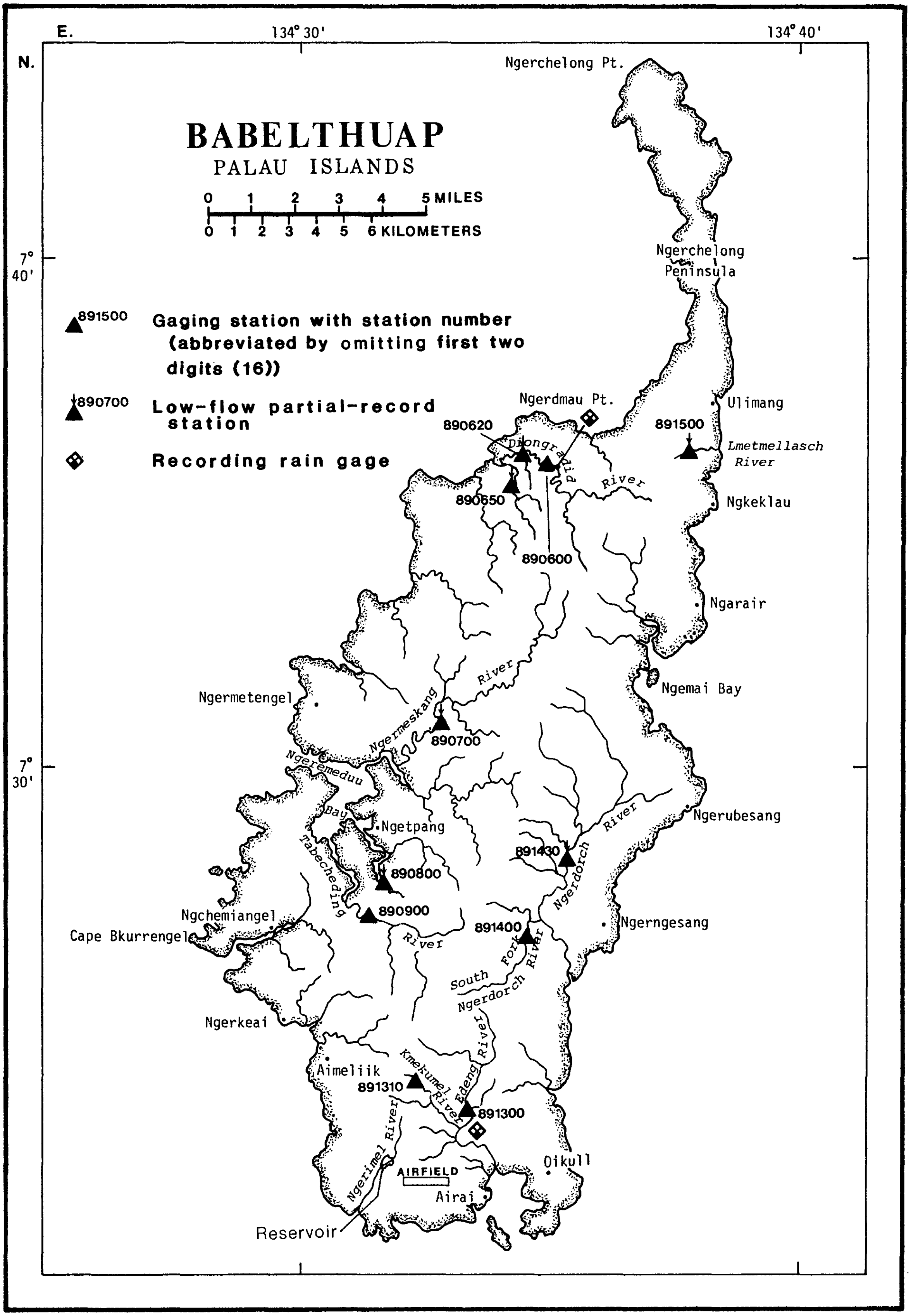


Figure 6. Locations of rain gages, gaging stations, and low-flow partial-record stations on Babelthuap.

Table 7. Monthly January through June rainfall, in inches, for the Palau Islands

	Jan.	Feb.	Mar.	Apr.	May	Total Jan. to May	June
Koror[1/]							
1905-82:							
Number of years	57	57	58	58	58	--	58
Mean	11.60	8.24	7.98	9.21	13.49	50.52	14.18
Percent of annual mean.	7.8	5.6	5.4	6.2	9.1	34.1	9.6
Minimum monthly	2.11	1.24	2.46	1.65	4.88	--	5.91
Year of minimum	1973	1973	1955	1948	1907	--	1976
1983:							
Rainfall	3.44	.64*	1.71*	3.12	5.73	14.64	18.48
Percent of mean	30	8	21	34	42	29	130
Departure from mean	-8.16	-7.60	-6.27	-6.09	-7.76	-35.88	+4.30
Diongradid River							
1983 rainfall	2.74	.76	.74	4.54	1.52	10.30	13.43
Airai							
1983 rainfall	2.57	.18	.81	3.19	2.83	9.58	13.26

1/ Compiled from the following sources: "Mitteilungen von Forschungreisenden und Gelehrten aus den deutschen Schutzgebieten", 1906-13; Institute of Human Relations, Yale University, 1943; U.S. Army, Chief of Engineers, 1956; U.S. National Oceanic and Atmospheric Administration, 1982, 1983.

* New minimum monthly total.

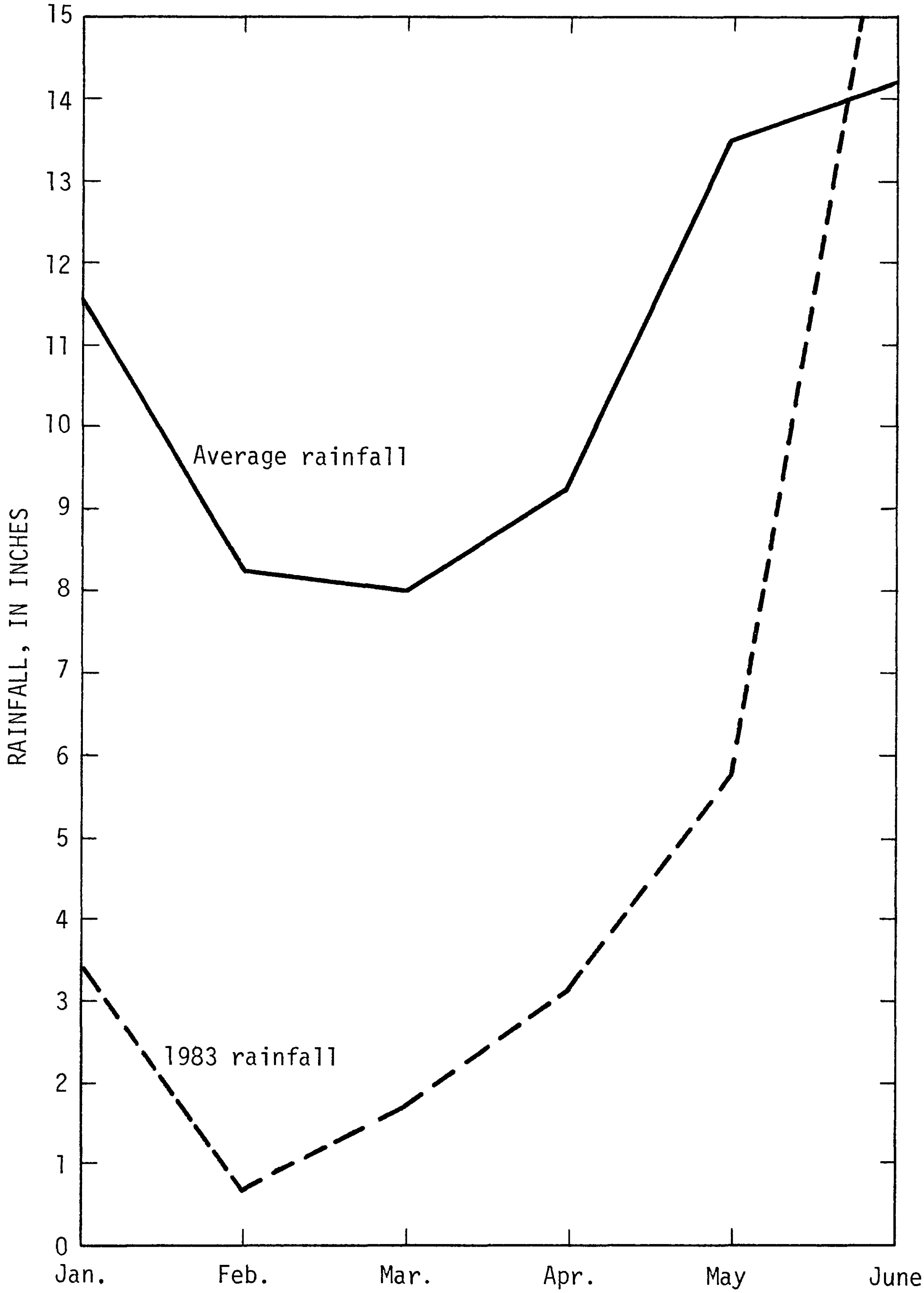


Figure 7. Comparison of average rainfall with 1983 rainfall for Koror.

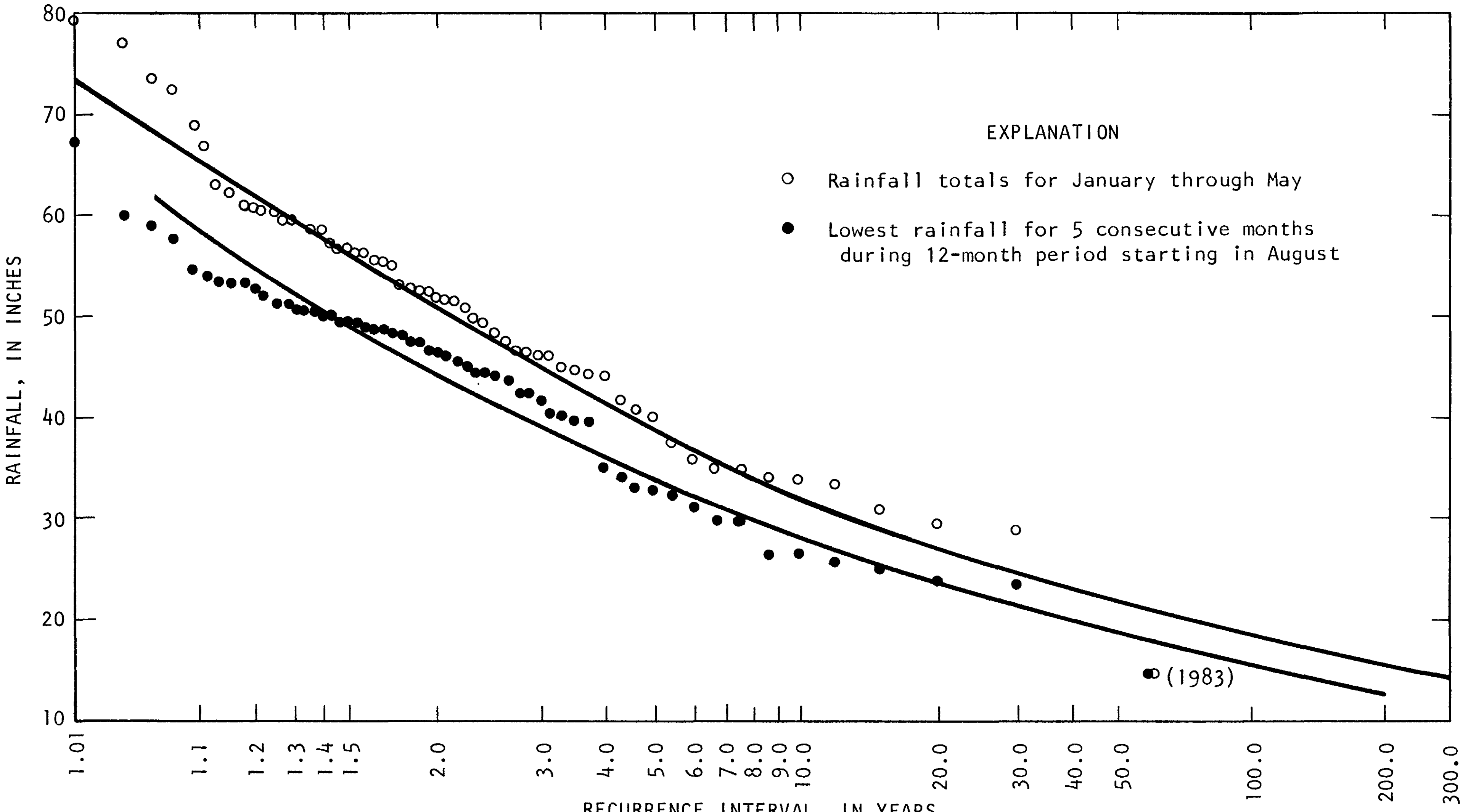


Figure 8. Recurrence intervals of lowest rainfall for 5 consecutive months on Koror during 12-month periods beginning in January and in August.

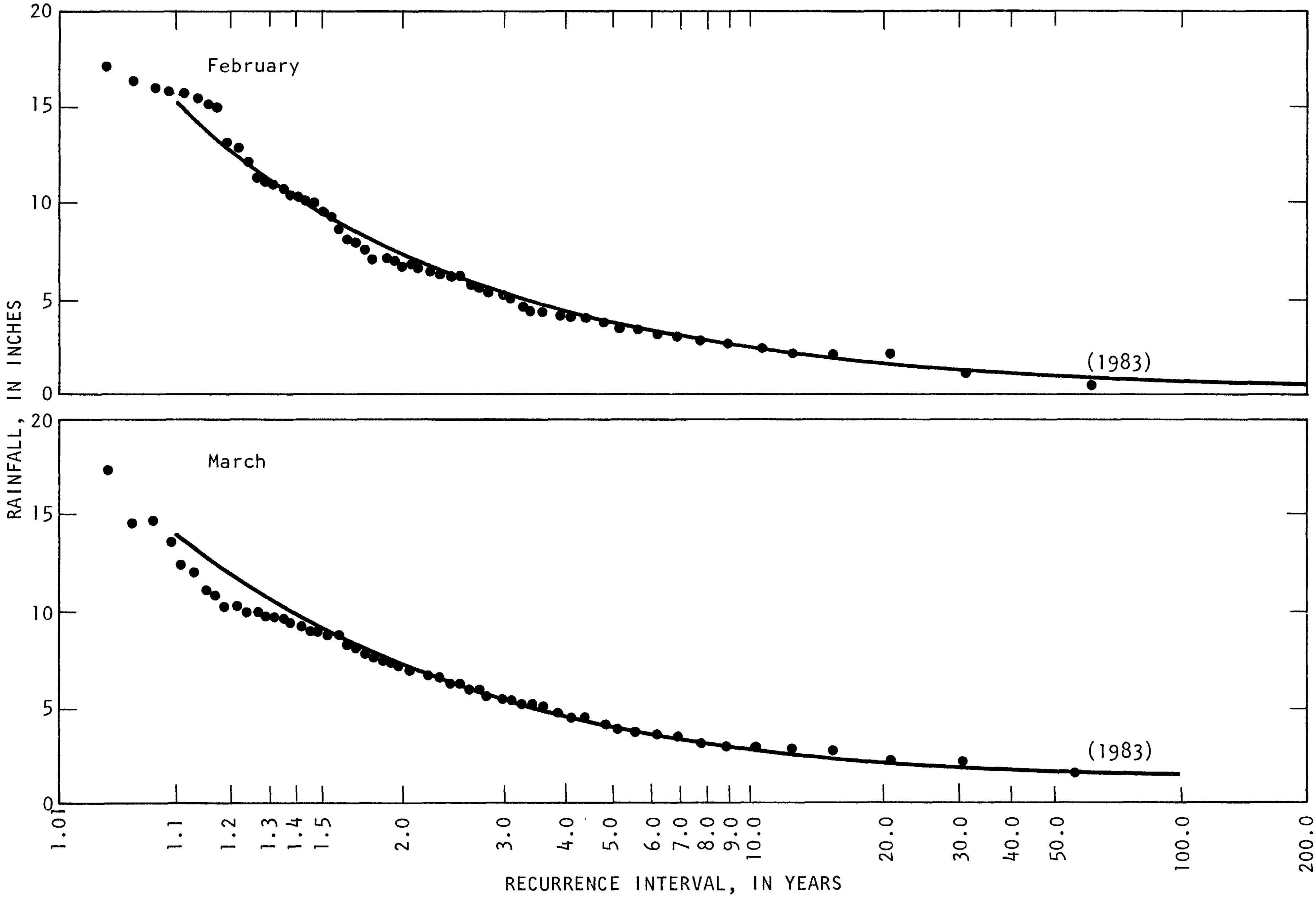


Figure 9. Recurrence intervals of rainfall totals for February and March on Koror.

Streamflow

The U.S. Geological Survey has collected continuous records of streamflow on Babelthuap at six gaging stations. Additional low-flow measurements have been made at a dozen streams, most of them on the island of Babelthuap. (See fig. 6).

During the 1983 drought, streamflow was recorded at five gaging stations, four of which had been in operation for more than 10 years. The means of their monthly discharge during the first 6 months of the calendar year are given in table 8 for the period of record through 1982 and for 1983. The comparison shows that streamflow on Babelthuap during January through May 1983 was 16 to 20 percent of normal and that streamflow in Diongradid River for each month was the lowest on record.

By correlation of discharge measurements at partial-record stations with concurrent discharge at nearby continuous-record stations, regression equations have been computed (Van der Brug, 1984a). On the basis of these equations, the minimum discharge at low-flow partial-record stations was determined. The minimum discharges prior to 1983 and in 1983 for all stations on Babelthuap are given in table 9.

Effects of Drought on Water Supply

Koror and the smaller islands of Ngerekebesang and Malakal are served by a central water system. Water for the system comes from the 28-Mgal Ngerimel River reservoir on Babelthuap through a 12-inch pipe across the bridge connecting Babelthuap and Koror. Water for the villagers in areas outside the central system comes from individual rain catchment or streams. On the island of Peleliu, a water system carries water from a catchment on the airstrip in the southern part of the island to the only village on the island at the northern end. On Angaur, water is provided by rain catchments and an old well.

