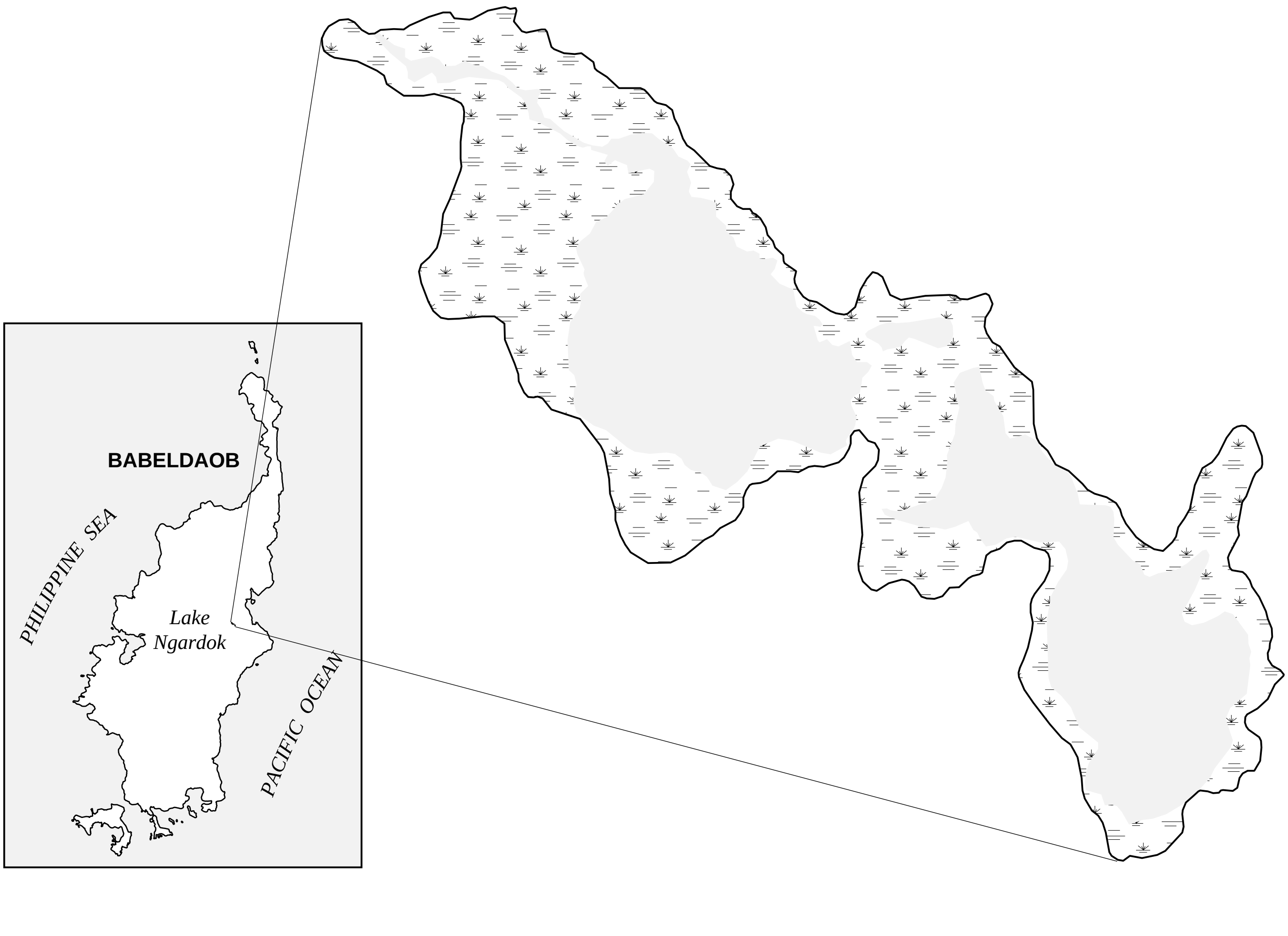
U.S. Department of the Interior

Storage Capacity and Water Quality of Lake Ngardok, Babeldaob Island, Republic of Palau, 1996–98

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 99-4118



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By Chiu Wang Yeung and Michael F. Wong

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Honolulu, Hawaii
1999

U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	0.3048	meter
inch (in.)	2.54	centimeter
square mile (mi^2)	2.590	square kilometer

Water temperature is given in degree Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$\text{Temp.°F} = (1.8\ \text{temp.} \times \text{°C}) + 32.$$

Air temperature is given by degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by the following equation:

$$\text{Temp.°C} = (\text{temp. °F} - 32) / 1.8.$$

Chemical concentrations are given only in metric units. These are milligrams per liter (mg/L), micrograms per liter (µg/L), or picograms per liter (pg/L). Milligrams per liter is a unit expressing the solute mass per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. One million picograms per liter is equivalent to 1 microgram per liter. Specific conductance is given in microsiemens per centimeter (µS/cm) at 25°C. Turbidity is given in NTU, nephelometric turbidity units.

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Abstract

A bathymetric survey conducted during March and April, 1996, determined the total storage capacity Lake Ngardok to be between 90 and 168 acre-feet. Elevation-surface area and elevation-capacity curves summarizing the current relations among elevation, surface area, and storage capacity were created from the bathymetric map. Rainfall and lake-elevation data collected from April 1996 to March 1998 indicated that lake levels correlated to rainfall values with lake elevation rising rapidly in response to heavy rainfall and then returning to normal levels within a few days. Mean lake elevation for the 22 month period of data was 59.5 feet which gives a mean storage capacity of 107 acre-feet and a mean surface area of 24.1 acre. A floating mat of reeds, which covered 58 percent of the lake surface area at the time of the bathymetric survey, makes true storage capacity difficult to estimate.

Water-quality sampling during April 1996 and November 1997 indicated that no U.S. Environmental Protection Agency primary drinking-water standards were violated for analyzed organic and inorganic compounds and radionuclides. With suitable biological treatment, the lake water could be used for drinking-water purposes. Temperature and dissolved oxygen measurements indicated that Lake Ngardok is stratified. Given that air temperature on Palau exhibits little seasonal variation, it is likely that this pattern of stratification is persistent. As a result, complete mixing of the lake is probably rare. Near anaerobic conditions exist at the lake bottom. Low dissolved oxygen (3.2 milligrams per liter) measured at the outflow indicated that water flowing past the outflow was from the deep oxygen-depleted depths of the lake.

INTRODUCTION

To alleviate overcrowding in Koror, the current capital of the Republic of Palau, the Palau government passed a resolution to relocate its capital to Melekeok on Babeldaob Island, the largest of the Palau Islands. Melekeok is on the east coast of Babeldaob and a nearby freshwater body, Lake Ngardok, was proposed as the major source of domestic water supply for the new capital and nearby villages. To evaluate the storage capacity and water quality of Lake Ngardok, and to learn more about freshwater lakes in tropical environments, the Republic of Palau entered into a cooperative agreement with the U.S. Geological Survey (USGS).

Purpose and Scope

This report describes storage capacity and water quality of Lake Ngardok. A bathymetric survey of Lake Ngardok was done to estimate storage capacity in relation to lake water-surface elevation. Samples were collected in late March and early April 1996, and November 1997, from the lake outflow for water-quality analyses. At selected lake cross sections, samples were collected at depth for analysis of water-quality properties and constituents.

Previous Studies

No previous studies on the storage capacity and water quality of Lake Ngardok exist, although various estimates have been made. The U.S. Army Chief of Engineers (1956) estimated Lake Ngardok to be 2,400 ft long, 600 ft wide at the widest part, as much as 9 ft in depth, and with a capacity of 46 acre-ft. Van der Brug (1984) used these estimates in his water-resource investigation of the Palau Island. AECOS Inc. (1997) estimated the lake area to be 16 acres and the capacity to be 46 acre-ft also. The AECOS Inc. (1997) study also included water-quality data for a sampling point 1.4 mi downstream from the Lake Ngardok outlet.