Before the onset of the drought, half the people of Koror, the population center of the islands, were provided water on a 24-hour basis while the other half received water only during 3 hours in the morning and 2 hours in the evening. Although sufficient streamflow was available, the amount distributed was limited by the quantity that could be piped from the Gihmel Reservoir to the Airai treatment plant and by large leaks in the distribution system. After the drought had begun, water hours on Koror were reduced to 3 hours in the evening in

Table 8. Mean monthly discharges, January through June, of rivers on Babelthuap prior to 1983 and in 1983

[Discharge in cubic feet per second]

Station number	16890600				16890900				16891300				16891400			
Station name	Diongradid River				Tabecheding River				Edeng River				South Fork Ngerdorch River			
Drainage area	4.45 mi^2				6.07 mi^2				4.26 mi^2				2.44 mi^2			
Years of record	13				12				13				11			
	1970-82		1983		1971-82		1983		1970-82		1983		1971-82		1983	
	Mean	Lowest monthly mean	Mean	1/ Per-cent	Mean	Lowest monthly mean	Mean	1/ Per-cent	Mean	Lowest monthly mean	Mean	1/ Per-cent	Mean	Lowest monthly mean	Mean	1/ Per-cent
January	30.4	9.7	9.3*	31	43.2	6.7	16.7	39	33.1	5.3	11.9	36	19.7	3.2	6.0	30
February	30.3	5.8	5.3*	17	38.9	2.7	5.2	13	27.1	2.7	4.3	16	17.4	1.4	2.0	11
March	20.4	3.8	3.5*	17	24.2	1.6	2.7	11	17.6	2.2	2.7	15	9.3	1.0	1.6	17
April	22.6	4.1	3.4*	15	36.3	4.9	4.0*	11	25.3	4.8	2.0*	8	17.2	2.2	1.3*	8
May	20.8	10.2	3.1*	15	37.8	21.2	4.4*	12	24.3	6.6	3.0*	12	15.3	6.0	1.8*	12
June	37.1	13.3	13.0*	35	66.5	31.9	22.2*	33	37.7	14.7	9.3*	25	24.7	11.6	8.0*	32
January to May	24.8	--	4.91	20	36.0	--	6.67	19	25.4	--	4.78	19	15.7	--	2.56	16
Annual	33.1	--	--	--	49.5	--	--	--	32.8	--	--	--	19.9	--	--	--

1/ Percentage of 1970-82 (1971-82) mean for the month.

* New minimum mean discharge.

Table 9. Lowest discharge, in cubic feet per second, of rivers on Babelthuap

[Y, discharge for partial-record station;
X, discharge for continuous-record station]

Station number	Station name	Drainage area (mi^2)	Lowest instantaneous discharge: To 1982	In 1983	Method of determination	Period of record
16890600	Diongradid River	4.45	2.7	2.1	Gaging station record	1970-83.
16890620	Ngechutrong River*	.25	.17	.13	Correlation with Diongradid River, $Y=0.066X^{0.96}$	1974-82.
16890650	Ngerchetang River*	1.51	1.5	.70	Correlation with Diongradid River, $Y=0.32X^{1.06}$	1974-77, 1980-82.
16890700	Ngermeskang River*	7.14	4.4	3.4	Correlation with Diongradid River, $Y=1.63X^{0.99}$	1973-82.
16890800	Ngatpang River*	.34	.09	.08	Correlation with South Fork Ngerdorch River, $Y=0.16X^{0.91}$	Do.
16890900	Tabecheding River	6.07	.80	.57	Gaging station record.	1971-83.
16891300	Edeng River	4.26	1.6	1/ 1.4	do.	1970-83.
16891310	Kmekumel River	1.44	.78	.18	do.	1970-78*, 1978-83.
16891400	South Fork Ngerdorch River.	2.44	.55	.48	do.	1971-83.
16891430	North Fork Ngerdorch River.*	9.70	2.2	2.0	Correlation with South Fork Ngerdorch River, $Y=4.16X^{1.04}$	1975-83.
16891500	Lmetmellasch River*	.32	.09	.06	Correlation with Diongradid River, $Y=0.026X^{1.21}$	1971-75, 1977, 1980-81.

* Partial-record station.

1/ Includes 0.36 ft^3/s diverted upstream from gaging station.

January and to 2 hours in February. In March, the Gihmel Reservoir ran dry for the first time since the dam was built in 1969. Although the new 16-inch pipeline from nearby Edeng River to the Gihmel reservoir had been completed in March, the pumps had not yet arrived on the island.

Water from Edeng River is pumped to a small reservoir at the U.S. Geological Survey rain gage in Airai for distribution to nearby farms for irrigation. As the water source for Koror's central water system was drying up, more water was pumped to the reservoir and a pipe was laid from the reservoir to the mouth of the Ngerikiil River (downstream from the confluence of Edeng and Kmekumel Rivers) where facilities for showers and laundry were erected. Many people from Koror would make the 10-mile trip to Airai on Babelthuap to use these facilities. Water was also transported to Koror and distributed house to house by truck. Discharge measurements made of Edeng River above and below the diversion on April 8, 1983, showed 230,000 gal/d (gallons per day) were diverted.

Numerous 55-gallon asphalt drums, from a recent street paving project, were distributed to the public. Every second or third day, two of these drums per family were filled with water. The population was repeatedly advised to boil the water before use. Truck drivers, sanitation department personnel, or hamlet councilmen would occasionally add chlorine bleach to each drum. The water being distributed was regularly checked for total coliform. Hauling continued from March 1 to April 28, when the pumps for the Edeng River to Airai treatment plant pipeline became operational. Subsequently, one Mgal/d was pumped from Edeng River, which at times during May was almost the entire flow of the river. Schools, which had been closed since March, were reopened and water service was restored, although limited to 2 hours in the evening until the end of the drought.

Effects of Drought on Agriculture

Food crops, which are produced mainly by subsistence farming, were seriously affected by the drought on most of the Palau Islands, except on the island of Peleliu, where no drought damage was reported. All areas on Babelthuap, especially in the northern part, were affected, and losses of taro and cassava ranged from 80 to 95 percent of the crop. Taro corms wilted and dried, and the tubers turned brown when cooked. No planting of new taro was feasible as the mud in which the taro grows had hardened. Cassava roots became fibrous and remained hard when cooked. No new cassava cuttings could be planted as planting materials were reduced and the soil was too dry. New crops did not mature until about six months after the end of the drought. Most coconut and banana trees on the islands survived.

YAP ISLANDS

Physical and Cultural Setting

The Yap Islands, the main island group of Yap State, lie at latitude 9°27' to 38' N. and longitude 138°03' to 12' E., 500 statute miles southwest of Guam, 1,100 miles east of Manila, and 4,300 miles west of Honolulu.

The four major islands--Yap, Gagil-Tamil, Maap, and Rumung--have a total land area of 38 mi^2 (fig. 10). Of these islands, Yap has more than half the total land area, most of the population, and almost all of the economic development. The islands of Maap and Rumung, together, comprise only 15 percent of the land area and population. Mangrove swamps border much of the shoreline; interiors of the islands are mountainous with forested valleys and rolling grass-covered hills.

Nearly 8,000 people live in the Yap Islands, mostly in villages scattered along the coast. The only town on Yap is Colonia, the seat of government during German, Japanese, and American administrations, and now the capital of Yap State. The economic base of the islands is narrow and practically all employment is provided by the government in Colonia.

Rainfall

Although rainfall records for the Yap Islands, other than those at or near Colonia, are of short duration or uncertain quality, they are adequate to show little difference in annual rainfall among the islands. Of the two principal seasons, December through April is normally the dry and July to October is the wet season. Rainfall data collected at or near Colonia or at the old Yap airport are available from German (1901-14), Japanese (1914-42), and American (1948-present) sources and are combined to provide a long-term record. The average annual rainfall for about 74 years of record during 1901 to 1982 is 122 inches (Van der Brug, 1983a). A comparison between average rainfall on Yap Island for January through June for the period of record, and the rainfall recorded during these months in 1983, is given in table 10 and shown in figure 11. During the first 5 months of 1983 only 27 percent of normal rainfall was recorded.

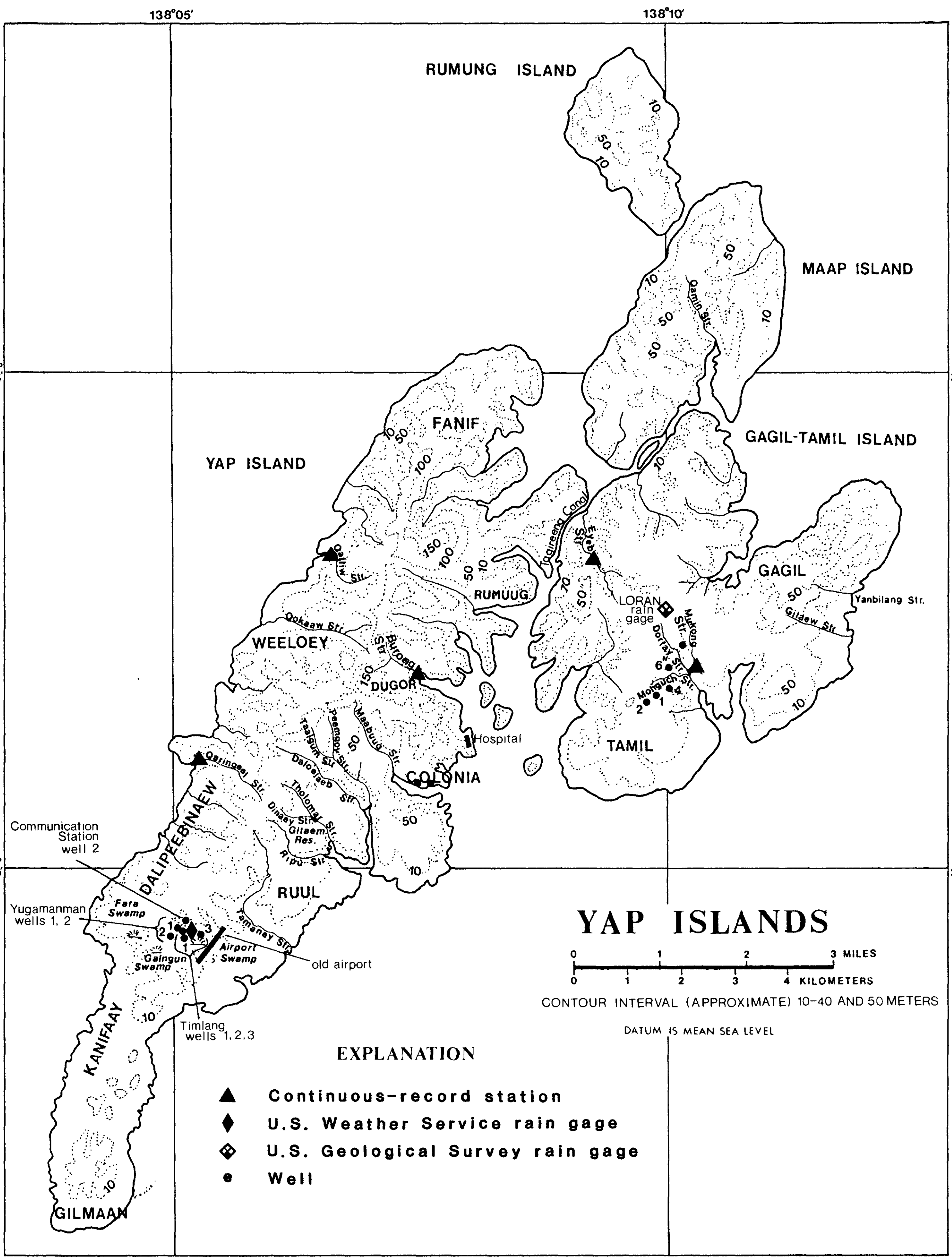


Figure 10. Locations of rain gages, gaging stations, and wells in the Yap Islands.

Table 10. Monthly January through June rainfall, in inches, for Yap State

	Jan.	Feb.	Mar.	Apr.	May	Jan.-May	Total June
Yap Island[1/]							
1901-82:							
(Number of years)	75	74	73	74	75	--	75
Mean	7.5	5.7	5.8	5.9	9.5	34.4	11.0
Percent of annual mean.	6.1	4.7	4.8	4.8	7.8	28.2	9.0
Minimum monthly	1.5	.7	.8	.2	2.6	--	3.4
Year of minimum	1913	1915	1929	1926	1926	--	1913
1983:							
Rainfall	1.25*	.27*	2.76	1.36	3.59	9.23	6.98
Percent of mean	17	5	48	23	38	27	63
Departure from mean	-6.3	-5.4	-3.0	-4.5	-5.9	-25.2	-4.0
Other 1983 rainfall:							
Gagil-Tamil	.70	.19	2.24	.45	3.05	6.63	7.93
Ulithi	.76	.11	1.22	.72	1.83	4.64	6.65
Woleai	--	--	--	.94	4.31	--	9.78

1/ Compiled from the following sources: "Mitteilungen von Forschungreisenden und Gelehrten aus den deutschen Schutzgebieten", 1902-13; "Institute of Human Relations, Yale University, 1943; Government of the Phillipine Islands, Weather Bureau, annual summaries 1913-20; Smithsonian Institution, 1934; U.S. Weather Bureau, 1959; U.S. National Oceanic and Atmospheric Administration, 1982, 1983.

* New minimum monthly total.

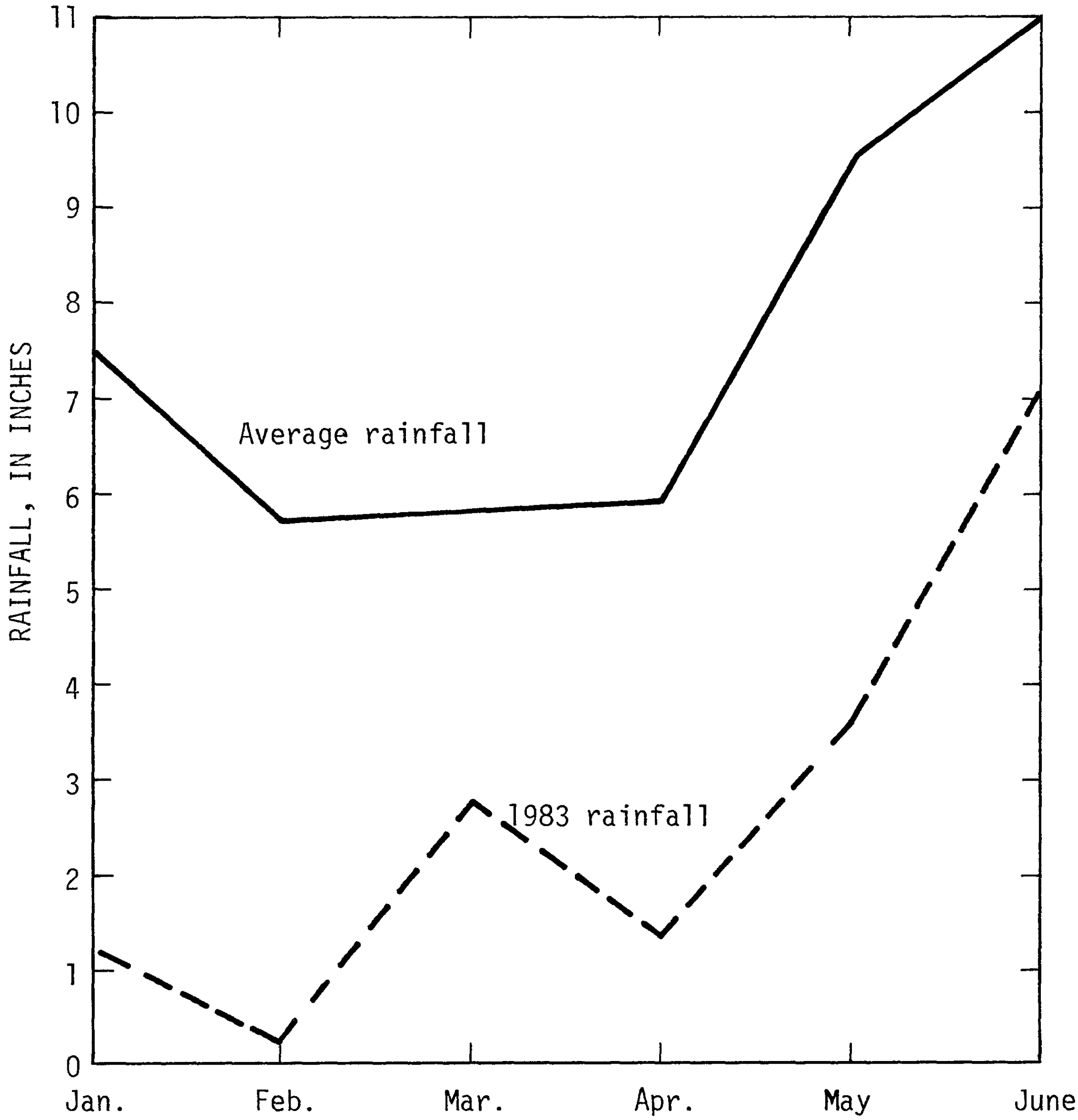


Figure 11. Comparison of average rainfall with 1983 rainfall for Yap Island.

The only other location in the Yap Islands where rainfall data were collected during 1983 is the U.S. Geological Survey continuous-record rain gage at the LORAN station on Gagil-Tamil which was established in December 1981. For completeness, monthly rainfall totals from other islands in Yap State have been included in table 10. For Ulithi and Woleai atolls, respectively, 100 miles northeast and 400 miles east of the Yap Islands rainfall data were compiled at National Weather Service Station, Yap, from twice daily readings submitted by local observers. Figure 12 shows that the probability of a 5-month dry period similar to the one of 1983 recurring on the island of Yap is about once in 125 years. The curve was computed for the 12-month period beginning in August by the methods described previously for the Palau Islands.

Streamflow

Although the rainfall averages 122 inches per year, there are no perennial streams on Yap Island. The streams are normally dry for periods ranging from a few days to several months each year between January and May. The stream with the largest yearly discharge on Yap, Qaringeel Stream, was dry an average of 10 weeks per year during the period 1968 to 1982. The streams on Yap go dry because they have small drainage areas (only a few exceed a quarter of a square mile) and there is low water-retention capacity in the soil and rock in their watersheds. On Gagil-Tamil, the principal geologic formation is the deeply weathered Tomil (Tamil) Volcanics of Tayama (1935), which allows more infiltration of rainfall and subsequent release to the streams during long periods of dry weather.

The U.S. Geological Survey has collected streamflow data on the Yap Islands since 1968. During the 1983 drought, three continuous-record stations were operating on Yap Island and two on Gagil-Tamil. Of the five stations, however, two (one on Qatliw Stream on Yap, and the other on Eyeb Stream on Gagil-Tamil), had only one year of record. Records for the stations on Yap Island show that, for the period January through June 1983, Qaringeel Stream had only 6 percent and Burong Stream only 5 percent of the average January through June flow.

Streams on Gagil-Tamil normally do not go dry. The minimum flow of Mukong Stream during 1975 to 1982 was 0.07 ft^3/s, for one day in 1979, in 1980, and in 1981. For 1983, the minimum flow was 0.02 ft^3/s on May 17 to 24. Comparisons of monthly streamflows prior to 1983 and in 1983 are given in table 11.

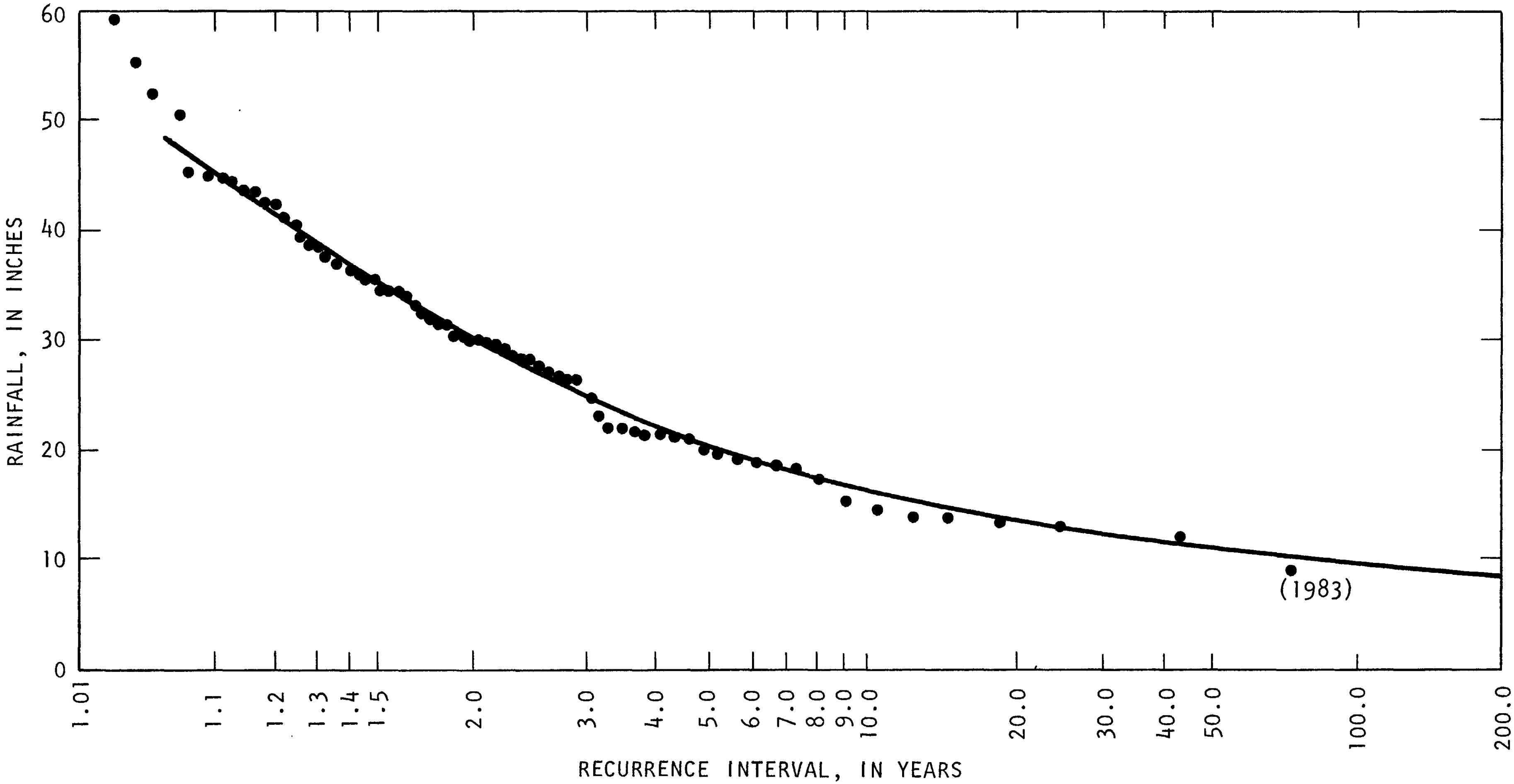


Figure 12. Recurrence intervals of lowest rainfall for 5 consecutive months at Colonia, Yap, during 12-month periods starting in August.

Table 11. Mean monthly discharges, January through June, of streams on the Yap Islands prior to 1983 and in 1983

[Discharge in cubic feet per second and in percentage]

Station number -----	16892000	16892400		16893100		16893200				16893400
Station name -------	Qatliw Stream,	Qaringeel Stream,		Burong Stream,		Mukong Stream,				Eyeb Stream,
Location -----------	Yap	Yap		Yap		Gagil-Tamil				Gagil-Tamil
Drainage area ------	0.31 mi^2	0.24 mi^2		0.50 mi^2		0.50 mi^2				0.22 mi^2
Years of record ----	1	14		14		8				1
	1983	1969-82	1983	1969-82	1983	1975-82		1983		1983
	Mean	Mean	Mean	Mean	Mean	Mean	Lowest monthly mean	Mean	1/ Per-cent	Mean
January	0.004	0.67	0.003	0.55	0.001	1.70	0.52	0.37*	22.8	0.18
February	0	.44	0	.42	0	1.22	.30	.17*	13.9	.046
March	0	.36	0	.30	0	.62	.22	.13*	2.1	.047
April	0	.33	0	.24	0	.62	.16	.09*	1.5	.028
May	0	.59	0	.37	0	1.04	.30	.04*	3.8	.020
January to May	.0008	.48	.001	.38	0	1.04	--	.16	15.4	.065
June	.19	1.55	.093	1.40	.068	2.76	.89	.25*	9.1	.32
Annual	--	1.10	--	.98	--	1.95	--	--	--	--

1/ Percentage of 1975-82 mean for the month.

* New minimum mean discharge.

Note: Lowest monthly mean discharge for January to May for Qaringeel and Burong Streams prior to 1983 is 0 each month.

Effects of Drought on Water Supply

A central water system provides water for Colonia and the surrounding area. The water for the system comes from an old 2-Mgal and a newer 25-Mgal reservoir at Gitaem. For the areas outside those served by the central water system, the people depend on rain catchments, shallow dug wells, or springs. Prior to the construction of the 25-Mgal upper Gitaem reservoir in 1975, supplemental water was obtained at times during the dry season from Luweech Swamp and transported to the lower 2-Mgal Gitaem reservoir, where the intake to the filterplant is located. Luweech Swamp, more commonly called Airport Swamp, is a small lake at the old Yap airport.

During the 1983 drought, the reservoirs were inadequate because of an extended water system, heavier demand, and increased losses in the distribution lines. On February 17, 1983, the reservoirs ran dry. Beginning in February 1983, water from the Airport Swamp was transported in makeshift tank trucks to five strategic sites where water was available to the general public. An attempt to ration the water to three gallons per person in the morning and again in the evening was abandoned when people panicked. Water was hauled from the Airport Swamp until the water depth had been reduced to 2 feet, at which point hauling was stopped to protect small fish in the swamp. The remaining water, however, evaporated and the swamp dried up in May 1983. Prior to 1983, the swamp had not completely dried up, so far as is known.

Meanwhile, an agreement had been reached with local village people to haul water from their so-called "taro patch", a swampy area of about 100,000 square feet located behind the communication station. As part of the agreement, the government made road improvements and provided an electrical power extension to the village. In a more or less continuous operation, water was hauled from the taro patch until the end of the drought. During this period, the water level dropped only a few feet, although an estimated 23,000 gallons were pumped daily. The quality of the water remained unchanged.

The old Spanish well and the so-called "American" well in Colonia were cleaned and people were able to obtain water there. These wells had not been used since the central water system was started. Although close to shore, the water apparently did not become saline.

Drinking water could be obtained from wells at the communication station and nearby weather service station (Timlang 3). The well water was not treated. Water from the Airport Swamp and the taro patch, was chlorinated by the Sanitation Department and monitored closely. At all distribution points, the water was chlorinated daily. People were advised to boil all water before consumption. Total coliform of the water before treatment ranged from 256 colonies per 100 mL (milliliter) to colonies too numerous to count. No increase in illnesses due to drinking water was documented. Outside the Colonia area the people managed with their traditional water sources. On Gagil-Tamil, the streams did not go dry and on northern Yap and Maap, some springs continued to flow.

On the low coral outer islands, water continued to be obtained from shallow wells but salt water intrusion caused wells on some atolls to become brackish. On Ulithi, crops near the wells suffered due to the increased salinity of the water table. Use of the wells was limited and the water was mixed with water from the high school roof catchment.

Exploratory wells drilled in 1979 confirmed the potential for development of ground water at the Yap Airport and in Gagil-Tamil. Subsequently, wells were drilled to provide water for the people in those areas. In 1983, the construction of storage and distribution facilities at Gagil-Tamil had not yet been completed and those scheduled for the Yap Airport not yet begun.

The wells on Yap and Gagil-Tamil were completed in 1982 and no long-term record of water levels is available. However, the U.S. Geological Survey has collected monthly water levels of most wells since August 1982. Significant water-level readings are listed in table 12. They show that the water level of the wells at the communication station and the nearby Airport Swamp (Communication Station, Yugamanman, and Timlang wells) dropped about 20 feet between October 1982 and May 1983. A continuous water-stage recorder installed on well Dorfay 6" on May 5, 1983, showed that the ground-water levels on Gagil-Tamil reached their lowest level on May 24, 1983, having dropped 4 feet after September 1982.

Table 12. Depth to water, in feet, of wells on Yap and Gagil-Tamil

[Measuring point is top of casing]

Well	1/ Altitude top of casing (ft)	Depth to water below land surface 1982 Mar. 9	1982 Sept. 1	1982 Oct. 28	1983 Jan. 27	1983 May 12, 13	Water level decline Sept. 1, 1982 to May 12, 13, 1983
Yap Island							
Communication Station 2. 2/	39.40	11.7	7.5	8.9	17.0	(May 13) 28.7	21.2
Yugamanman 1	42.68	15.52	12.24	14.53	19.69	30.44	18.20
Yugamanman 2	38.83	12.83	10.30	12.06	16.19	26.79	16.49
Timlang 1	42.68	11.30	--	8.61	14.82	31.49	--
Timlang 2	40.43	11.79	4.54	9.51	17.26	29.05	24.51
Gagil-Tamil							
Monguch 1	21.38	--	0	.40	1.23	(May 12) 3.19	3.19
Monguch 2	26.47	--	1.75	2.66	3.70	6.28	4.53
Monguch 4	--	--	5.39	6.89	8.38	11.78	6.39
Mukong	25.83	--	9.64	10.38	11.37	13.15	3.51
Dorfay 6"	30.92	--	11.22	11.86	12.60	3/ 14.83	3.61

Note: Yugamanman wells also called Faraq-Lamaer wells and Timlang wells also called Weather Bureau wells.

1/ From Nance, 1982.

2/ Date of water-level readings are a few days earlier or later than dates given for the other wells. The well is located about 50 ft from the well in use by the Communication Station.

3/ Greatest depth to water: 15.15 ft, May 24, 1983 (from continuous recorder chart).

Effects of Drought on Agriculture

(Most of the following information was based on a 1983 unsigned drought damage report from Yap State Department of Agriculture.)

The principal crops of the Yap Islands are wet and dry taro, sweet potato, yam, banana, breadfruit, and coconut. The overall reduction in the normal yield of the crops due to the drought was 50-75 percent, with the exception of the banana yield which was, surprisingly, reduced only by about 20-25 percent.

The most important crop in the islands is wet taro or swamp taro (cyrtosperma). This is the principal staple food and also a reserve food supply since the taro can be left unharvested when not needed. Where this taro tapped the water lens or had some surface flow available, losses were small (10 to 20 percent) but where the water source dried up, losses were as high as 80 percent. Because much of the taro reserves were used up during the drought, it is expected to take 3 to 4 years to obtain the level of pre-drought supply although the pre-drought production level may be reached much sooner.

Because dry taro or land taro (xanthosoma and colocasia) is normally planted on dry land, the lack of moisture killed more of this crop than of the wet taro and a reduction of 60 to 70 percent of the normal yield was estimated. However, pre-drought conditions were regained in 12 to 18 months after the drought.

No new planting of sweet potato or yams could be done until there was once again sufficient rain. Estimated losses were 60 to 70 percent. The reduction in the yield from breadfruit and coconut trees was about 50 percent. The spring harvest of breadfruit was eliminated because no fruit could develop on the dead branches; and coconuts did not develop fully.

Conditions normally differ between such outer islands as Ulithi, which is always short of food, and Woleai, which has normally a plentiful supply. As a direct result of the drought, supplemental food (rice and fruit juice) is now distributed to all outer islands.

TRUK ISLANDS

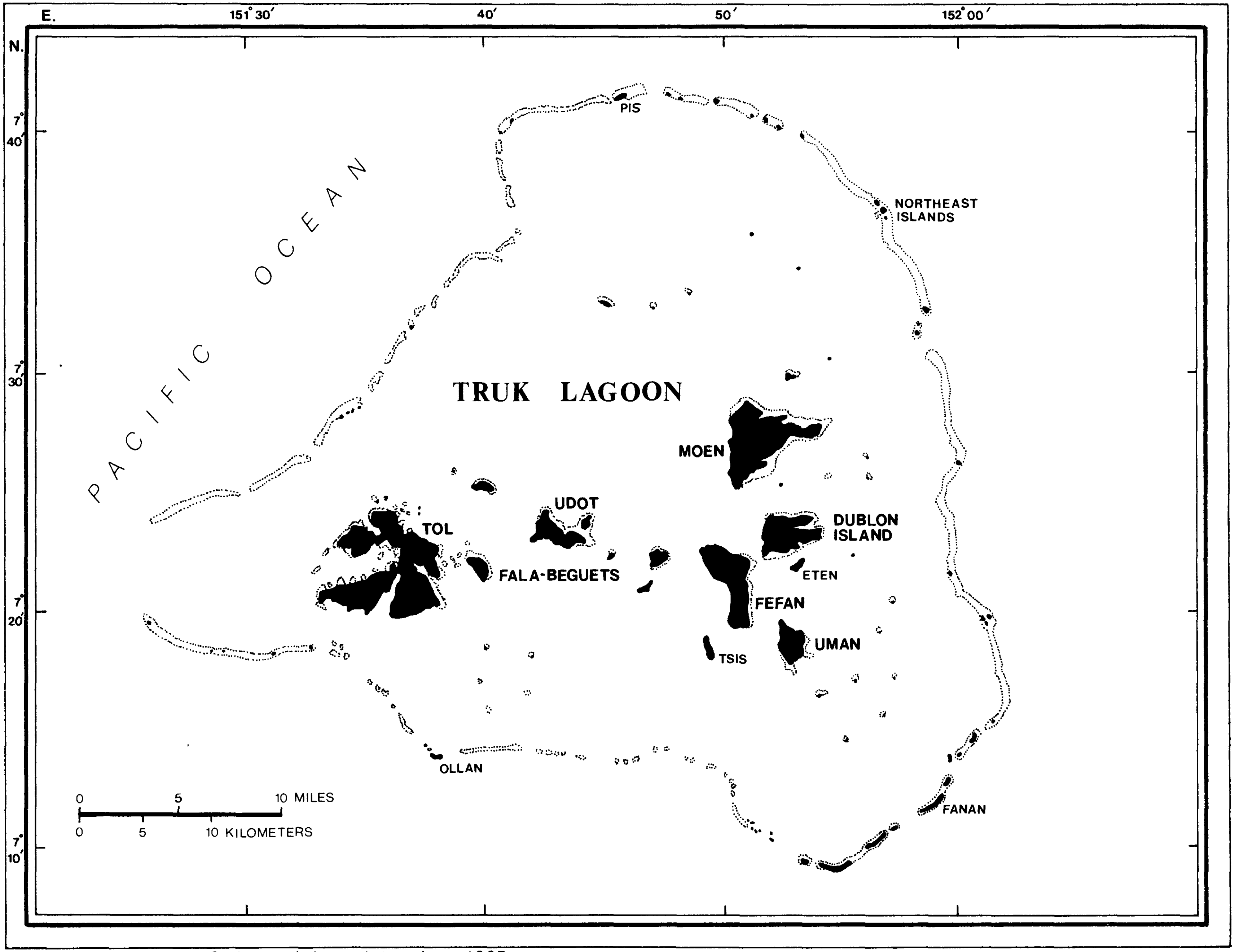
Geographic Setting

The Truk Islands consist of 19 high volcanic islands and at least 65 low coral islets. Many of the coral islands are part of a barrier reef, 125 miles in length, that encloses an 820-mi^2 lagoon, in which the volcanic islands and remaining coral islets are scattered (fig. 13). The volcanic islands are erosional remnants of a large, partly submerged shield volcano, which has long been inactive (Stark and others, 1958); they comprise about 97 percent of the total land area of the Truk Islands (35 mi^2).

Tol, the largest island, has an area of 13 mi^2 and consists of four volcanic areas separated by deep bays. Moen, with a land area of 7.2 mi^2, is the second largest island; like Tol, much of the area consists of steep and rugged terrain. Moen is the administrative, commercial, educational, and transportation center of the islands. Fefan, 4.7 mi^2 in area, is a continuous mountain ridge. Dublon Island, 3 miles south of Moen with an area of 3.4 mi^2, was the administrative and military center during the Japanese administration (1914-1945) and was the most developed island during that period. Udot, 1.8 mi^2, consists of three volcanic highlands connected by narrow necks and Uman, 1.6 mi^2, is a conical-shaped volcanic rock. The remaining islands are much less than one square mile in area and have few inhabitants.

The economic base of the islands is narrow, and the government is the principal employer. Only a small amount of income is derived from tourism, fishing, and copra production.

Preliminary figures of the 1980 U.S. census show more than 37,000 people residing in Truk State (The New Pacific Magazine, 1981). Truk State includes a number of atolls in the vicinity of the Truk Islands with a total population of nearly 10,000 people. The population totals for the major islands in the Truk Lagoon were: Moen, 10,351; Tol, 6,705; Dublon Island, 3,223; Fefan, 3,076.



Modified from Austin, Smith and Associates, Inc., 1967.

Figure 13. Truk Lagoon.

Rainfall

Records of rainfall are available for most years since 1903 but the data were collected on several islands. German records were collected on Eten, a small island off the south coast of Dublon Island, during 1903 to 1913. The Japanese collected rainfall data on Dublon Island during 1927 to 1940 and for 2 years on some of the other islands. A weather station was operated at Moen airport by the U.S. Navy during 1945 to 1951 and by the National Weather Service thereafter (fig. 14).

Table 13 provides monthly rainfall data for Moen during October through June for the period of record prior to 1983 and for 1983. The table shows that rainfall for each month during February through May 1983 was the lowest on record. Figure 15 shows the comparison of the average rainfall with the 1982 to 1983 rainfall for the island of Moen. Rainfall at the other Truk islands was not measured but was probably of similar magnitude.