Acknowledgments

Special acknowledgment is made to Patrick Colin of the Coral Reef Research Foundation for providing the aerial photographs of Lake Ngardok.

DESCRIPTION OF STUDY AREA

The Republic of Palau consists of a chain of islands in the western Pacific Ocean, east of the Philippine Sea, between latitude 6°53′ and 8°12′ north and longitude 134°07′ and 134°39′ east (fig. 1). Babeldaob Island is near the northern end of the island chain and, with an area of 153 mi^2, is the largest of the Palau Islands. Koror, the current administrative, commercial, and population center of Palau, lies directly south of Babeldaob Island, from which it is separated by a narrow channel (fig. 1).

Lake Ngardok is east of Rael Kedam, the central ridge of Babeldaob, less than 2 mi northwest of Melekeok. The lake is part of the headwaters of the North Fork of Ngerdorch River (fig. 1). Ngerdorch River, with a drainage area of almost 18 mi^2, is the largest perennial stream in Palau (van der Brug, 1984).

The reference marker at USGS lake-stage gage 16891425 (fig. 2) , near the outlet of Lake Ngardok, was estimated to be at an elevation of 70 ft above mean sea level from the 1:25,000-scale USGS Ngermetengel topographic map (1983). The drainage area upstream of the outlet is 1.66 mi^2 and the highest elevation in the drainage area is 590 ft, near Mount Ometochel (fig. 1). The main channel length from the headwaters to the outlet is about 2.22 mi with an average slope of 0.014 ft/ft.

Climate.--The Palau Islands have a uniform tropical warm and moist climate throughout the year. Seasonal changes are minimal. At the long-term weather station on Koror Island, the mean temperature is 81.7°F (National Oceanic and Atmospheric Administration, 1995). Mean temperature for the coolest months (January and February) is 81.0°F and for the warmest months (April, May, and November) is 82.2°F (National Oceanic and Atmospheric Administration, 1995). Average annual rainfall is 148 in. (National Oceanic and Atmospheric Administration, 1995). Rainfall is variable from month to month and is usually heaviest in June and July (National Oceanic and Atmospheric Administration, 1995).

Rainfall data for Babeldaob are available for short periods from scattered locations. Van der Brug (1984) determined that climatic descriptions for Koror are representative of conditions at Babeldaob. Comparison of the available rainfall records for Babeldaob with those for Koror showed no significant difference in rainfall totals. Nance (1986) estimated that rainfall across Babeldaob was between 90 and 110 percent of the rainfall at Koror and that rainfall in the region of Lake Ngardok is 90 percent that of Koror.

Geology.--Babeldaob is a volcanic island formed primarily by the accumulation of volcanic breccia and interbedded tuff which form three geologic formations: the Babelthuap Formation, the Aimeliik Formation, and the Ngeremlengui Formation (U.S. Army Chief of Engineers, 1956). The general features of the island include rolling uplands, rugged areas of sharp ridges and cliffs, flat alluvial areas, and irregular coastlines bounded by dense mangrove swamps (van der Brug, 1984).

About 76 percent of the total drainage of Lake Ngardok is underlain by the Aimeliik Formation. The remainder of the drainage area is underlain by the Babelthuap Formation (20 percent) and alluvium (4 percent). Percentages were determined by geographic information systems (GIS) analysis of a 1:62,500-scale geologic map (U.S. Army Chief of Engineers, 1956). The Aimeliik Formation is Eocene in age (38 to 58 million years old) and consists of andesitic-basaltic volcanic breccias and tuff. The upper layers are deeply weathered to depths up to 10 ft, with weathered breccia covering 58 percent and weathered tuff covering 18 percent of the drainage basin (U.S. Army Chief of Engineers, 1956). The Babelthuap Formation is also

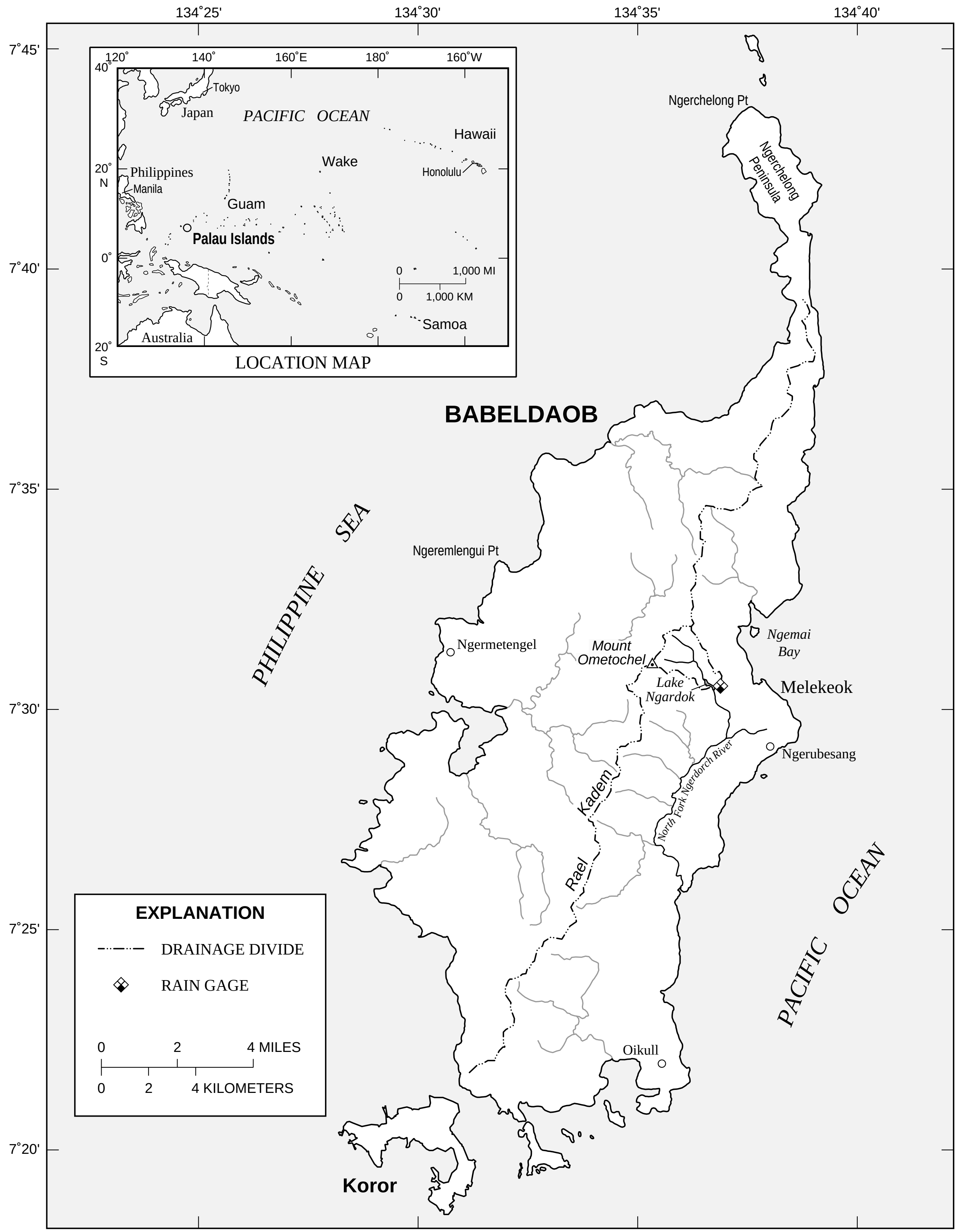

Figure 1. The island of Babeldaob, Palau Islands, western Pacific Ocean.