Cumulative rainfall readings were made by the U.S. Geological Survey during 1973 to 1977 on Moen, Dublon Island, and Tol. Rainfall at Chun Stream on Dublon Island during the period for which cumulative rainfall data are available for a number of consecutive months, was within 1 percent of rainfall on Moen; rainfall at Tumunu Stream on Dublon Island was within 10 percent of the Moen rainfall. On Tol, precipitation was within 3 percent of the Moen rainfall. These comparisons involve only relatively short periods but indicate that areal distribution of rainfall in the Truk Islands generally does not vary much. The mean annual rainfall on Eten during 1903 to 1913 was 126 inches; on Dublon during 1927 to 1940, 117 inches; and on Moen during 1948 to 1983, 144 inches. Rainfall was fairly uniformly distributed over the period April through December, but was low from January through March (fig. 16).

The severity of the drought can be expressed in terms of recurrence interval. Figure 17 shows that the probability of a 4-month dry period, similar to the one in 1983, would be about once in 100 years; of a 5-month dry period, about once in 125 years. The curves were computed for the 12-month period beginning in August by methods described for the Palau Islands.

Rainfall for calendar year 1982, the year preceding the drought, was the lowest annual total ever recorded on Moen; 11 of the 12 months of the year had below average rainfall. The Truk Islands were the only area in the Western Pacific with record low annual rainfall during 1982.

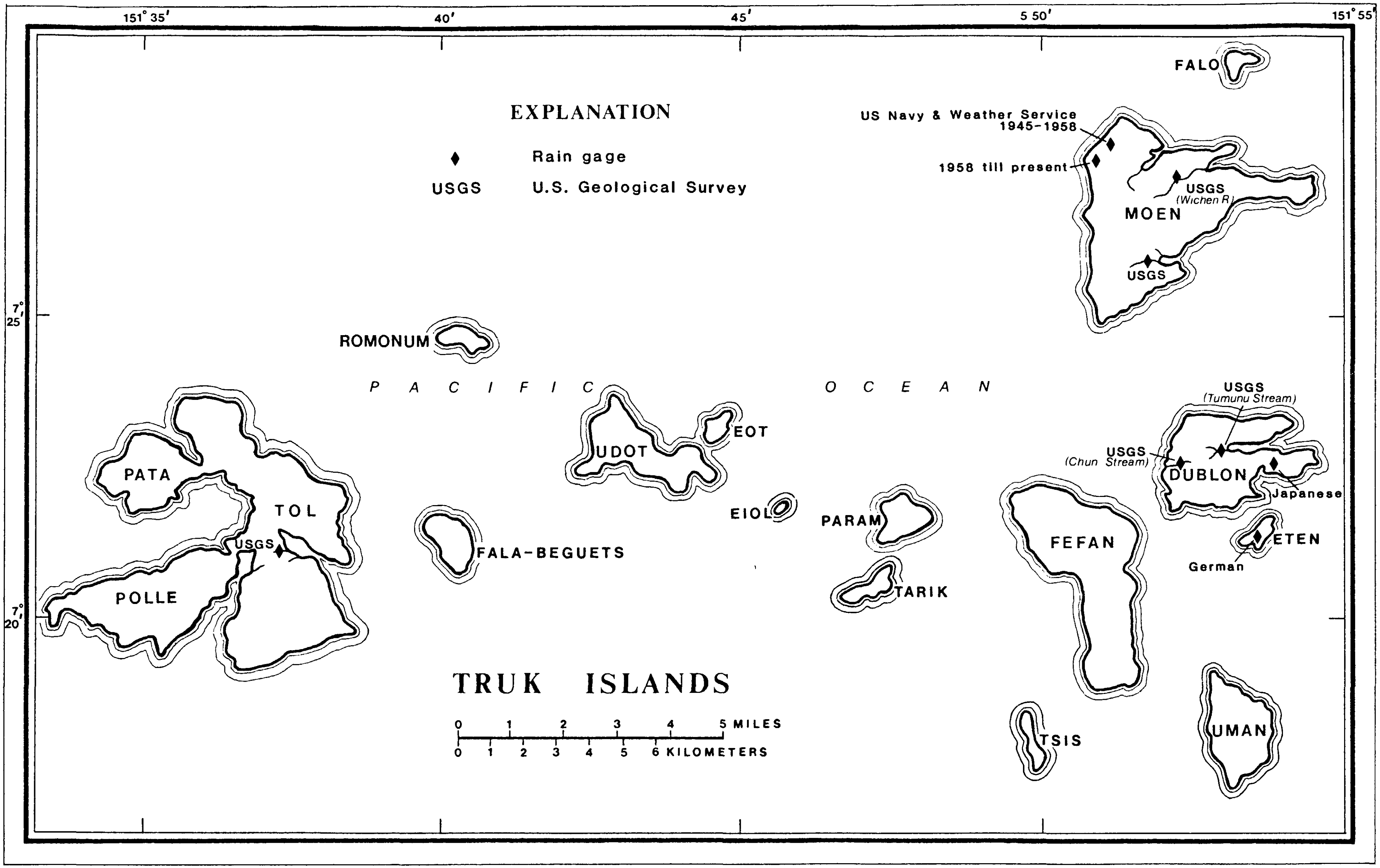


Figure 14. Locations of rain gages in the Truk Islands.

Table 13. Monthly October through June rainfall, in inches, for Moen

[Source: U.S. National Oceanic and Atmospheric Administration, annual summary 1982, monthly reports, 1983]

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total Jan. to May	June
Moen airport (33 years)										
1948, 1950, 1952-82[1/]:										
Mean	14.43	11.89	13.42	8.35	6.24	8.80	12.29	15.44	51.12	12.78
Percent of annual mean	10.0	8.3	9.3	5.8	4.3	6.1	8.5	10.7	35.5	8.9
Minimum monthly	4.17	2.98	3.24	.96	.84	2.30	4.25	6.04	--	6.10
Year of minimum	1972	1980	1977	1959	1950	1950	1975	1981	--	1966
1982-83:										
Rainfall	6.76	1.88*	4.61	5.16	.56*	1.95*	3.28*	3.80*	14.75	9.28
Percent of mean	48	16	35	62	9	22	27	25	29	73
Departure from mean	-7.67	-10.01	-8.81	-3.19	-5.68	-6.85	-9.01	-11.64	-36.37	-3.50

1/ 1952-81 for October to December.
* New minimum monthly total.
Note: For period October 1982 to May 1983, rainfall was 31 percent of normal and 62.86 inches deficient.

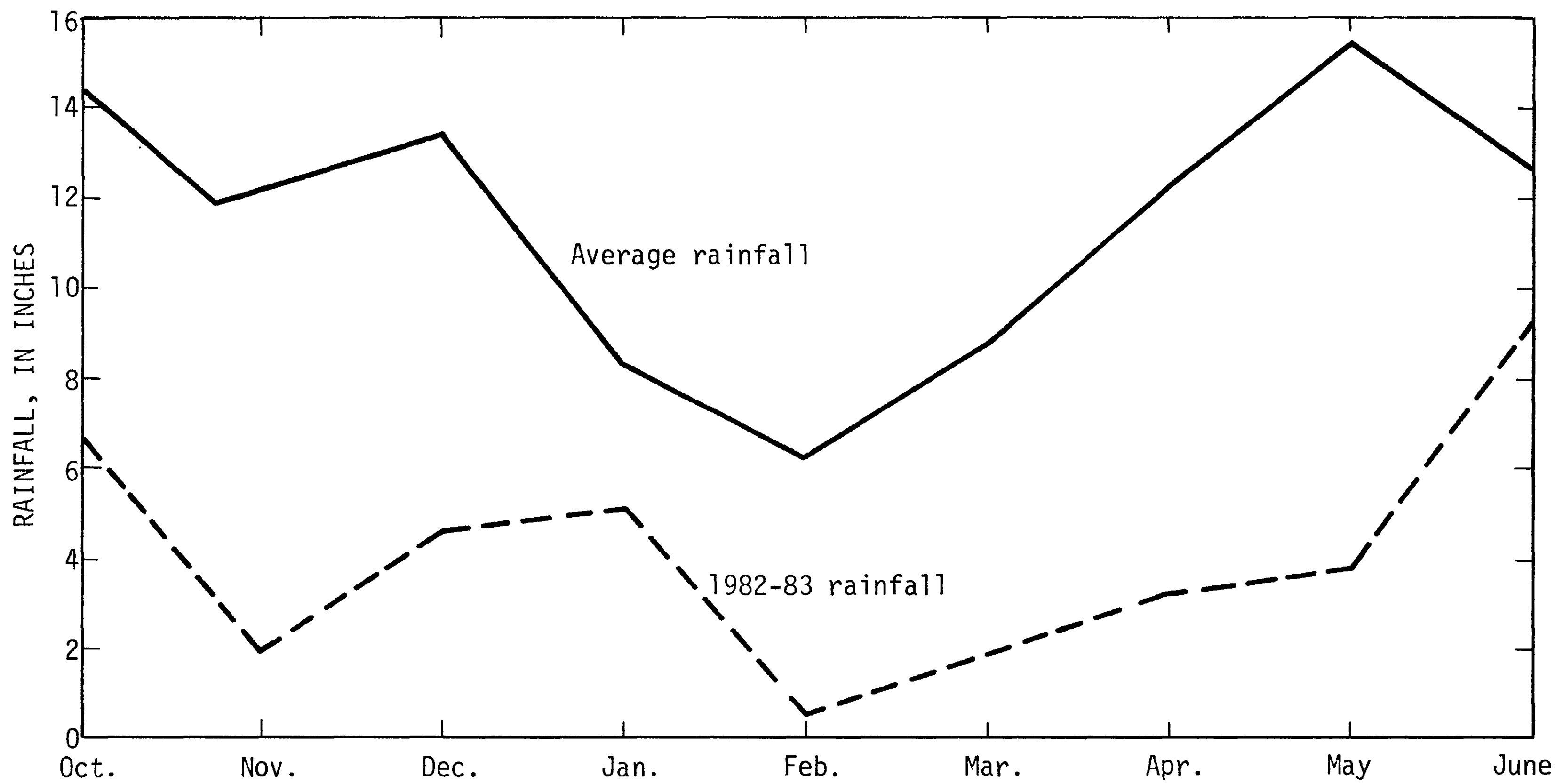


Figure 15. Comparison of average rainfall with 1982-83 rainfall for Moen.

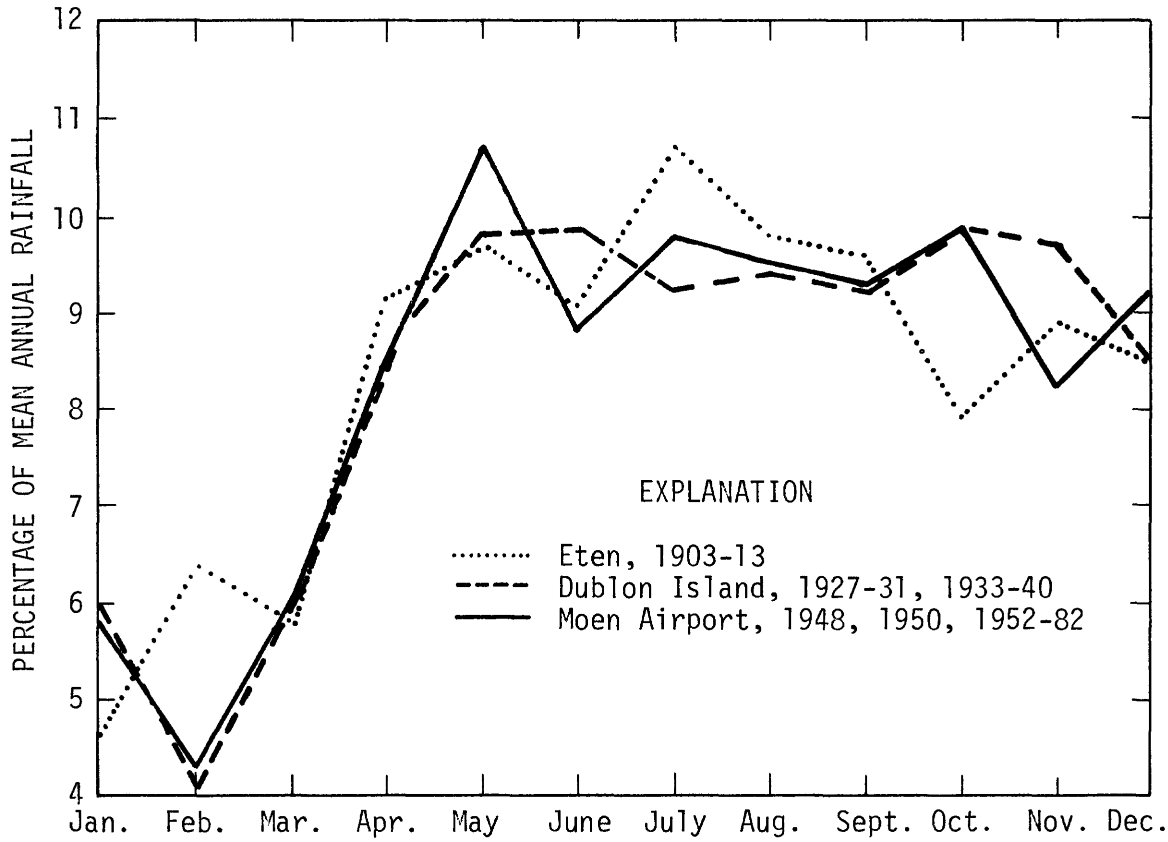


Figure 16. Average monthly mean rainfall in the Truk Islands in percentage of mean annual total.

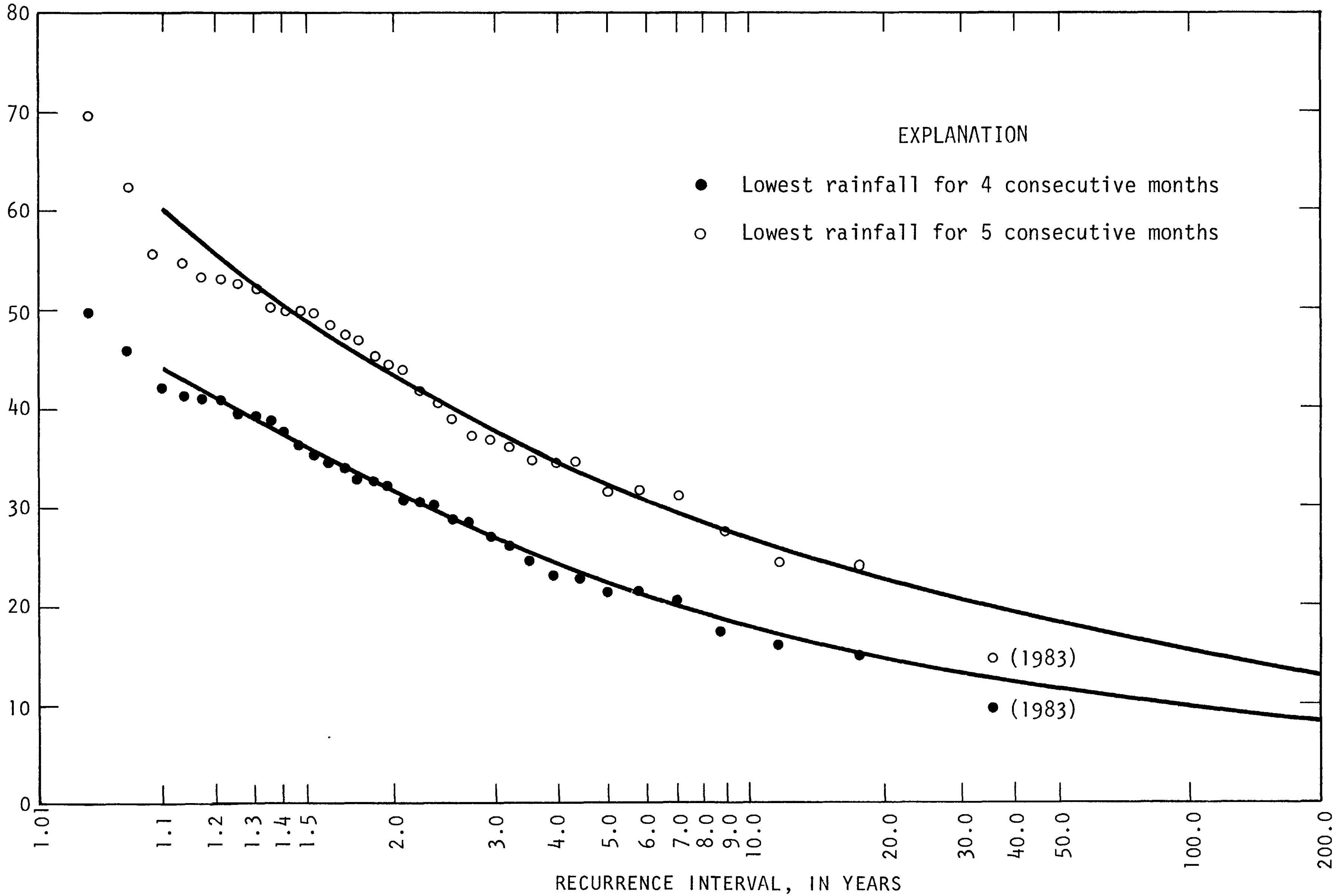


Figure 17. Recurrence intervals of lowest rainfall for 4 and 5 consecutive months on Moen during 12-month periods starting in August.

Streamflow

In 1968, six gaging stations were established by the U.S. Geological Survey on Moen, Dublon Island, and Tol. During 1983, only the station Wichen River at altitude 18 m, on Moen, remained in operation as the emphasis of the data-collection program had been shifted to ground water. Table 14 gives a comparison between mean monthly discharge of Wichen River at altitude 18 m, before and during the drought. The table shows that during the period January through May 1983, the mean discharge was only 8.4 percent of normal and that from October 1982 through May 1983 half the monthly mean discharges were the lowest on record.

Effects of Drought on Water Supply

Only on the island of Moen is most of the population served by a central water system. On the other Truk Islands, the people depend on shallow wells, rain catchments, springs, and small streams for water. The water for the Moen system comes from 16 deep wells and from the Pou catchment, a 90-acre area at the head of Pou Stream on the north slope of Mount Tonoken (fig. 18). The use of water in the islands is primarily domestic and small amounts from springs and seeps are used for subsistence farming.

Although the drought, as expressed in percent of normal rainfall, was not as severe in the Truk Islands as on Pohnpei, Kosrae, and the Marshall Islands, it started much earlier; and rainfall during the 8-month period October 1982 through May 1983 was only 31 percent of normal.

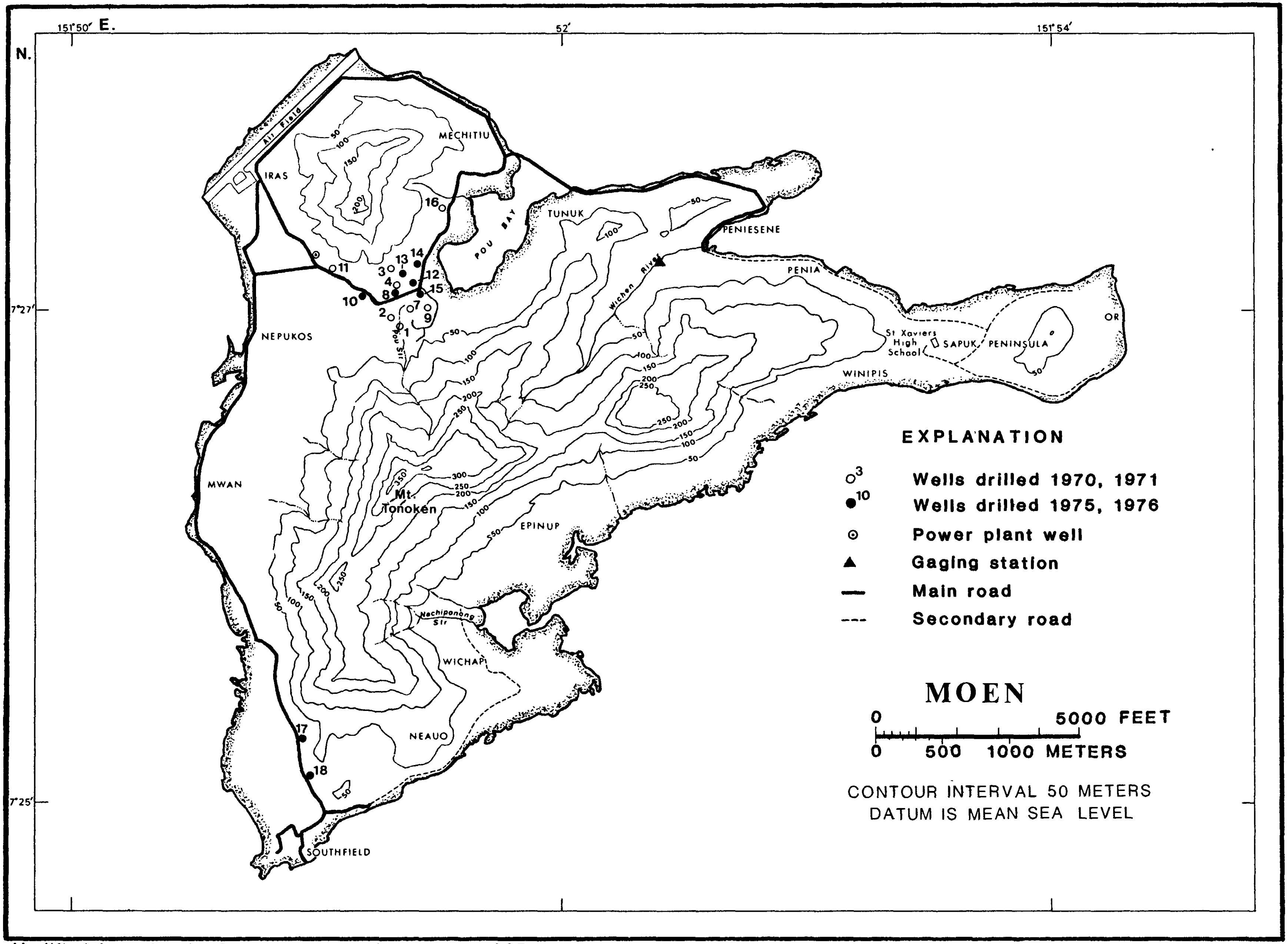
Consequently, the 90-acre Pou catchment area, which normally supplies about 150,000 gal/d was drying; and the pumpage of ground water was cut gradually from 670,000 gal/d in September 1982 to 318,000 gal/d in June 1983 to prevent further intrusion of salt water. The combined decrease in daily water production from the two sources was about 0.5 Mgal/d. Nevertheless, the chloride concentration of the well water doubled in wells 1, 7, 10, 15, and 17. (See fig. 18.) The chloride concentration of well 12 rose from 40 mg/L in September 1982 to 1,250 mg/L in April 1983 and that of well 14 rose from 81 to 1,200 mg/L during the same period (Van der Brug, 1983b). Apparently, ocean water from Pou Bay was intruding into the aquifer due to continued pumping and limited recharge. The weighted average chloride concentration of the pumped water increased from 78 mg/L on February 10, 1983 to 410 mg/L on April 20, 1983 (fig. 19).

Table 14. Mean monthly discharge of Wichen River at altitude 18 m, Moen, prior to and since October 1982

	1968-82 1/			1982-83	
	Average of monthly means (ft^3/s)	Number of years	Lowest monthly mean (ft^3/s)	Mean (ft^3/s)	Percent of 1968-82 1/
October	5.44	13	1.22	1.78	32.7
November	3.78	13	.99	.51*	13.5
December	2.77	13	.72	.47*	17.0
January	2.35	14	.21	.32	13.6
February	1.19	13	.061	.067	5.6
March	1.85	13	.076	.056*	3.0
April	2.40	12	.19	.49	20.4
May	4.05	13	.38	.056*	1.4
January to May	2.39	--	--	.20	8.4
October to May	2.89	--	--	.47	16.3
Annual	3.15	--	--	--	--

1/ 1968-81 for October to December.

* New minimum discharge for the month.



Modified from Austin, Smith and Associates, Inc., 1967.

Figure 18. Locations of water-production wells and Wichen River gaging station on Moen.

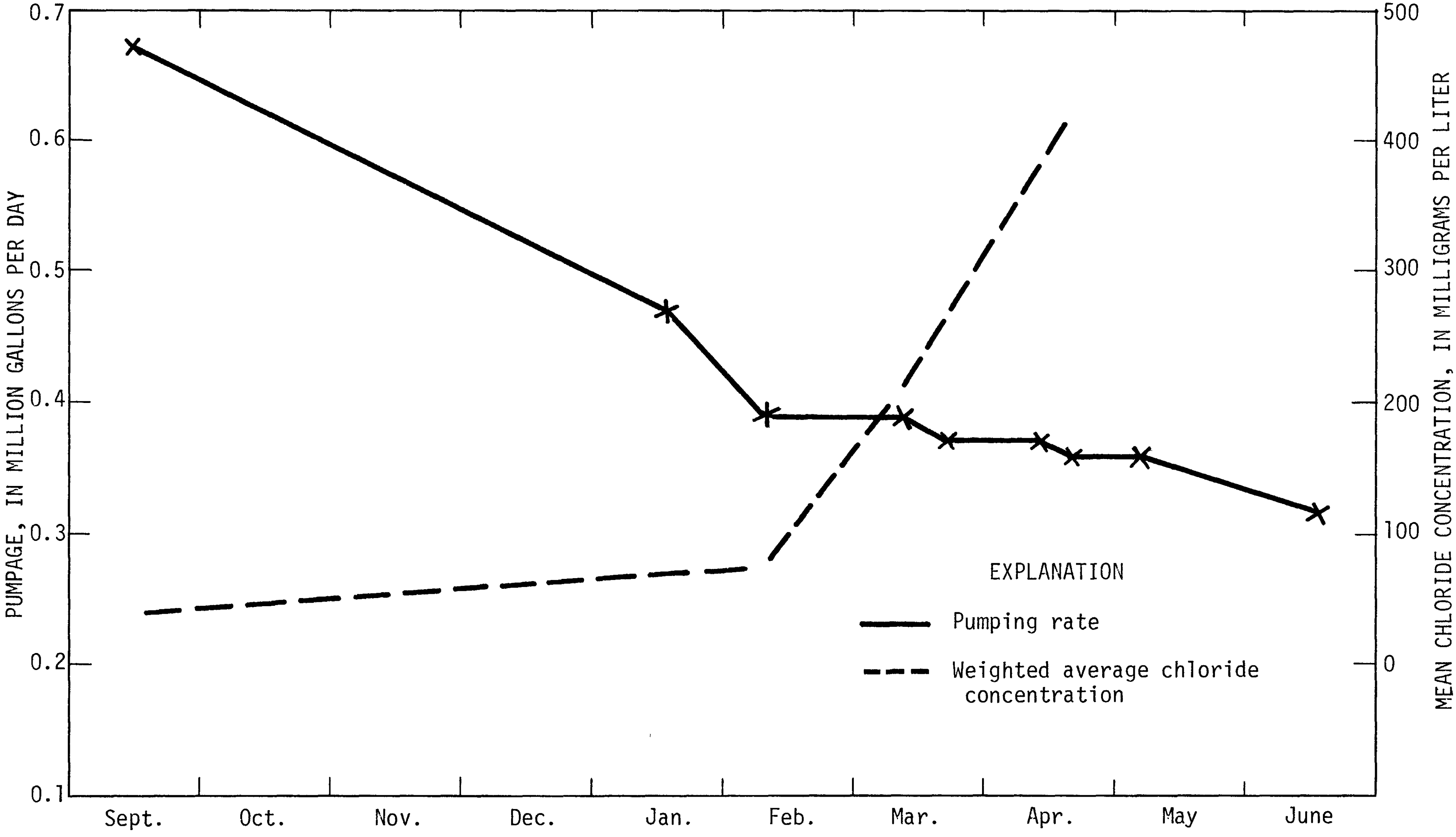


Figure 19. Pumpage and chloride concentration of water from Moen wells, September 1982 through June 1983.

Because of leakage in the transmission lines and in house connections and because of waste by consumers, water is only supplied for 2 hours in the morning and 2 hours at night even during periods of normal rainfall. During the drought, this supply was further reduced, by stages, to 1 hour daily in March 1983. On May 6, the scheduled water supply had to be suspended and water was available only at the fire hydrant at Truk High School. Storage reservoirs were near empty.

On some of the smaller islands in the Truk Lagoon, conditions were worse and water was shipped there twice weekly from Moen and Dublon Island. The small coral reef islands depend on shallow wells for water. On Tsis (population 500), only one well did not go dry and the entire population relied on that well for water with people waiting in line for hours (Billimon, B. I., oral commun., 1983).

The main concern on Truk during the drought was a recurrence of the cholera epidemic which started in August 1982. Personal hygiene was affected due to the shortage of water. Although no large new cholera outbreaks were reported during the drought, there was a significant increase in skin ailments, diarrhea and related diseases (cable from the Governor of Truk to the Disaster Control Officer, Federated States of Micronesia, April 1983).

Effects of Drought on Agriculture

During the 8-month drought on Truk, less than a third of the normal rain was recorded. Where sufficient depth of soil was available, coconut, breadfruit, and fruit trees survived easily; where growing in shallow soil, the trees lost their fruit or produced only undersized fruit. On the coral islands, salt water intrusion killed most of the taro plants, breadfruit trees produced no fruit, and coconut trees produced undeveloped nuts. People were compelled to purchase rice on Moen. It was estimated that at least a year would be required for the attainment of pre-drought yields (Ivra, David, State Agriculturist, oral commun., 1983).

POHNPEI

Physical and Cultural Setting

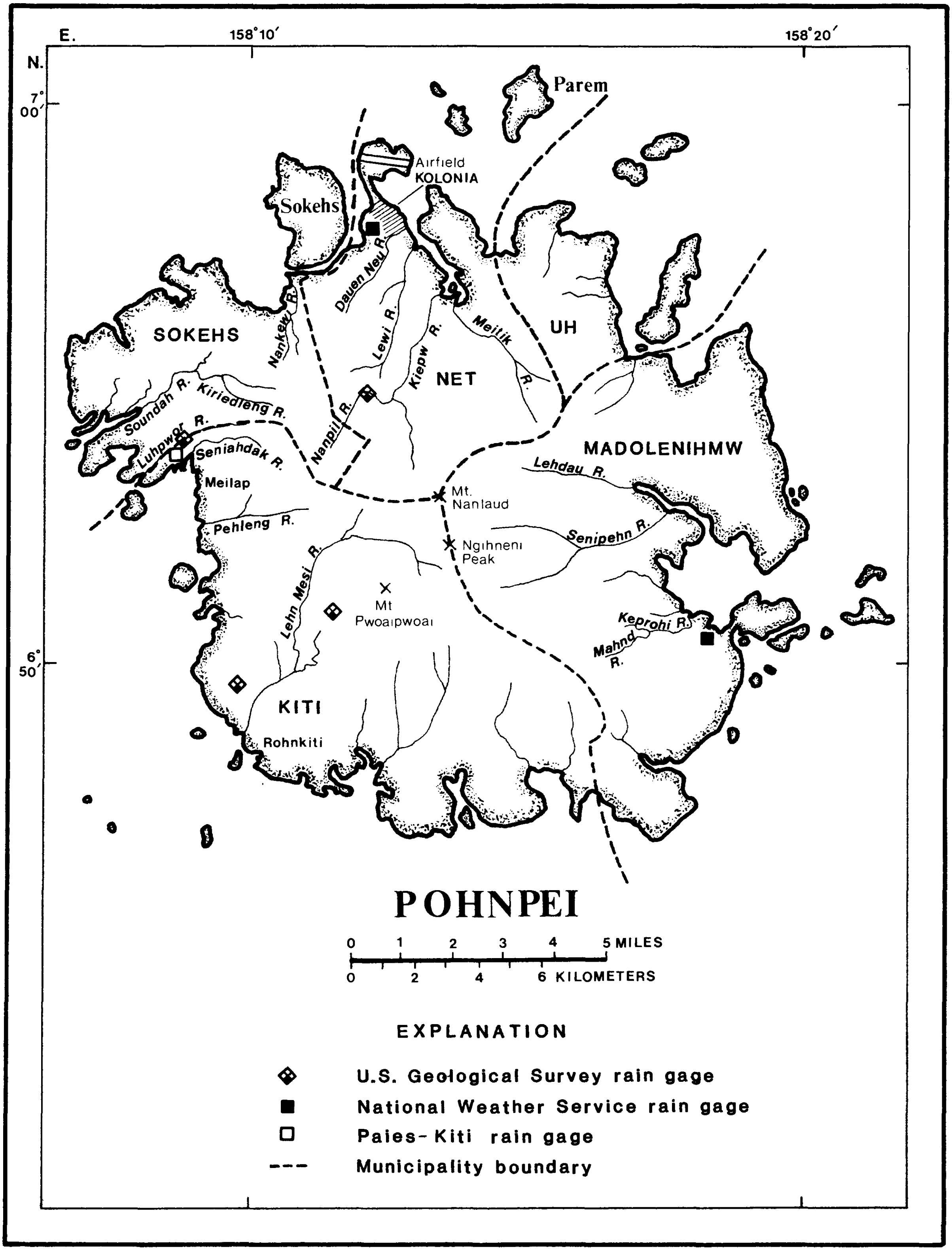
Pohnpei, the third largest island in the Western Pacific, is at latitude $6^{\circ}47'$ to $7^{\circ}01'$ N. and longitude $158^{\circ}06'$ to $22'$ E. The mountainous interior of the 129-mi^2 island has the highest peaks in the Western Pacific. The inhabitants live in the flat coastal areas, which are separated from the ocean by mangrove swamps as much as three-fourths mile in width. According to the 1980 census, 22,081 people live in Pohnpei State (U.S. Department of Commerce, 1982). Pohnpei State includes Mokil, Pingelap, Ant, Ngatik, Oroluk, Nukuoro, and Kapingamarangi atolls, which had a combined total population of 2,046 in 1980. About half the population of Pohnpei is in and around Kolonia and the rest live in villages along or near the coast. The interior of the island is uninhabited.

Practically the only employment opportunities are with the governments of the Federated States of Micronesia and Pohnpei State. Agriculture is mainly limited to the growing of some pepper and copra for export and to subsistence farming.

Rainfall

Records of rainfall at various locations on Pohnpei are available for most years since 1900. At present (1983), rainfall data are published by the U.S. National Oceanic and Atmospheric Administration for Kolonia, Madolenihmw, and Paies-Kiti and are collected by the U.S. Geological Survey at Nanpil River, Luhpwor River, Kiti, and on Mount Pwoaipwoai (fig. 20). Rainfall records were collected in or near Kolonia by the Germans (1900-10), the Japanese (1928-43), and the Americans (1950-present) and have been combined to represent a long-term period. The annual mean is 191 inches and the average rainfall for the driest month (February) is 10 inches. In contrast, no monthly total during the period January through May 1983 exceeded 2.21 inches.

Rainfall data collected on Pohnpei during the first 6 months of 1983 and comparisons with long-term rainfall at Kolonia and at Madolenihmw, are given in table 15. The table shows that in the 5-month period January through May 1983, rainfall in Kolonia was deficient by 65.54 inches and for 4 of these 5 months, rainfall was the lowest on record.



Base from U.S. Geological Survey, 1981, 1:10,000.

Figure 20. Location of rainfall stations on Pohnpei.

Table 15. Monthly January through June rainfall, in inches, for Pohnpei

	Jan.	Feb.	Mar.	Apr.	May	Total of Jan. to May	June
Kolonia							
1900-82[1/]:							
Number of years	57	57	59	56	57	--	58
Mean	11.52	10.11	13.75	19.08	20.45	74.91	16.88
Percent of annual mean.	6.0	5.3	7.2	10.0	10.7	39.2	8.8
Minimum monthly	3.31	1.05	3.30	6.07	11.72	--	9.00
Year of minimum	1973	1977	1931	1966	1953	--	1939
1983:							
Rainfall	1.89*	1.72	1.52*	2.03*	2.21*	9.37	15.91
Percent of mean	16	17	11	11	11	13	94
Departure from mean	-9.63	-8.39	-12.23	-17.05	-18.24	-65.54	-0.97
Madolenihmw							
1967-82:							
Number of years	15	15	15	15	14	--	12
Mean	9.42	9.59	12.30	18.45	19.01	68.77	16.99
Percent of annual mean.	5.3	5.4	6.9	10.3	10.6	38.5	9.5
1983:							
Rainfall	1.29*	.80*	1.24*	.70*	2.21*	6.24	12.15
Percent of mean	14	8	10	5	12	9	72
Departure from mean	-8.13	-8.79	-11.06	-17.75	-16.80	-62.53	-4.84
Other 1983 rainfall:							
Nanpil River	3.15	2.39	2.78	2.91	4.39	15.62	16.47
Luhpwor River	1.18	1.82	1.57	.65	1.97	7.19	14.65
Mt. Tolen Pwoaipwoai	3.39	3.18	4.07	2.39	6.44	19.47	24.07
Paies-Kiti	2.80	2.33	1.92	2.10	2.35	11.50	17.82

[1/] Compiled from "Mittheilungen von Forschungreisenden und Gelehrten aus den deutschen Schutzgebieten", 1902; Institute of Human Relations, 1943; Taylor, 1973; U.S. National Oceanic and Atmospheric Administration, 1982, 1983.

* New minimum monthly total.

Figure 21 shows that the recurrence probability of a 5-month dry period similar to the one in 1983 would be about once in 250 years. The curve was developed for the 12-month period beginning in August as described in the section on the Palau Islands.