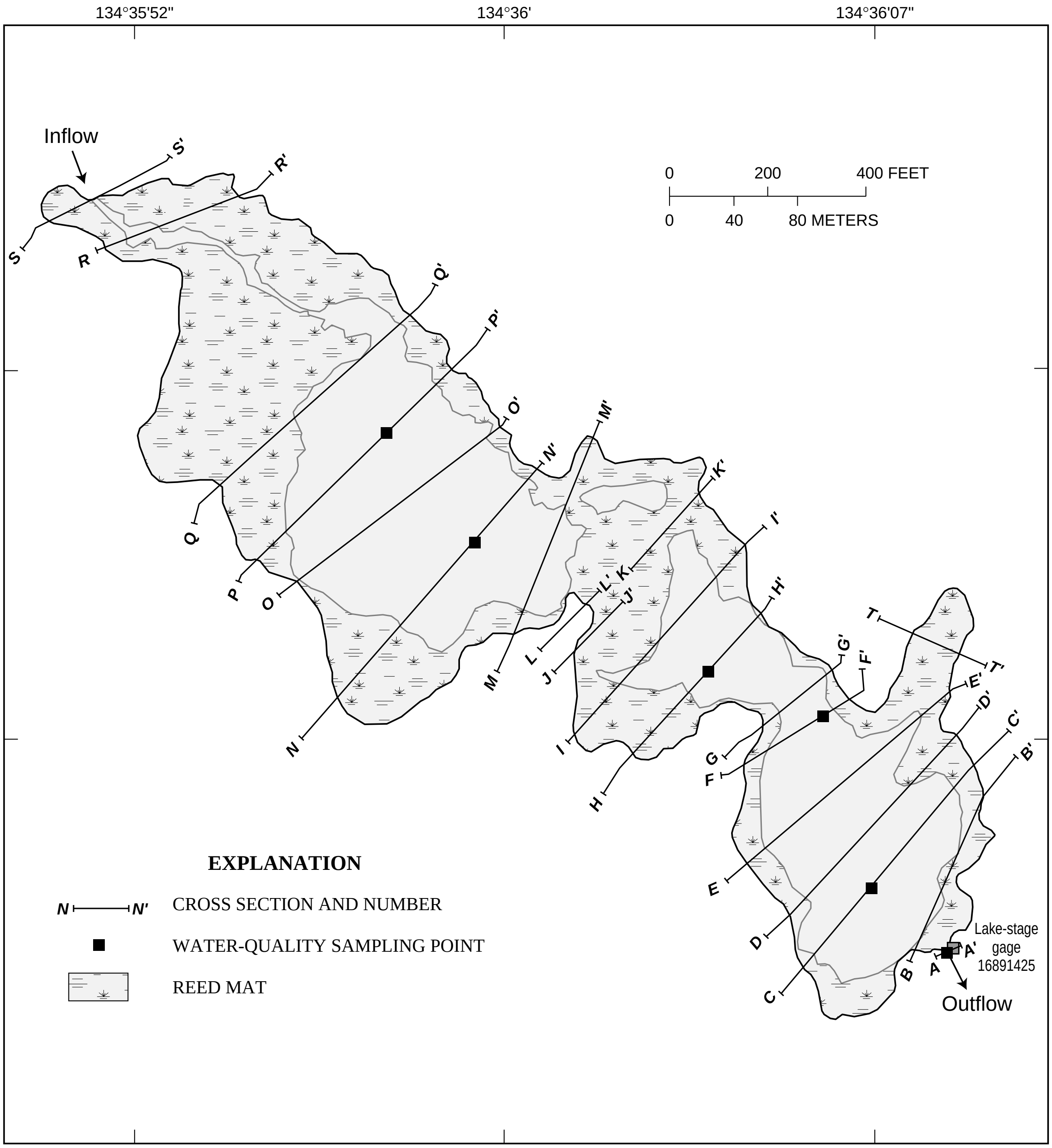

Figure 2. Cross sections and water-quality sampling sites, Lake Ngardok, Palau, 1996.

Eocene in age and consists of massive basaltic-andesitic volcanic breccia with tuff breccia and a layer of interbedded tuff. This formation is found in the higher elevations of the drainage basin along the Rael Kedam around Mount Ometochel and is not as deeply weathered as the rocks of Aimeliik Formation. Alluvium is found in the floodplain of the Ngerdorch River. Lake Ngardok was created by a natural dam formed of alluvial deposits from a small tributary (U.S. Army Chief of Engineers, 1956, p. 192). The source of the deposits was a large quantity of clay eroded during heavy rains (U.S. Army Chief of Engineers, 1956, p. 146).

Soils.--Soils in the study area are derived from the weathering of the volcanic rocks. The resultant red soil is highly erodible, acidic, high in iron and aluminum oxides, and low in silica. On the basis of terminology described by Smith (1983), the principal soil types in the Lake Ngardok basin were determined to be the Aimeliik-Palau complex (42 percent) and the Ngardok silt loam (48 percent). Along the ridges of the Rael Kedam, soils of the Babelthaup-Ngardmau complex (6 percent) exist. These three soils all have moderate permeability. The remaining soil (4 percent), found along the stream valleys, is poorly drained muck classified as Dechel-Mesei complex. This soil underlies Lake Ngardok and on the basis of field observations is composed of very fine silt and clay. Percentages were determined by geographic information systems (GIS) analysis of a 1:62,500-scale soil map (U.S. Army Chief of Engineers, 1956) which classified the soils on the basis of a 1938 system of soil classification.

Biota.--Vegetation surrounding the lake consists of a mixture of tropical forest and open area with scrub vegetation and ferns. The shoreline of Lake Ngardok is completely surrounded by freshwater marshes. These marshes have floating vegetated mats of *Hanguana malayana*, a reed-like plant. During fieldwork, a large section of mat was observed to have separated from one shoreline edge and floated freely on the lake. The lake is largely undisturbed and supports aquatic plants, freshwater fishes, marine crocodiles, and several roosting and nesting waterbirds (AECOS, 1997). The marine crocodile, *Crocodylus porosus*, is listed as an endangered species and the upper reach of the Ngerdorch River around Lake Ngardok is one of the few remaining breeding areas of the crocodile in Palau (AECOS Inc., 1997).

DATA-COLLECTION METHODS

Fieldwork, which included the bathymetric survey and water-quality sampling, was done in late March and early April 1996 and in November 1997. The bathymetric survey was carried out by crossing the lake with a total of 19 cross sections (fig. 2). The reference mark at gage 16891425 was used as a reference datum for the survey. Because the datum was estimated from a topographic map, the absolute accuracy is 20 ft. The first surveyed cross section endpoint was referenced to the reference mark and the location and elevation of each subsequent cross section endpoint was referenced to the preceding endpoint. A tagline was placed between endpoints for recording distance increments. Depth readings were recorded along each cross section at about a 10 ft interval from one shoreline to the other. Cross sections *J–J′*, *K–K′*, and *L–L′* did not completely extend across the lake because crocodiles were observed at those locations.

Water depths were measured along the cross sections from a boat using a modified surveying rod with a precision of 0.1 ft. The modification involved the addition of a perforated 8-inch diameter wood base attached to the bottom of the rod to prevent the rod from sinking into soft mud. The thickness of the base was taken into account during the fabrication of the rod, so all readings were direct. Depth was recorded from water surface to the lake bottom. Elevation readings along the cross sections, above the water surface, were measured with standard leveling equipment with a precision of 0.01 ft.

On the basis of the surveyed cross sections, storage capacity and surface area of the lake were computed by using a geographic information system (GIS) computer program. First, the survey data points were converted to a format of northings, eastings, and ground elevations using the coordinates of the cross section endpoints, the elevation of the water surface, measurements of distance between monuments, and measured depths. Then, using GIS, cross sections were plotted as shown in figure 2 and manually interpolated contours were drawn to create the bathymetric map of Lake Ngardok (fig. 3). The contour interval was variable: a 2-foot interval was used on the lake region of high relief and a smaller contour interval was used on regions of low relief. The shoreline was entered into GIS from recent aerial photographs of the lake (Patrick Colin, Coral Reef Research Foundation, written commun., 1997) to provide additional data in shaping the contour lines. Storage capac-

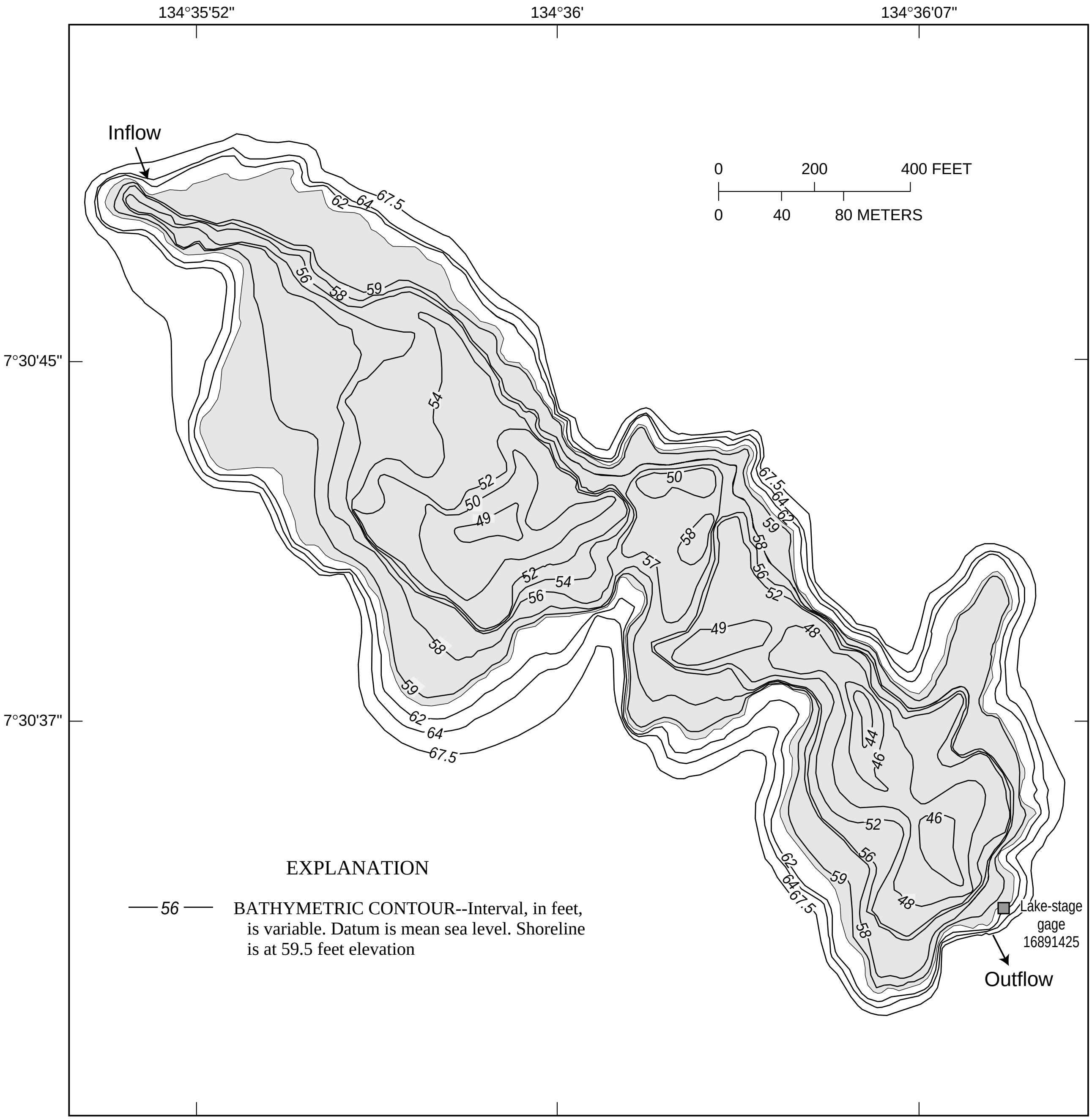

Figure 3. Bathymetry of Lake Ngardok, Palau, 1996.

ity and surface area at 0.1 foot increments were computed from the contour lines by a triangulated irregular network (TIN) numeric analysis in the GIS computer program.

Field measurements of temperature, specific conductance, and dissolved oxygen were collected at various depths at a location in the deep-water part of five selected cross sections on April 5 and 7, 1996 (figs. 2 and 4 [fig. 4 at end of report]). For depths of less than 10 ft, measurements were made by submerging the instrument probe. Field measurements for depths greater than 10 ft were made in a bottle used to collect the deep water samples. Field measurements and water-quality samples also were collected at the lake outlet on April 3, 1996 and November 10, 1997 (fig. 2). Water-quality samples collected at the center of the outflow were analyzed for concentrations of major ions, nutrients, trace metals, pesticides, herbicides, volatile organic compounds, and radiation and radionuclides, following U.S. Environmental Protection Agency (USEPA) Safe Drinking Water Act methods (U.S. Environmental Protection Agency, 1996).

STORAGE CAPACITY

Lake Ngardok is estimated to be about 2,400 ft in length between the inflow and outflow points shown on figure 3 and to have maximum width of about 700 ft. The greatest water depth measured in the lake was 16.9 ft and the mean of all 751 depth measurements was 4.8 ft. The measured depth readings and above-water ground elevations were originally referenced to an arbitrary datum. However, instead of relating the capacity and surface area to an arbitrary datum, elevation readings were tied in to the datum associated with the USGS lake-stage gage 16891425, Lake Ngardok near Melekeok. The gage datum is based on the elevation of the reference marker at the gage that was estimated to be 70 ft above mean sea level from the 1:25,000-scale USGS Ngermetengel topographic map (1983).

Using GIS, surface area and storage capacity were calculated from results of the bathymetric survey (fig. 3). Lake-elevation data collected from April 3, 1996 to March 3, 1998 are shown in table 1. Mean elevation for the 22 complete months covered by this period was 59.5 ft. The storage capacity of the lake at this water-surface elevation of 59.5 ft is 107 acre-ft with a corresponding surface area of 24.1 acres. Lake elevation-surface area and lake elevation-capacity curves are shown in figure 5 and presented numerically in table 2.

According to the lake-elevation data, daily mean lake elevations fluctuated from 58.71 to 61.88 ft during the study period. The fluctuations were generally in response to rainfall as shown by the rainfall data from rain gage 073037134361570 (Ngerdok rain gage near Melekeok) (table 3). Graphical comparison of rainfall and lake elevation (fig. 6) showed that high daily rainfall totals corresponded to days with high daily mean lake elevation. Lake elevation returned to a mean level within a few days after a heavy rain because of the natural outflow from the lake (tables 1 and 3).

Error analysis.--Three sources of error affected the storage-capacity determination: survey error, digital conversion error, and the floating reed mats. A discrepancy was found between the cross section lengths measured in the field using a tagline and the cross section lengths computed as the distance between mapped locations of the land survey endpoints. Differences between the two sets of distance readings ranged from 0 to 30 percent and averaged 13 percent. The error was corrected by arithmetically adjusting the computed cross section lengths to conform with the measured tagline lengths. This adjustment was justified by comparing measured tagline lengths with the lake shoreline as established from a recent aerial photo (Patrick Colin, Coral Reef Research Foundation, written commun., 1997). This comparison showed that the measured tagline lengths of the cross sections corresponded well with shore-to-shore distances measured on the aerial photo. Using the aerial photo shoreline as the most accurate source, cross sections that had tagline to land-survey distances differences of greater than 5 percent were shifted to match the shoreline indicated by the aerial photographs. The irregular shape of the shoreline aided in the identification of the approximate cross section endpoints. Assessment of the error associated with the cross section adjustments was not possible.

Digitizing the shoreline from the aerial photographs also contributed error to the accuracy of the computed lake area and volume. It was not possible to rectify the aerial photoraphs for distortion before digitizing. On the basis of the digitizer error, the accuracy of the computed surface area was within a reasonable range of ±3 percent from measured data. The digitizer error for the volume computation was ±5 percent.