Streamflow

Since 1970, the U.S. Geological Survey has collected continuous records of streamflow at six gaging stations and has made low-flow discharge measurements at nine partial-record stations. The locations are shown in figure 22.

Three of the continuous-record stations that were in operation in 1983, had been operated for at least 10 years. For these three stations, the mean monthly discharges for the first 6 months of the calendar year during the period of record until 1982 and for 1983 are given in table 16. Comparison of these discharges show that during January through May 1983, only about 5 percent of the normal discharge was recorded, and that in 1983 the discharge from January through May was the lowest on record for each month. Figure 23 shows the comparison of average rainfall with 1983 rainfall for Kolonia; and of average streamflow with 1983 streamflow for Nanpil River.

By correlation of discharge measurements from partial-record stations with concurrent discharge at nearby continuous-record stations, regression equations have been developed (Van der Brug, 1984b). From these equations, estimates of minimum discharge at low-flow partial-record stations prior to 1983 and for 1983 have been made. These minimum discharges, as well as those for continuous-record stations, are listed in table 17. At most of the stations and at the miscellaneous sites listed in the table, a discharge measurement was made once a month during the drought. The lowest of these measurements is given in the table.

Effects of Drought on Water Supply

All water used on Pohnpei is for domestic purposes. There are no industries on the island and, because of abundant rainfall, water is not used for irrigation. A central water system supplies Kolonia and surrounding areas. Water for the system comes from the Nanpil River. The average daily discharge of the Nanpil River for the first 5 months of the calendar year during 1971-82 was

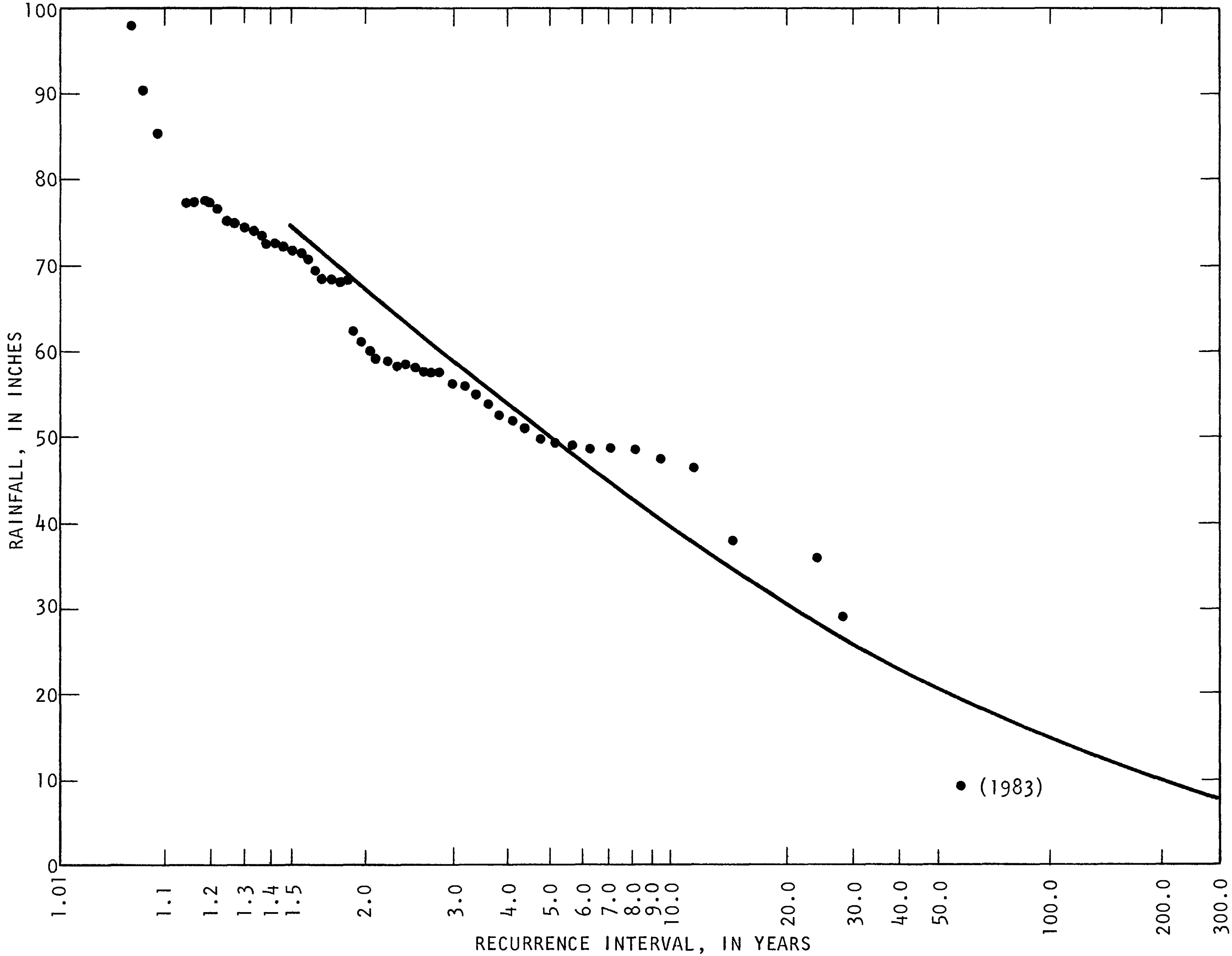
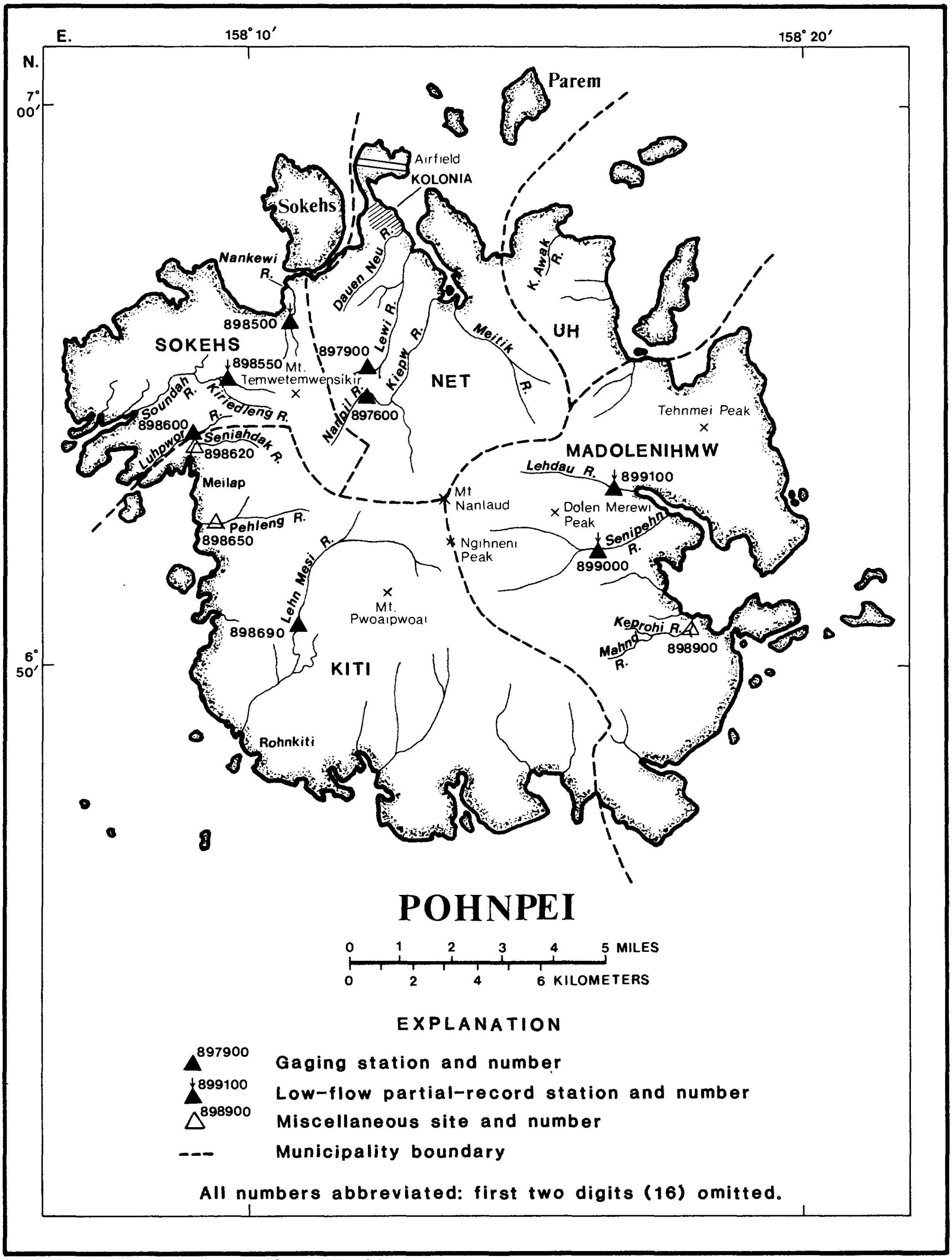


Figure 21. Recurrence intervals of lowest rainfall for 5 consecutive months at Kolonia during 12-month periods starting in August.



Base from U.S. Geological Survey, 1981, 1:10,000.

Figure 22. Locations of surface-water stations and miscellaneous measurement sites on Pohnpei.

Table 16. Mean monthly discharges, January through June, of rivers on Pohnpei prior to 1983 and in 1983

[Discharge in cubic feet per second and in percentage]

Station number	16897600				16897900				16898600			
Station name	Nanpil River				Lewi River				Luhpwor River			
Drainage area	3.00 mi^2				0.46 mi^2				0.72 mi^2			
Years of record	12				12				10			
	1971-82		1983		1971-82		1983		1971-82		1983	
	Mean	Lowest mean	Mean	Per-cent 1/	Mean	Lowest mean	Mean	Per-cent 1/	Mean	Lowest mean	Mean	Per-cent 1/
January	32.4	10.0	3.80*	11.7	3.6	0.77	0.40*	11.1	5.8	1.16	0.97*	16.7
February	34.0	4.4	2.99*	8.8	3.6	.40	.25*	6.9	5.9	1.09	.72*	12.2
March	42.8	16.6	2.62*	6.1	4.2	1.69	.091*	2.2	6.5	2.51	.46*	7.1
April	60.1	37.8	1.55*	2.6	6.7	4.10	.092*	1.4	10.3	6.64	.28*	2.7
May	59.0	34.3	4.40*	7.5	7.9	4.55	.11*	1.4	10.8	5.48	.29*	2.7
January to May	46.8	--	3.08	6.6	5.2	--	.19	3.7	9.9	--	.54	5.5
June	53.4	32.2	36.3	68.0	7.0	3.86	2.43*	34.7	11.3	7.33	3.35*	29.6
Annual	47.1	--	--	--	5.64	--	--	--	9.19	--	--	--

1/ Percentage of 1971-82 mean for the month.

* New minimum mean discharge.

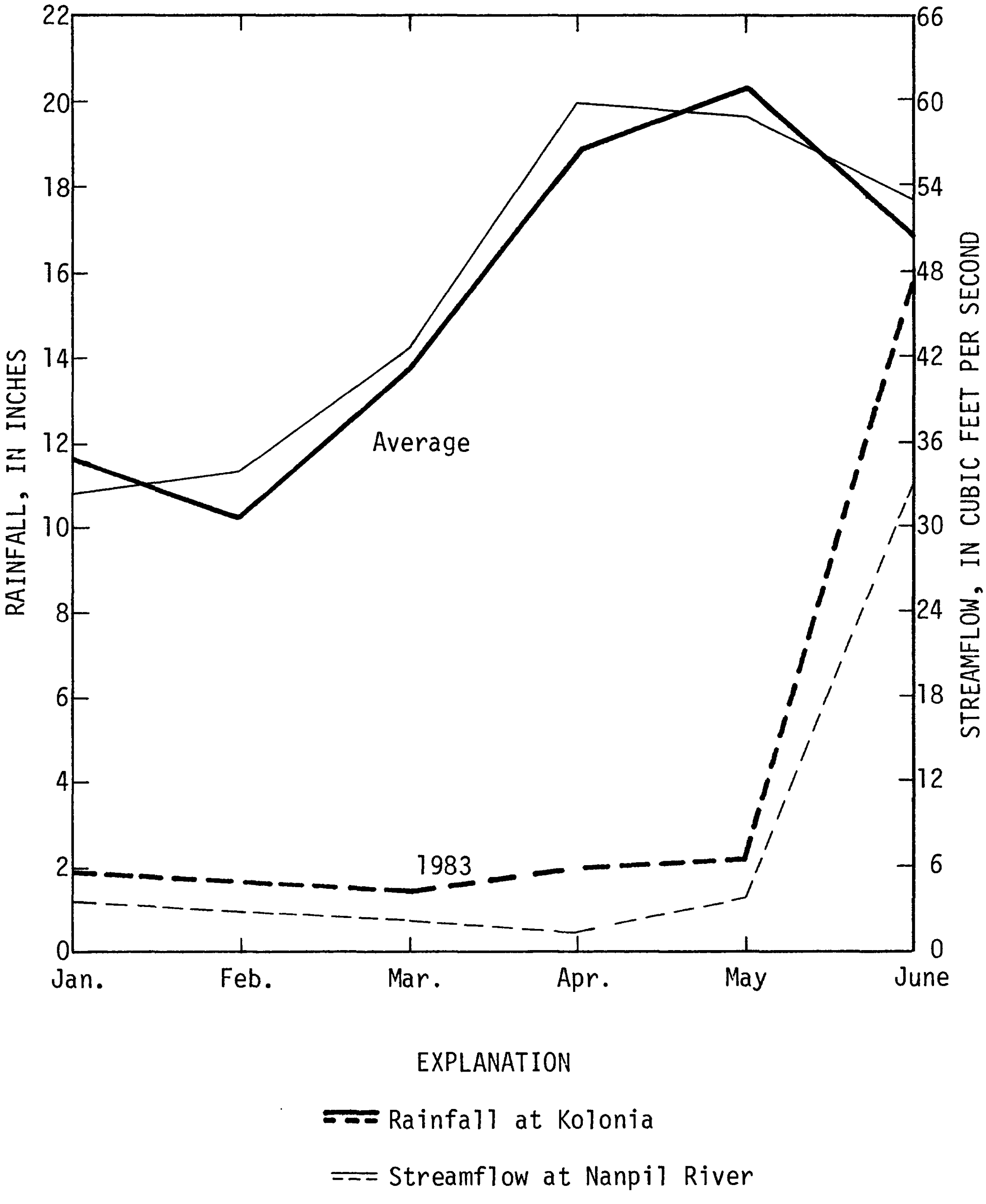


Figure 23. Comparisons of average rainfall and streamflow with 1983 rainfall and streamflow on Pohnpei.

Table 17. Lowest discharge, in cubic feet per second, of rivers on Pohnpei

[Y, discharge for partial-record station;
X, discharge for continuous-record station]

Station number	Station name	Drainage area (mi^2)	Lowest discharge measurement made in 1983	Minimum discharge: Before 1983	Minimum discharge: In 1983	Minimum discharge: Method of determination	Period of record
16897550	Meitik River	5.04	--	1.0	0.23	Correlation with Nanpil R., $Y=0.45X^{1.59}$.	1971, 1973, 1977, 1980, 1983.
16897600	Nanpil River	3.00	0.65 (Apr. 12)	1.6	.54	Gaging station record.	1970-83.
16897800	Kiepw River at mouth.	11.2	--	6.3	2.6	Correlation with Nanpil R., $Y=4.01X^{0.99}$.	1970-71, 1973-74, 1977, 1980, 1983.
16897900	Lewi River	.46	.03 (Apr. 12)	.13	.02	Gaging station record.	1970-83.
16898500	Nankewi River	1.48	.51 (May 25)	1.1	.38	Correlation with Luhpwor R., $Y=2.81X^{0.98}$.	1971-74, 1976-77, 1980-83.
16898550	Kiriedleng River	.73	.42 (Apr. 27)	.53	.15	Correlation with Luhpwor R., $Y=1.44X^{1.10}$.	1972-77, 1980-83.
16898600	Luhpwor River	.72	.18 (June 8)	.40	.13	Gaging station record.	1973-83.
16898620	Seniahdak River*	.56	.31 (Apr. 27)	--	--		1981-83.
16898650	Pehleng River*	2.01	.56 (Apr. 27)	--	--		1981, 1983.
16898690	Lehn Mesi River	2.31	5.1 (Apr. 21)	16.0 1/	4.5	Gaging station record.	1982-83.
16898900	Keprohi River*	2.05	1.0 (May 26)	--	--		1981-83.
16899000	Senipehn River	6.04	3.4 (Mar. 24)	5.0	2.3	Correlation with Nanpil R., $Y=3.34X^{0.85}$.	1971, 1973, 1976-77, 1980-81, 1983.
16899100	Lehdau River	2.44	1.5 (Mar. 24)	2.9	1.4	Correlation with Nanpil R., $Y=1.99X^{0.77}$.	Do.

* Miscellaneous discharge measurement site.

1/ Only one year of record.

30 Mgal/d (46.8 ft^3/s). In the same period in 1983, the average flow was 2.0 Mgal/d, not much more than the amount of water normally diverted, as the capacity of the treatment plant is 1.7 Mgal/d. The total river flow was below the normal diversion rate for many days.

In the central water system, leakage and waste account for a very large percentage of the water supplied. Most of the losses occur at house connections or through waste by consumers, who leave faucets running continuously. As much as 88 percent of the water may be lost or wasted (Barrett, Harris and Associates, Inc., preliminary leak detection studies, July 5, 1983 and Sept. 22, 1983). Consequently, even when rainfall and streamflow are normal, water is available only during part of the day. Because of the drought, the "water hours" were reduced by the end of February to one hour in the morning and one hour at night. At times, the higher locations were without water for several days. All public schools in the State were closed starting on April 22. The hospital stopped all but emergency surgery.

Little or no use is made of roof rain catchments in or outside Kolonia. In Kolonia, the dependency is on the central water system and outside Kolonia water is obtained from streams, seeps, or shallow wells. During the drought almost all the shallow wells and most of the seeps dried up and water was mainly obtained from perennial rivers, sometimes at a considerable distance from home.

The islands in Pohnpei lagoon were supplied by boat with 1,000 gallons of water every third day and 10,000 gallons of water were shipped to the outer islands once a month.

As a measure for preventing the spread of disease, the need for purification of water was communicated to the population in writing and by radio broadcasts. Also, health education teams visited the villages to demonstrate techniques for use of disinfectants. Daily tests and analyses of water were made by sanitation teams, but no records of these were obtained. During the drought, untreated supplemental water was added to the distribution system, which may have been the cause of a small increase in infectious hepatitis and a significant increase in diarrhea cases (FSM Disaster Control Officer to the President of the Federated States of Micronesia, written commun., May 19, 1983).