Table 1. Daily mean lake elevation at Lake Ngardok near Melekeok, Palau

[Values are in feet above mean sea level; U.S. Geological Survey gage number 16891425; --, no data or not applicable]

	1996									1997		
DAY	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1	--	59.72	59.46	59.64	60.05	59.11	59.92	59.69	59.19	59.53	59.52	60.78
2	--	59.66	59.75	59.59	60.05	59.10	59.79	59.94	59.18	59.45	59.46	60.44
3	61.60	59.54	59.57	59.50	60.00	59.09	59.64	59.79	59.16	59.38	59.33	60.25
4	60.71	59.45	59.42	59.92	59.92	59.10	59.78	60.60	59.15	59.39	59.24	60.21
5	60.19	59.39	59.37	59.80	59.88	59.35	59.64	60.42	59.13	59.35	59.41	60.79
6	59.96	59.50	59.48	59.62	59.72	59.62	59.50	60.53	59.11	59.28	59.35	60.82
7	59.83	59.93	59.61	59.70	59.64	60.24	59.41	60.33	59.10	59.24	59.40	60.39
8	59.72	59.82	60.02	59.65	59.66	60.48	59.34	60.04	59.09	59.22	59.31	60.15
9	59.71	59.73	59.74	59.54	59.72	60.23	59.32	59.94	59.08	59.22	59.24	60.07
10	59.69	60.23	60.00	59.44	59.76	59.94	59.33	59.82	59.07	59.22	59.31	59.99
11	59.59	60.18	59.93	60.29	59.58	59.68	59.37	59.67	59.59	59.22	59.60	59.82
12	59.76	60.02	59.90	60.25	59.47	59.49	59.37	59.61	59.66	59.22	60.48	59.71
13	60.00	59.85	59.82	59.91	59.39	59.36	59.38	59.64	59.35	59.21	61.16	59.65
14	59.75	59.73	59.66	59.72	59.35	59.28	59.30	59.77	59.20	59.21	61.78	59.60
15	59.62	59.64	59.55	59.79	59.43	59.21	59.45	59.61	59.15	59.21	61.17	59.52
16	59.51	59.58	59.54	59.76	59.33	59.18	59.51	59.49	59.14	59.20	61.31	59.44
17	59.43	59.55	59.59	59.73	59.25	59.18	59.45	59.42	59.14	59.19	61.30	59.37
18	59.37	59.53	59.49	59.77	59.21	59.18	59.45	59.35	59.13	59.17	61.40	59.31
19	59.54	59.97	59.83	59.94	59.18	59.18	59.48	59.29	59.12	59.16	61.85	59.27
20	59.51	60.09	59.74	60.05	59.19	59.18	59.39	59.25	59.22	59.15	61.14	59.26
21	59.54	59.80	59.57	60.54	59.22	59.20	59.29	59.26	60.29	59.14	60.69	59.26
22	59.51	59.65	59.72	60.60	59.18	59.90	59.25	59.24	60.04	59.14	60.36	59.26
23	59.54	59.57	59.97	60.23	59.18	60.44	59.30	59.23	60.00	59.13	60.12	59.26
24	59.55	59.54	59.82	60.18	59.18	60.20	59.48	59.23	59.89	59.12	59.97	59.25
25	60.07	59.51	59.62	60.24	59.19	60.15	59.30	59.23	61.20	59.52	61.36	59.25
26	60.10	59.45	59.77	60.02	59.18	60.33	59.26	59.22	61.44	60.04	61.69	59.23
27	59.81	59.38	59.95	59.99	59.16	60.87	59.31	59.22	60.61	59.81	61.82	59.22
28	59.65	59.33	59.75	60.94	59.15	60.68	59.30	59.22	60.19	59.59	61.26	59.21
29	59.63	59.43	59.88	61.04	59.14	60.20	59.23	59.20	59.94	59.44	--	59.20
30	59.67	59.45	59.78	60.47	59.13	59.95	59.39	59.19	59.76	59.26	--	59.19
31	--	59.36	--	60.20	59.11	--	59.49	--	59.63	59.38	--	59.18
Mean	--	59.66	59.71	60.00	59.44	59.70	59.43	59.61	59.58	59.32	60.43	59.69
Max	--	60.23	60.02	61.04	60.05	60.87	59.92	60.60	61.44	60.04	61.85	60.82
Min	--	59.33	59.37	59.44	59.11	59.09	59.23	59.19	59.07	59.12	59.24	59.18

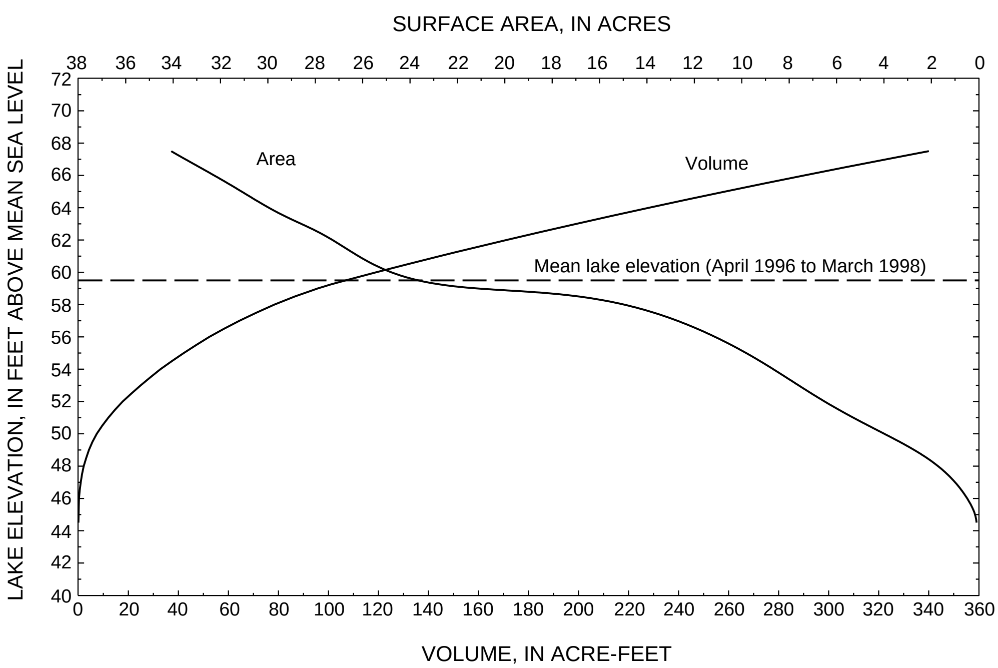

Figure 5. Elevation/surface-area and elevation/capacity curves for Lake Ngardok, 1996, Palau.

Table 2. Elevation/surface-area and elevation/storage-capacity for Lake Ngardok near Melekeok, Palau, 1996
[Datum is mean sea level]

Water elevation (feet)	Surface area (acres)										Difference in area per foot
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	
44.0						0.09	0.10	0.10	0.11	0.12	0.08
45.0	0.13	0.14	0.14	0.15	0.16	0.17	0.21	0.26	0.32	0.39	0.35
46.0	0.48	0.52	0.55	0.59	0.63	0.68	0.72	0.77	0.82	0.87	0.44
47.0	0.92	0.97	1.02	1.08	1.14	1.20	1.31	1.44	1.57	1.72	0.96
48.0	1.88	1.91	1.95	1.98	2.02	2.05	2.16	2.27	2.39	2.51	0.76
49.0	2.64	2.73	2.82	2.92	3.02	3.12	3.30	3.50	3.70	3.91	1.50
50.0	4.14	4.23	4.33	4.43	4.53	4.63	4.73	4.84	4.94	5.05	1.02
51.0	5.16	5.27	5.38	5.49	5.60	5.72	5.93	6.16	6.39	6.62	1.71
52.0	6.87	6.94	7.01	7.08	7.15	7.22	7.29	7.36	7.43	7.50	0.70
53.0	7.57	7.64	7.70	7.77	7.84	7.91	8.09	8.28	8.47	8.66	1.29
54.0	8.86	8.94	9.03	9.12	9.20	9.29	9.38	9.47	9.56	9.65	0.88
55.0	9.74	9.83	9.92	10.0	10.1	10.2	10.4	10.6	10.9	11.1	1.57
56.0	11.3	11.5	11.6	11.8	11.9	12.1	12.2	12.4	12.6	12.8	1.72
57.0	13.0	13.2	13.4	13.6	13.8	14.0	14.2	14.4	14.7	14.9	2.09
58.0	15.1	15.5	16.0	16.4	16.8	17.3	17.8	18.4	18.9	19.5	4.91
59.0	20.0	20.8	21.6	22.4	23.2	24.1	24.2	24.4	24.5	24.6	4.72
60.0	24.8	24.9	25.0	25.1	25.3	25.4	25.5	25.7	25.8	25.9	1.31
61.0	26.1	26.2	26.3	26.4	26.6	26.7	26.8	27.0	27.1	27.2	1.34
62.0	27.4	27.5	27.6	27.7	27.9	28.0	28.0	28.2	28.3	28.4	1.10
63.0	28.5	28.6	28.7	28.9	29.0	29.1	29.2	29.4	29.5	29.6	1.25
64.0	29.8	29.9	30.0	30.1	30.3	30.4	30.5	30.6	30.8	30.9	1.27
65.0	31.0	31.1	31.3	31.4	31.5	31.7	31.8	31.9	32.0	32.1	1.25
66.0	32.3	32.4	32.5	32.6	32.8	32.9	33.0	33.1	33.2	33.4	1.22
67.0	33.5	33.6	33.7	33.8	34.0	34.1					

Water elevation (feet)	Storage capacity (acre-feet)										Difference in volume per foot
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	
44.0						0.04	0.05	0.06	0.06	0.08	0.10
45.0	0.09	010	0.12	0.13	0.15	0.17*	0.18	0.20	0.22	0.24	0.17
46.0	0.26	0.30	0.35	0.41	0.47	0.55*	0.61	0.68	0.76	0.85	0.69
47.0	0.95	1.04	1.14	1.24	1.36	1.48*	1.60	1.72	1.86	2.00	1.21
48.0	2.16	2.33	2.51	2.70	2.92	3.14	3.33	3.54	3.75	3.98	2.06
49.0	4.22	4.48	4.74	5.03	5.33	5.65	5.96	6.28	6.62	6.98	3.14
50.0	7.36	7.76	8.17	8.61	9.07	9.55	10.0	10.5	11.0	11.5	4.64
51.0	12.0	12.5	13.0	13.6	14.1	14.7	15.3	15.9	16.5	17.1	5.73
52.0	17.7	18.4	19.1	19.8	20.5	21.2	21.9	22.7	23.4	24.2	7.22
53.0	25.0	25.7	26.4	27.2	28.0	28.8	29.6	30.4	31.2	32.0	7.91
54.0	32.9	33.7	34.6	35.5	36.4	37.4	38.3	39.2	40.2	41.2	9.29
55.0	42.2	43.1	44.1	45.1	46.1	47.1	48.1	49.2	50.2	51.3	10.2
56.0	52.4	53.5	54.6	55.8	57.0	58.2	59.4	60.6	61.9	63.1	12.1
57.0	64.4	65.7	67.1	68.4	69.8	71.2	72.6	74.0	75.4	76.9	14.0
58.0	78.4	80.0	81.5	83.2	84.8	86.5	88.3	90.1	91.9	93.8	17.3
59.0	95.7	97.9	100	102	105	107	109	112	114	117	23.4
60.0	119	122	124	126	129	132	134	137	139	142	25.4
61.0	144	147	150	152	155	158	160	163	166	168	26.7
62.0	171	174	177	179	182	185	188	191	193	196	28.0
63.0	199	202	205	208	211	214	216	219	222	225	29.0
64.0	228	231	234	237	240	243	246	249	252	255	30.4
65.0	259	262	265	268	271	274	277	281	284	287	31.7
66.0	290	294	297	300	303	307	310	313	316	320	32.9
67.0	323	327	330	333	337	340					

Table 3. Daily total rainfall, in inches, from Ngardok rain gage near Melekeok, Palau
[U.S. Geological Survey gage number 073037134361570; --, no data or not applicable]

DAY	1996						1997				
	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	--	0.00	0.00	0.52	1.03	0.00	0.00	0.77	0.00	0.26	0.00
2	--	.00	.00	.00	.26	.00	.00	.51	.00	2.32	.00
3	--	.26	.77	.51	2.32	.26	.00	.00	.00	.00	.00
4	--	.52	.26	.26	.77	.00	.26	.26	.26	.00	.00
5	--	.00	1.29	.00	1.29	.00	.00	.51	2.83	.00	.00
6	--	.00	1.29	.00	1.03	.00	.00	.51	.26	.26	.00
7	--	.26	.52	.00	.00	.00	.00	.00	.00	.00	.00
8	--	.00	1.54	.00	.00	.00	.00	.00	.26	.00	.00
9	--	1.29	.26	.00	.51	.00	.00	.00	1.03	.52	.00
10	--	.00	.26	.26	.00	.52	.00	.77	.00	.26	.00
11	--	.00	.00	.26	.00	1.54	.00	1.03	.00	1.29	.00
12	--	.00	.00	.26	.00	.00	.51	3.61	.00	.00	.51
13	--	.00	.00	.00	.51	.26	.00	1.29	.00	.00	1.29
14	--	.00	.00	.26	.26	.26	.51	3.35	.00	.00	.00
15	--	.00	.00	.77	.00	.00	.00	1.03	.00	.00	.00
16	--	.00	.00	.00	.26	.00	.00	1.29	.00	.00	.52
17	--	.00	.00	.26	.00	.00	.00	1.80	.00	.00	.00
18	--	.00	.00	.26	.00	.00	.00	2.57	.00	.00	.26
19	--	.00	.00	.26	.00	1.03	.26	.51	.00	.00	.00
20	--	.77	.00	.00	.00	2.57	.00	.00	.00	.00	.00
21	--	.00	1.55	.51	.00	.51	.00	.00	.00	.00	.00
22	--	.00	3.35	.00	.00	1.29	.00	.00	.00	.00	.00
23	0.00	.00	.26	1.03	.00	.51	.00	.00	.00	.00	.00
24	.51	.00	1.29	.00	.26	1.29	.00	.26	.00	.00	.00
25	.00	.00	2.06	.00	.00	4.12	1.80	4.12	.00	.00	.00
26	.00	.00	.00	.77	.00	.00	.26	2.06	.00	.00	.00
27	.51	.00	1.55	.51	.26	.00	.00	1.29	.26	.00	2.32
28	3.09	.00	.00	.26	.00	.00	1.03	.26	.00	.00	.00
29	.00	.26	.00	.26	.51	.00	.00	--	.00	.51	.00
30	.00	.00	.51	1.03	.00	.00	.00	--	.77	.26	.00
31	.00	.26	--	.00	1.29	--	.00	--	.00	--	--
Total	--	3.62	16.8	8.25	9.27	14.2	5.92	27.8	5.67	5.68	4.90

Table 3. Daily total rainfall, in inches, from Ngardok rain gage near Melekeok, Palau--Continued

[U.S. Geological Survey gage number 073037134361570; --, no data or not applicable]