Effects of Drought on Agriculture

Most of the agriculture on Pohnpei is subsistence farming; the only cash crops are copra, black pepper, and some vegetables. Copra production did not suffer substantially in 1983 as a supply of old coconuts was still available; but production was significantly less the following year as few new coconuts were produced in 1983. Brush fires burned on 20 to 25 percent of the island and destroyed much of the pepper plantings. Consequently, in September 1983, the 1983 pepper production was 7,500 pounds below that of 1982. The acreage of commercially grown vegetables is only about 3.3 acres; that of tapioca, 7 acres; sweet potato, 23 acres; and dry taro, 3 acres. Practically all these crops perished during the drought (Vega, R. R., State Agriculturist, oral commun., 1983).

Subsistence farming (of breadfruit, coconut, tapioca, taro, sweet potato and banana) is the main source of food for most people living outside Kolonia. Although many of the breadfruit and coconut trees survived, the other crops did not. People living near a perennial stream were able to save some of their crops. For the others, there was little production in 1983 and imported food was purchased until new crops could be harvested 6 months to 2 or more years after the end of the drought, depending on the crop (Panuel, Waltick, oral commun., 1983).

The State Agriculture Department has distributed some planting material (sweet potato, tapioca) but has not been able to assist with yam and taro. The yam plays an important part in Pohnpeian culture and the traditional feast of the harvesting of the yams is the center of cultural and social life. It was feared that because of the drought, the harvest would fail.

Agricultural losses until April 15, 1983, in percent and in dollar value were tabulated by the State Agriculture Department (table 18). Although the drought lasted an additional month and a half, most of the damage had occurred by that time. For instance, the time when breadfruit starts to develop had passed.

Of the small islands in Pohnpei State, the greatest losses were reported at Parem off the Pohnpeian coast. Here, 100 percent loss was reported for all crops and most of the residents moved to Pohnpei (Lighor, Hermina, Nett area coordinator, written commun., May 3, 1983). Due to the increase in salinity and the lowering of the water table, taro plants and many breadfruit trees died on the atolls of Pohnpei State. Supplemental food, consisting of rice, powdered milk, and fruit juices have been made available by the U.S. Department of Agriculture to 13,473 citizens of the State (Governor State of Pohnpei to Acting Speaker Pohnpei State Legislature, written commun., Aug. 1, 1983).

Table 18. Estimate of drought damage to crops in Pohnpei State until April 15, 1983

[Source: Agriculture Department, State of Pohnpei]

Crops	Percent of total crop production	Percent damaged	Estimated value damaged crops (U.S. $)	Number of months to restore production to pre-1983 level
Banana	4.8	75	195,800	18
Black pepper	1.1	60	23,000	12
Breadfruit	5.2	80	449,300	36
Coconut (fresh)	13.5	55	269,300	12
Copra	4.6	55	92,400	12
Fruit	.4	75	23,400	24
Kava (sakau)	4.1	90	405,000	36
Root crops (taro, yam, sweet potato).	62.4	85	3,845,400	24
Vegetables	3.8	90	62,600	6
Total	99.9	--	5,366,200	--

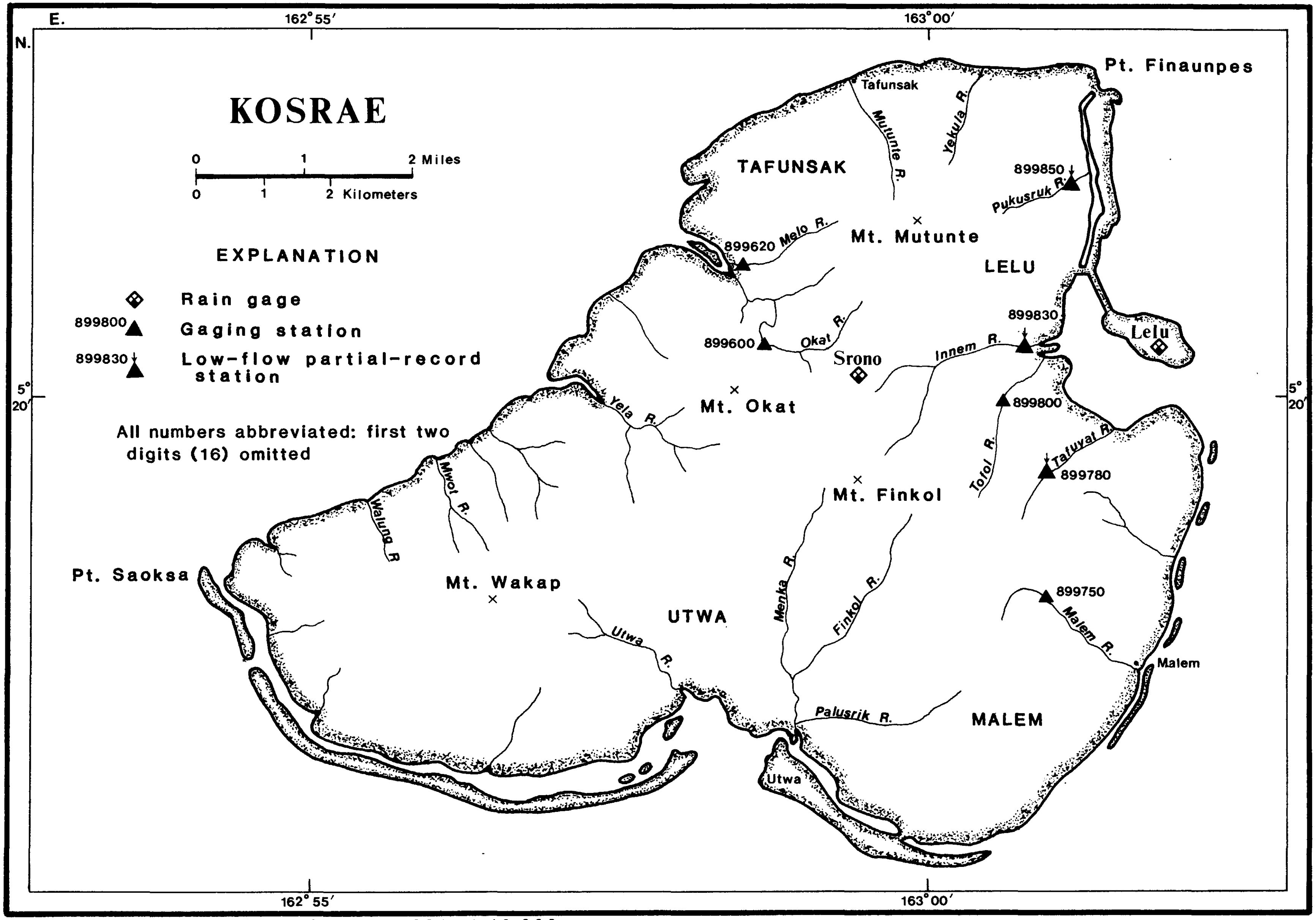
KOSRAE

Physical and Cultural Setting

Kosrae, the easternmost of the Caroline Islands, is at latitude 5°16' to 23' N. and longitude 162°55' to 163°03' E. The island is 42 mi^2 in area. The mountainous interior is covered with lush, tropical vegetation, and mangrove swamps border much of the coastline. Rainfall averages about 200 inches per year on the coast and is higher in the interior. The climate is uniformly warm and humid. Rivers, some large in relation to the size of the island, radiate out from the interior in all directions and are perennial. The inhabitants live on a narrow coastal strip or off the eastern coast on the small island of Lelu which is connected to the main island by a causeway. A third of the total population of 6,000 lives on Lelu, the remaining two-thirds in coastal villages. The only employment of any consequence is with the government. Agriculture is limited to copra production, limes, and small-scale farming for local markets.

Rainfall

Rainfall records have been collected at various locations on Kosrae since 1895; however, the records are incomplete except for short periods during the German, Japanese, and United States administrations. During the German administration, rainfall records were collected at the American Mission at Mwot River on the western side of the island (1895, 1899-1904) and at Lelu on the eastern side (1903-12). The Japanese recorded the rainfall at Lelu only during 1932 to 1934 and these records were not available. Under the United States administration, the National Oceanic and Atmospheric Administration published rainfall records for Lelu for most of the months from 1954 to 1978. Since 1971, the U.S. Geological Survey has collected rainfall records at various locations on the island. Daily readings were made by observers for a few years at some of the locations but most were cumulative totals read once or twice monthly. In June 1982, the Survey established a continuous-record rain gage in the center of the island (at Srono) at an altitude of 330 ft (fig. 24). During the 1983 drought, this was the only rain gage in operation on the island.



Base from U.S. Geological Survey, 1981, 1:10,000.

Figure 24. Locations of rain gages and surface-water stations on Kosrae.

Only 14 years of complete record were collected at Lelu from 1903 to 1978 and the average annual rainfall for the 14 years is 206 inches. The total of all monthly means of 26 to 30 years is 200.59 inches. Rainfall is distributed fairly uniformly throughout the year, ranging from 6.3 percent of the annual rainfall in October to 10.8 percent in April. April is clearly the wettest month of the year with the highest minimum total (10.59 inches) and the highest maximum total (53.19 inches). Comparison of short-term rainfall records at Survey rain gages on Kosrae indicate that, although there are substantial differences in daily rainfall in various parts of the island, rainfall totals (at least in coastal areas) are similar.

To evaluate the amount of rain which fell during the first 5 months of 1983, rainfall at Srono for this period is compared with the longer-term rainfall at Lelu (table 19). This table shows that rainfall for each month of January through April 1983 was the lowest on record and that rainfall for the first 4 months of 1983 was deficient by 62.56 inches and was only 12 percent of normal. This deficiency probably was even higher than shown because the rainfall data at Lelu were collected near sea level and the rain gage at Srono is located at an altitude of 330 ft above mean sea level. Normally, rainfall at higher altitudes is greater than in coastal regions.

Because of the limited amount of rainfall data available for Kosrae, no recurrence interval for the drought could be determined. However, since rainfall on Pohnpei and Kosrae is similar, and the percentage of rain falling during the first 4 months of the year on Pohnpei was 13 percent of normal and on Kosrae 12 percent, it can be assumed that the recurrence interval for the 1983 drought also will be similar. For Pohnpei, this was estimated to be about 250 years.

The dams on Kosrae are at higher altitudes where no people reside. Contamination of the water supply sources has, therefore, never been a problem and none of the water is treated. During the drought, chlorine pellets were supplied for individual rain catchment tanks. In addition, the people were advised to boil their water. At the dams, no bacterial counts were made of the water although discoloration was noticeable. A significant increase in the number of cases of hepatitis and gastro entritis occurred during the drought. The increase in insect population, especially mosquitoes, did not pose a health hazard (Palsis, Nena, State Director of Environmental Health, oral commun., 1983). No schools were closed on Kosrae because of the shortage of water.

Table 19. Monthly rainfall, in inches, prior to 1978 at Lelu and for 1983 at Srono, Kosrae

[Sources: Lelu rainfall for 1903-12, monthly and annual totals, "Strategic Bulletins of Oceania" No. 7, publication of Institute of Human Relations and "Mitteilungen von Forschungreisenden und Gelehrten aus den deutschen Schutzgebieten", 1905, 1913; for 1954-78, monthly and annual totals, U.S. Weather Bureau, 1968; daily figures, U.S. National Oceanic and Atmospheric Administration, 1956-72 and 1973-78; Srono rainfall, U.S. Geological Survey data]

	Jan.	Feb.	Mar.	April	Total Jan.-April	May
Lelu						
1903-12, 1954-78:						
Number of years	27	29	30	26	--	26
Mean	14.39	16.35	18.67	21.66	71.07	18.80
Percent of annual mean.	7.2	8.1	9.3	10.8	35.4	9.4
Minimum monthly	3.51	3.97	3.93	10.59	--	7.71
Year of minimum	1973	1970	1970	1978	--	1970
Srono						
1983:						
Monthly total	1.74*	1.32*	1.02*	4.43*	8.51	13.81 1/
Percent of mean Lelu rainfall.	12	8	5	20	12	--
Departure from Lelu mean.	-12.65	-15.03	-17.65	-17.23	-62.56	--

* New minimum monthly total.

1/ For May 1-25.

Streamflow

The U.S. Geological Survey has collected surface-water data on Kosrae since 1971. In 1983, gaging stations were in operation on Melo River on the west coast and Malem and Tofol Rivers on the east coast. Table 20 compares the mean monthly discharges of the three stations for the first 6 months of the calendar year in 1983 with discharges for 1971-82. Streamflow on the east coast during the first 4 months of the year was only about 4 percent of normal and on the west coast, 7 percent of normal.

By correlation of discharge measurements at partial-record stations with concurrent discharge at Tofol River, regression equations have been developed (Van der Brug, 1984c). Minimum discharges at low-flow partial-record stations were calculated on the basis of these equations for the period 1971 to 1982. Because practically all water was diverted from Tofol River during the drought, the correlation could not be used to determine the lowest discharge at the partial-record stations in 1983. Therefore, only results of the lowest discharge measurements made in 1983 are listed in table 21.

Effects of Drought on Water Supply

There is no central water system on Kosrae but most of the villages have their own supply -- a pipeline from a small dam on a nearby stream to the village. Due to abundant rainfall, there normally is sufficient water all year. Lelu receives water from Pukusruk River, the village of Tafunsak from Mutunte River, Malem from Malem River, and Utwa from Palusrik River. No ground water is used on Kosrae. There are eight small dams on Kosrae to impound and divert water for domestic use. During the drought, water levels were at their lowest but only the reservoir on the Walung River went dry. At the other reservoirs, some storage remained behind the dams and in the long transmission lines.

Because of the population density, residents on Lelu were much affected by the water rationing. Water was available only for two hours in the morning and two hours at night. Water rationing was also in effect in the villages of Utwa, Malem, and Tafunsak, for which the government supplied water tanks to augment the village supply.

Table 20. Mean monthly discharges, January through June, of three rivers on Kosrae prior to 1983 and in 1983

[Discharge in cubic feet per second and in percentage]

Station number	16899620				16899750				16899800			
Station name	Melo River				Malem River				Tofol River			
Drainage area	0.68 mi^2				0.76 mi^2				0.53 mi^2			
Years of record	8				11				12			
	1974-82		1983		1971-82		1983		1971-82		1983	
	Mean	Lowest mean	Mean	1/ Percent	Mean	Lowest mean	Mean	1/ Percent	Mean	Lowest mean	Mean	1/ Percent
January	5.61	2.43	0.67*	12	5.04	2.03	0.42*	8	4.90	1.91	0.48*	10
February	5.57	1.86	.44*	8	4.75	1.42	.26*	5	4.05	1.53	.17*	4
March	9.03	2.43	.40*	4	9.12	2.44	.27*	3	7.60	2.25	.073*	1
April	9.62	5.52	.59*	6	9.27	5.81	.34*	4	8.45	4.08	.13*	2
May	8.36	5.70	4.40*	53	9.55	4.22	2.79	29	8.22	3.55	1.51*	18
June	8.58	4.26	5.20	61	7.45	2.97	3.38	45	7.48	2.96	2.18*	29
January to:												
April	7.46	--	.53	7	7.04	--	.33	5	6.25	--	.18	3
May	7.67	--	1.32	17	7.59	--	.83	11	6.68	--	.48	7
June	7.80	--	1.97	25	7.53	--	1.25	17	6.78	--	.76	11
Annual	7.13	--	--	--	7.17	--	--	--	6.05	--	--	--

1/ Percentage of mean discharge 1974-82 (1971-82).

* New minimum mean discharge.

Table 21. Lowest discharge, in cubic feet per second, of rivers on Kosrae

[Y, discharge for partial-record station;
X, discharge for continuous-record station]

Station number	Station name	Drainage area (mi^2)	Lowest discharge In 1983	Lowest discharge Before 1983	Lowest discharge Method of determination	Period of record
16899600	Okat River	1.94	1/ 0.74 (Mar. 9)	1.4	Gaging station record	1971-82.
16899620	Melo River	.68	.11 (Apr. 6, 7)	.58	do.	1975-83.
16899750	Malem River	.76	2/ .07 (Apr. 30, May 1).	.26	do.	1971-83.
16899780	Tafuyat River. 3/	.27	1/ .15 (Mar. 31)	.21	Correlation with Tofol River, $Y=0.40X^{1.19}$.	1974-75, 1977-83.
16899800	Tofol River	.53	2/ .01 (Apr. 1)	.58	Gaging station record.	1971-83.
16899830	Innem River 3/	1.82	1/ .21 (Mar. 31)	1.85	Correlation with Tofol River, $Y=3.05X^{0.92}$.	1971-74, 1977-83.
16899850	Pukusruk River. 3/	.27	1/ .07 (Mar. 8)	.21	Correlation with Tofol River, $Y=0.36X^{0.83}$.	1974-75, 1980-83.

1/ Lowest discharge measurement made; minimum discharge may have been less.
2/ Below diversion.
3/ Low-flow partial-record station.

Effects of Drought on Agriculture

Crops were destroyed or damaged both by accidental fires and by lack of moisture. Taro, which requires much water, was most affected by the drought. Losses applying to 90 percent of the island, based on estimates by farmers, are given in table 22.

Table 22. Crop losses sustained on Kosrae by drought in 1983 in numbers and in percentages

[Compiled from memorandum from local Agriculture Division to the Lt. Governor of Kosrae]

Crop	Number of plants lost	Percent of total
Tuber crops (yam, taro, cassava, sweet potato)	196,000	60
Vegetables (cabbage, watermelon, cucumber, pineapple.	2,450	30
Vascular plants (sugar cane, bananas, papaya)	100,000	26
Coconut trees	9,750	26
Other bearing fruit trees (mainly breadfruit)	10,100	30

MARSHALL ISLANDS

Physical and Cultural Setting

The Marshall Islands are between latitudes 5^{o} and 15^{o} N., longitudes 162^{o} and 173^{o} E., in an area of about 300,000 mi^2 of ocean. Grouped in 34 atolls and 870 reefs are 1,152 islands, which have a total land area of 69 mi^2 (Stanley, 1983) and a population of 31,000 in 1980 (The New Pacific Magazine, 1981). Geographically the islands can be separated into two chains, the northeastern Ratak (Sunrise) chain and the southwestern Ralik (Sunset) chain, about 150 miles apart (fig. 25). The atolls are all low islands of coral and sand; the highest point is 30 ft at Likiep atoll in the northeastern chain (Pacific Island Yearbook, 1981).

Large atolls in the northeastern chain include Mili atoll, a chain of 90 islets extending for 32 miles; Arno atoll, with a land area of 3 mi^2 and a population of 1,487 in 1980; and Majuro atoll. Majuro atoll, about 2,300 miles southwest of Honolulu, has a length of 35 miles and an average width of 500 ft. Majuro, the seat of government since World War II, has a population of about 12,000.