	1997							1998		
DAY	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
1	0.00	0.00	0.00	0.00	0.00	0.00	3.35	0.52	0.00	0.00
2	.26	.00	.00	.77	.00	.00	.00	.00	.00	.00
3	.00	.00	.00	.77	1.03	.00	.00	.26	.00	.00
4	.26	.00	.00	3.09	.26	.00	.00	.26	.00	--
5	.00	.00	.00	.52	.00	.00	.26	.77	.00	--
6	.00	.26	.26	.26	.00	.00	.26	.00	.00	--
7	.00	.00	.26	.00	.00	1.29	1.29	.00	.00	--
8	.00	.77	2.58	.52	.26	.00	1.55	1.03	.00	--
9	.00	.26	.00	.00	.00	.00	.00	.00	.00	--
10	2.06	.26	.52	.00	.00	.00	.00	.00	.00	--
11	.00	2.32	.00	.00	.26	2.06	.00	.52	.00	--
12	1.03	.26	.00	1.03	.00	.00	.52	.26	.00	--
13	1.03	.00	.00	.52	.00	.00	.00	.00	.00	--
14	.00	.26	.00	.77	.52	.00	.52	.00	1.80	--
15	.52	.00	.26	.52	.77	.00	1.03	.00	.26	--
16	.00	.00	.00	.00	.52	.26	.00	.00	.00	--
17	.00	.00	.00	.00	.00	.00	.52	.00	.00	--
18	.00	.00	.00	.00	.26	.00	.00	.00	.00	--
19	.00	.52	.00	.52	1.29	.00	.00	.00	.00	--
20	1.03	.77	.00	.00	.00	.00	.00	.52	.00	--
21	5.92	.00	.00	.52	.00	.00	.00	.00	.00	--
22	.00	.00	.00	1.29	.00	.00	.00	.26	.52	--
23	.00	.00	.00	.26	.00	1.03	.26	.00	.00	--
24	.00	.00	.00	.00	.00	.00	.00	.00	.00	--
25	.00	.00	.00	2.58	.00	.52	.00	.26	.00	--
26	.00	.00	.00	1.29	.52	.26	.00	.52	.00	--
27	.00	.26	.00	.00	.00	.00	1.80	.00	.00	--
28	.52	.00	.00	.00	.00	.00	.77	.77	.00	--
29	.00	.00	.00	.00	.00	.00	.26	.00	--	--
30	1.80	.00	.00	.77	.26	.00	.00	.00	--	--
31	--	.00	.00	--	.00	--	.26	.00	--	--
Total	14.43	5.94	3.88	16.0	5.95	5.42	12.7	5.95	2.58	--

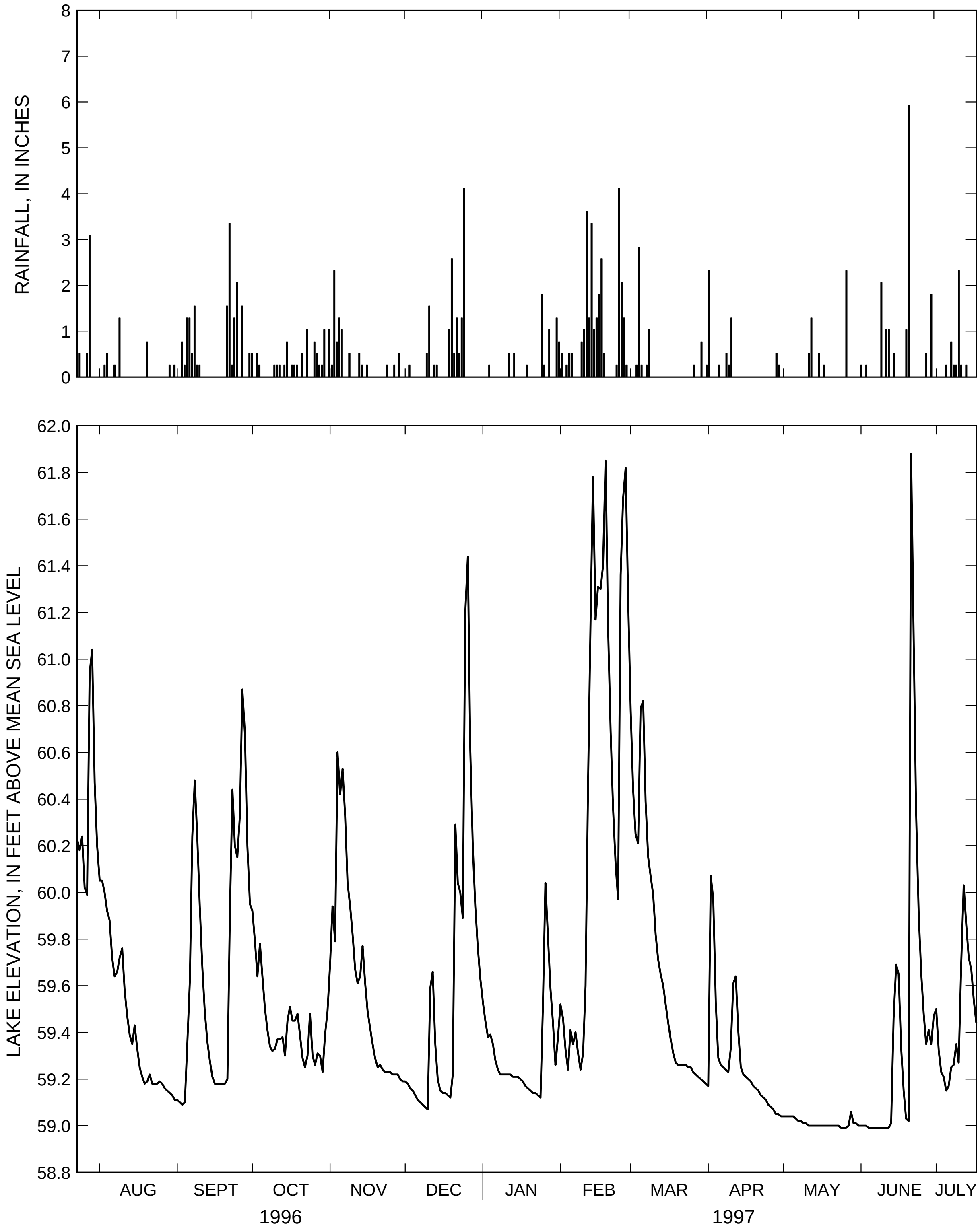

Figure 6. Rainfall and lake elevation at Lake Ngardok, Palau, from July 1996 to July 1997.

The mat of reeds, which surrounds the lake shoreline, covers about 58 percent of the total lake surface area. This mat of reeds affects the storage capacity analysis owing to the difficulty in determining which part of the mat was floating and which part rested on the lake bottom. The reason is that the root structure of the reed mat may have hindered the penetration of the survey rod and as a result the depth readings measured in those locations may not reflect the true depth to the lake bottom. The cross sections in figure 4 show the highly varying depths measured in the field. Therefore, in the mat areas, depth readings and resulting storage capacity estimates will contain some level of uncertainty. However, field observations indicated that errors in the measured depths are not large.

WATER QUALITY

Temperature, dissolved oxygen, and specific conductance were measured at various depths at a location in the deep water part of five lake cross sections (figs. 2 and 4). Near-surface temperatures of water ranged from 28.0°C to 29.0°C while lake bottom water temperatures ranged from 26.0°C to 27.8°C. Temperature also varied with depth, showing a consistent 2°C drop from water surface to the deepest point measured at all five cross sections (table 4).

Dissolved oxygen is second only to temperature as a critical factor for aquatic life in lakes (Goldman and Horne, 1983). Dissolved oxygen measurements decrease from upstream to downstream. Values at the 1 ft depth ranged from 6.0 mg/L at cross section *C–C′* to 7.0 mg/L at cross section *P–P′* (table 4, fig. 2). Dissolved oxygen at the sampling locations initially increased slightly with depth before dropping sharply. For example at cross section *H–H′* (table 4) dissolved oxygen at the water surface was 6.6 mg/L. The dissolved oxygen readings increased to 6.8 mg/L at a depth of 2.0 ft before dropping sharply to 2.6 mg/L at a depth of 12.0 ft. These decreases in dissolved oxygen values with depth are similar to those observed in Fena Reservoir on Guam, which had values ranging from 10 mg/L at the surface to 2 mg/L at the 15 ft depth (LaBaugh, 1985), approaching anaerobic conditions at lake bottom.