Large atolls in the southwestern chain are Jaluit (population 1,450), Ailinglaplap (population 1,385), Kwajalein, Bikini, and Enewetok. Jaluit consists of 84 islands having a land area of 4.4 mi^2; its triangular lagoon measures 30 by 12 miles. Kwajalein, the largest atoll on earth, consists of a reef 175 miles in length surmounted by 90 islands and enclosing a 1,000-mi^2 lagoon; the U.S. missile base is on the main island. Bikini and Enewetok atolls in the Northern Marshalls are the sites of U.S. nuclear testing.

According to the 1980 U.S. census, the population of Ebeye is 6,169 (20 percent of the total population of the Marshall Islands), although its land area is only 0.1 mi^2. Marshallese employees, and their dependents, of the nearby U.S. missile base live on Ebeye.

Rainfall

Rainfall is fairly high throughout the Marshall Islands. At the two locations where long-term rainfall data are available, Kwajalein (since 1945) and Majuro (since 1955), average annual rainfall is 103 and 136 inches, respectively.

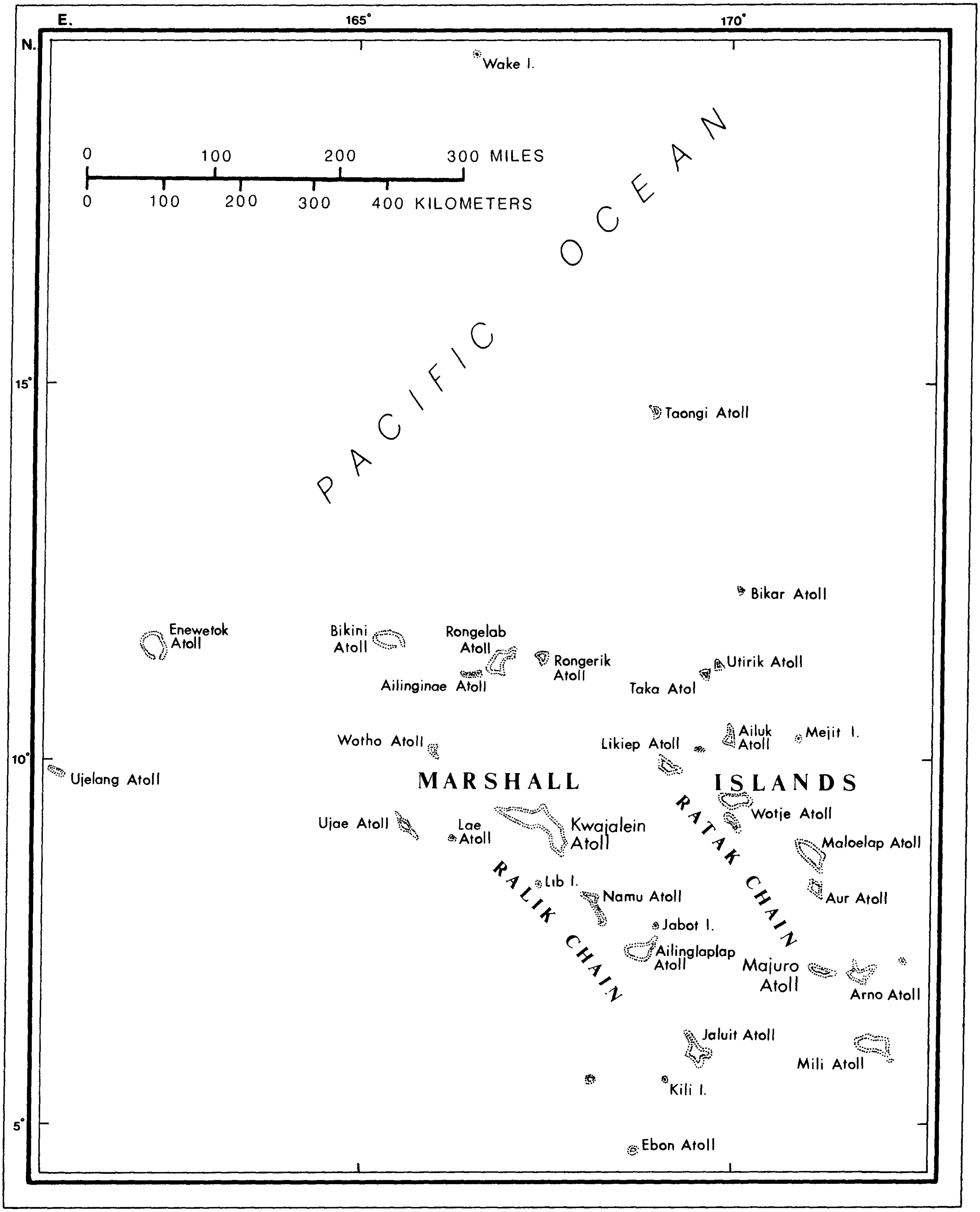


Figure 25. The Marshall Islands.

Average annual rainfall in 1894-1913 at Ujelang, the westernmost atoll of the Marshall Islands, was 77 inches; and at Jaluit, a southern atoll near Majuro, 159 inches (Reed, 1927). On Wake Island, north of the Marshall Islands, annual rainfall in 1935-72 was 37 inches. These average rainfall values indicate that the annual rainfall normally increases from north to south in the islands.

During the 1983 drought, rainfall data were available for Kwajalein and Majuro (U.S. National Oceanic and Atmospheric Administration, 1983) and for Ailinglaplap, Wotje, and Mili atolls (compiled by Paul Peter, National Weather Service station, Majuro, from twice daily readings submitted by local observers).

On Kwajalein, the 1983 drought began in January and lasted until June. On Majuro, the drought began in December 1982 and ended in May 1983. For the period January through May 1983, rainfall at both locations was only 13 percent of normal (table 23). The total rainfall for the 5-month period January through May 1983 was only one third of the previous lowest 5-month total in 28 years of rainfall record.

Figure 26 shows that the recurrence probability of a 5-month dry period similar to the one in 1983 on Majuro is about once in 125 years. The curve was computed for the 12-month period beginning in August by methods described in the section on the Palau Islands.

Effects of Drought on Water Supply

In the Marshall Islands, only Kwajalein and Majuro have a central water system. Kwajalein is a U.S. missile base and is well provided with water from a runway catchment system, a very productive well, and a saltwater conversion plant. Normally, mostly catchment water is used. During the drought, sufficient water was produced to continue the normal shipments of water to nearby Ebeye, where the base workers live, and to ship water to some of the small nearby islands which had little or no water.

On Majuro, almost all the water for the central water supply system comes from the airport runway catchment. This water is stored in a 17-Mgal reservoir at the airport, and transmitted about 8 miles through a 10-inch pipe to a 0.5-Mgal tank for distribution in the population center on the island. Near the tank are two wells which can be pumped when supplemental water is needed.

Table 23. Monthly rainfall, in inches, for the Marshall Islands during December 1982 through June 1983

[Source: U.S. National Oceanic and Atmospheric Administration, 1982, 1983]

	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total Jan.-May	June	Total Dec.-May
Majuro									
1955-82 (28 years):									
Mean	12.05	7.90	6.42	9.42	11.59	11.97	47.30	--	59.35
Percent of annual mean.	8.9	5.8	4.7	6.9	8.5	8.8	34.7	--	43.6
Minimum monthly	2.28	.78	.40	1.73	2.87	4.93	--	--	--
Year of minimum	1957	1973	1970	1970	1970	1967	--	--	--
1983:									
Rainfall	3.17	.83	.98	.66*	1.97*	1.49*	5.93	--	9.10
Percent of mean	26	11	15	7	17	12	13	--	15
Departure from mean	-8.88	-7.07	-5.44	-8.76	-9.62	-10.48	-41.37	--	-50.25
Kwajalein									
1945-82 (38 years):									Total Jan.-June
Mean	--	4.34	2.74	5.40	7.05	10.33	29.86	9.92	39.78
Percent of annual mean.	--	4.2	2.7	5.2	6.8	10.0	28.9	9.6	38.5
Minimum monthly	--	.48	.04	.16	.24	1.35	--	4.96	--
Year of minimum	--	1977	1977	1975	1965	1953	--	1953	--
1983:									
Rainfall	--	.89	.68	.36	.20*	1.76	3.89	3.83*	7.72
Percent of mean	--	21	25	7	3	17	13	39	19
Departure from mean	--	-3.45	-2.06	-5.04	-6.85	-8.57	-25.97	-6.09	-32.06
Other islands[1/]									
1983:									
Ailinglaplap	--	3.07	.65	.26	.45	.61	5.04	--	--
Wotje	--	.67	.11	.69	.12	.88	2.47	--	--
Mili	--	.47	.46	.33	0	.29	1.55	--	--

* New minimum monthly total.

1/ From U.S. National Weather Service, Majuro, Marshall Islands.

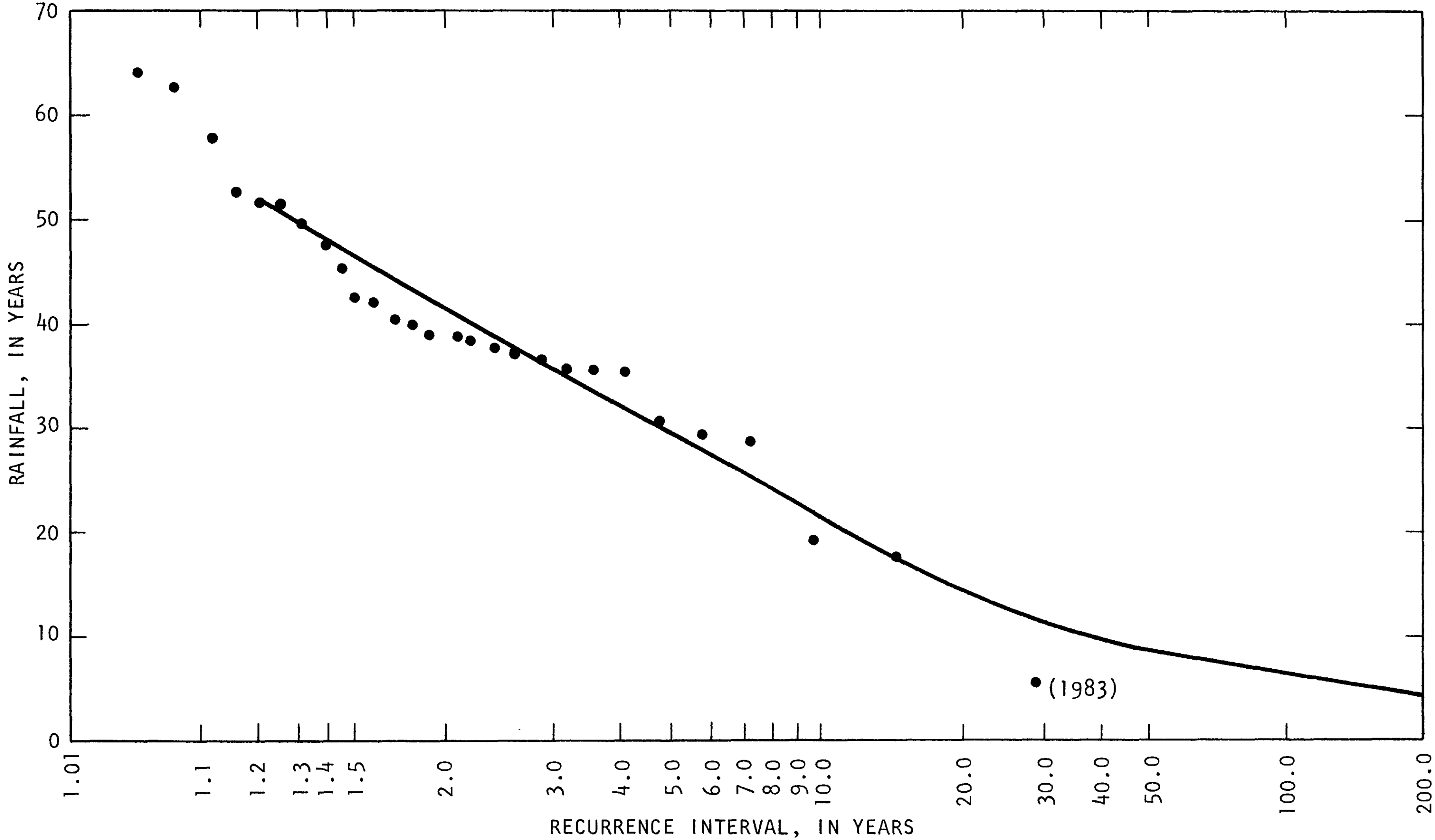


Figure 26. Recurrence intervals of lowest rainfall for 5 consecutive months on Majuro during 12-month periods starting in August.

The central water system provides water to about 90 percent of the population of Majuro and daily consumption averages about 400,000 gallons. This includes water provided to ships and to a Japanese fishing fleet. All private homes and businesses are metered but government installations are not. Even during periods of normal rainfall, water is provided only during daylight hours. Because of leaks in the distribution lines, the total storage of 17.5 Mgal is insufficient to provide water continuously.

For December 1982, only one-fourth of normal rainfall was recorded on Majuro and storage in the 17-Mgal airport reservoir had dropped to 7 Mgal on January 1, 1983. The number of hours that water was made available was set at two hours in the morning and two in the evening, and this restriction was reduced by stages to one hour every third day in February. At the end of May, total storage had dwindled to 0.8 Mgal, most of which was being reserved for the hospital.

To supplement the insufficient supply, the Department of Public Works dug shallow wells on private property upon request. These wells, about 4 feet square and an average of 4 feet deep, were dug by backhoe; and if potable water was found, owners were advised to reinforce the sides with brick or stone. Wells with brackish water were filled in. Water in many of the new wells later turned brackish due to overuse.

During the drought, two saltwater conversion units (reverse osmosis) were installed, supplied by brackish well water. Maximum production of the units is 46,000 gal/d. Although not always operational during the drought, they provided a much needed supplemental source of water.

The capacity of the pumps on the two wells near the 0.5-Mgal reservoir is 15,000 gal/d. To keep the water potable, the wells were used alternately. Initial chloride concentration, about 500 mg/L, increased somewhat during the drought. Well water was mixed with some fresh water from the airport prior to distribution. The Ministry of Public Works delivered well water to customers by tank truck upon request for the nominal fee of half a cent per gallon. At Rita on the eastern end of Majuro, water from wells near the center of the area (the only ones tested) remained potable throughout the drought. At Laura at the other end of the island, all wells except one kept producing fresh water. In between Rita and Laura only one well retained fresh water. This well, along the main road 1.9 miles east of the airport, provided water for houses in the area.

During the Japanese administration, all dwellings were expected to have a roof catchment and rainfall storage. At present, practically none of the houses or buildings have water tanks because of the dependency on the central water system. People who had their own water storage could supplement their water ration and thus were inconvenienced least during the drought.

On islands outside Kwajalein and Majuro, the inhabitants depend on the traditional sources of water: shallow wells and some storage from rain catchments. However, water from the wells turned brackish and little rain fell. On Jaluit atoll, where all wells became brackish, new wells were dug with a backhoe from Majuro, but fresh water was found in only one well, at one end of the 40-mile-long island. Water was transported from this well in drums to the town center, for the hospital and school and for a daily ration of one gallon per person. On Arno atoll, water from shallow wells remained usable.

The water from the airport runway catchment on Majuro is filtered and treated before transmission to the population center. The Environmental Health Division tests the water from the central system monthly at 11 locations. If any coliform is noted, additional sampling is done and more chlorination used. During the drought no contamination of the central system was noticed. However, most private wells were found to be contaminated. Through radio broadcast and newspaper articles, the public was warned either to boil the well water or to add 1/2 or 1 teaspoonful of bleach per gallon of water, depending on the clarity of the water. During the drought, no significant increase in diseases was noticed. Schools remained open as they did not depend on flush toilets for sanitation.

Effects of Drought on Agriculture

The principal source of income for Kwajalein atoll is from employment at Kwajalein missile base; for Majuro atoll, from employment by the Government of the Marshall Islands and from small shops and stores. For all the remaining atolls and islands, the only source of income is from copra production. A large part of this income is spent on the purchase of rice and other food to supplement the diet of breadfruit, pandanas, coconuts, and bananas.

After the drought had ended, surveys of the atolls and islands outside Kwajalein and Majuro atolls were conducted by the Ministery of Resources and Development. The atolls and islands were grouped geographically into Central, Western, Northern, Southern, and Eastern islands.

The main atoll in the Central group is Ailinglaplap. On the islands of this atoll, on nearby Jabot island, and on Namu and Lib atolls, at least three-fourths of all coconut trees were planted 50 or 60 years ago and most were too old to successfully recover from the drought. Copra production is thus expected to be reduced to about 50 percent in the coming years and will continue to decline. New trees will require 5 to 6 years before producing coconuts. On Woja Island of the Ailinglaplap atoll, most breadfruit trees were lost. In general, about half of all food crops were lost.

On Lae, Ujae, Wotho, and Rongelap atolls in the Western group, the Agriculture Department had completed the planting of young coconut trees before the drought. Most of the trees survived, except on Rongelap atoll, where fire killed 75 percent of the trees. On Ujelang atoll, the loss of food crops was small but on the other islands in the Western group, about half of the crops died (Mook, Joe, to Chief Secretary, written commun., Aug. 18, 1983).

Most atolls in the Northern group (population 3,300) suffered minor (10 to 20 percent) losses to crops except Mejit Island. On Mejit Island (population 325) 60 percent of coconut and 80 percent of breadfruit trees were lost. (Larry, Riba, to Chief Secretary, written commun., June 8, 1983).

On Jaluit atoll in the Southern group, many coconut and breadfruit trees died during or after the drought and conditions on many other islands in the group were similar (figs. 27 and 28).

The main islands of the Eastern group are Arno atoll and Mili Island. A report on 19 islands of the Arno atoll indicates wide variations in sustained losses, from 10 percent at Arno and Jabo Islands to 90 percent on Tinak and Longar Islands (Labi, Liki, to Chief Secretary, written commun., July 8, 1983). On Mili Island, most breadfruit trees, the main food source, died (written report, Mayor of Mili to the Government of the Marshall Islands, Apr. 15, 1983).

Overall, the loss in copra production was estimated at 20 to 30 percent, representing a loss of $700,000 in income. Because of the loss of most breadfruit trees on some of the islands, food shipments will be needed for some time. The total cost of the drought in the Marshall Islands has not been determined and may never be. However, with considerable losses in copra production, the replanting of coconut and other fruit trees, and the emergency food shipments, the cost will run into millions of dollars before conditions in the islands have returned to normal.

Figure 27. Drought damage to coconut trees on Drenojen, Jaluit atoll, Marshall Islands.

Figure 28. Drought damage to breadfruit trees on Jabor, Jaluit atoll, Marshall Islands.

Photographs courtesy of Mr. Phillip Kabua, Deputy Chief Secretary, Republic of the Marshall Islands.

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