Lake Ngardok is stratified based on temperature and dissolved oxygen differences. As noted earlier, air temperatures on Palau have only minor seasonal variations. As a result, the stratification indicated by the measurements made for this study are likely indicative of a pattern of persistent stratification in the lake. Hutchinson (1957, p. 634) made similar observations in tropical lakes near the equator.

Specific conductance is a measure of ionic concentrations in water. Values measured in Lake Ngardok showed no systematic variation across the lake or with depth and ranged from 41 to 61 µS/cm (table 4). These specific conductance values are quite low compared with those in Fena Reservoir, which ranged from 250 to 290 µS/cm (LaBaugh, 1985). The low values in Lake Ngardok probably indicate a negligible component of ground-water seepage which typically has higher ionic concentrations.

The color of the lake, observed during the survey period, was brown to greenish-brown and light penetration diminished rapidly with depth. However, no Seechi disk measurements were made to document these observations. The brown color was probably from organic degradation of the surrounding reed mats. The green color was probably from algae.

Results from the analyses of water quality at the lake outflow are presented in tables 5 and 6. Results show that no primary drinking-water standards were exceeded (U.S. Environmental Protection Agency, 1996) for any of the constituents measured. The concentration of total iron did, however, violate the secondary maximum contamination level of 300 µg/L (table 5), U.S. Environmental Protection Agency, 1996). The high iron concentration in the water may be a result of high iron concentrations in the local soils (Smith, 1983). The low dissolved oxygen (3.2 mg/L) measured at the outflow probably indicated that the water flowing past the outlet originated from the deeper, oxygen depleted depths. Other physical properties (conductivity, turbidity, and temperature) and nutrient concentrations fell within the range of averages observed in other streams on Palau (van der Brug, 1984) and are similar to those measured in Fena Reservoir (Labaugh, 1985). Recent measurements by AECOS Inc. (1997) at a point 1.4 mi downstream from the lake outlet (table 7) were similar to values measured in this study.

Table 4. Temperature, dissolved oxygen, and specific conductance at selected cross sections, Lake Ngardok, Palau, 1996

[Cross sections shown in figure 2; °C, degrees Celsius; mg/L, milligrams per liter; µs/cm, microsiemens per centimenter; ft, feet]

Depth	Water temperature (°C)	Dissolved oxygen (mg/L)	Specific conductance (µS/cm at 25°C)
Cross section *C–C′*; April 7, 1996; 1022 hours; total depth 11.7 ft			
surface	29.0	6.2	41
1.0	29.0	6.0	50
2.0	28.5	5.4	48
3.0	28.5	5.2	51
4.0	28.0	4.8	52
5.0	27.5	4.8	54
6.0	27.5	4.5	54
7.0	27.0	4.6	50
8.0	27.0	4.7	51
9.0	26.5	3.2	44
10.5	27.0	2.8	45
Cross section *F–F′*; April 7, 1996; 1000 hours; total depth 16.0 ft			
surface	29.0	5.9	48
1.0	29.0	6.5	48
2.0	29.0	6.9	48
3.0	28.5	4.6	51
4.0	28.0	5.4	52
5.0	27.5	5.4	52
6.0	27.5	5.8	56
7.0	27.5	5.3	52
8.0	27.0	5.6	50
9.0	26.5	4.1	51
11.0	27.0	3.5	46
13.0	27.0	3.6	46
15.0	26.5	3.3	44
Cross section *H–H′*; April 7, 1996; 0920 hours; total depth 12.8 ft			
surface	28.5	6.6	50
1.0	28.5	6.8	50
2.0	28.5	6.8	51
3.0	28.0	6.5	55
4.0	28.0	5.4	54
5.0	27.5	5.5	55
6.0	27.5	5.5	57
7.0	27.0	6.2	55
8.0	27.0	5.5	55
9.0	26.5	3.6	54
10.0	27.0	2.9	49
12.0	26.5	2.6	46
Cross section *N–N′*; April 5, 1996; 1515 hours; total depth 10.7 ft			
surface	28.0	6.7	54
1.0	28.0	6.6	56
2.0	27.5	7.5	57
3.0	27.0	5.5	55
4.0	26.5	5.7	54
5.0	26.5	4.8	47
6.0	26.0	3.9	45
7.0	26.0	3.4	44
8.0	26.0	3.2	42
9.0	26.0	3.9	42
Cross section *P–P′*; April 5, 1996; 1100 hours; total depth 7.4 ft			
1.0	28.0	7.0	50
2.0	27.0	7.8	61
3.0	26.5	8.4	60
4.0	26.0	7.7	52
5.0	26.0	6.6	56
6.0	26.0	5.3	55
7.0	26.0	--	57

Table 5. Water-quality data at outflow station on April 3, 1996 and November 10, 1997, Lake Ngardok, Palau

[<, actual value is less than value shown, value shown is detection limit; µs/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter,; --, not analyzed; pg/L, picograms per liter; pCi/L, picocurie per liter]

Property or constituent	April 3, 1996	November 10, 1997
INORGANIC		
Field measurements		
Specific conductance (µs/cm at 25°C	54	--
pH (units)	6.6	--
Major ions, total(mg/L)		
Calcium	2.9	3.4
Magnesium	2.7	--
Sodium	<5.0	<5.0
Alkalinity, total (as $CaCO_3$)	21.6	25.4
Alkalinity, bicarbonate (as $CaCO_3$)	21.6	25.4
Alkalinity, carbonate (as $CaCO_3$)	<5.0	<5.0
Alkalinity, hydrox (as $CaCO_3$)	<5.0	<5.0
Sulfate	0.69	0.73
Chloride	3.4	3.3
Flouride	<0.50	<0.50
Silica (as SiO_2)	13.4	16.5
Nutrients, total (mg/L)		
Nitrogen, nitrate (as N)	<0.50	0.50
Nitrogen, nitrite (as N)	<0.50	<0.50
Phosphorus, orthophosphate (as P)	<0.50	<0.50
Metals, total recoverable (µg/L)		
Aluminum	110	<100
Antimony	1.5	<1.0
Arsenic	<5.0	<5.0
Barium	<10	<10
Beryllium	<2.0	<2.0
Cadmium	<5.0	<5.0
Chromium	<10	<10
Copper	<20	<20
Iron	920	1000
Lead	<1.0	<1.0
Manganese	--	46
Mercury	<0.20	<0.20
Nickel	<40	<40
Selenium	<5.0	<5.0
Silver	<10	<10
Thallium	<0.10	<1.0
Zinc	<20	<20
OTHER INORGANIC		
Asbestos (structures/L)	0.23×10^6	$<0.20 \times 10^6$
PHYSICAL PROPERTIES		
Temperature, water (°C)	28.0	--
Turbidity (NTU)	3.5	2.9
Oxygen, dissolved (mg/L)	3.2	--
Solids, total dissolved (mg/L)	50	54
ORGANIC		
Cyanide, total (mg/L)	<0.010	<0.010
Pesticides and herbicides, total recoverable, (µg/L)		
alpha-Chlordane	<0.1	--
gamma-Chlordane	<0.1	--
2,3,7,8-TCDD (Dioxins)	<1.4 pg/L	<1.3 pg/L
Hexachlorobenzene	0.1	<0.1

Table 5. Water-quality data at outflow station on April 3, 1996 and November 10, 1997, Lake Ngardok, Palau--Continued

Property or constituent	April 3, 1996	Detection limit
RADIATION AND RADIONUCLIDES(pCi/L)		
Gross alpha	-0.171 ± 0.278	0.392
Gross beta	0.226 ± 0.450	0.683
Radium 226	0.0657 ± 0.141	0.256
Radium 228	0.193 ± 0.479	0.823
Uranium	<1.0 µg/L	1.0 µg/L

Property or constituent	November 10, 1997	Detection limit
RADIATION AND RADIONUCLIDES(pCi/L)		
Gross alpha	0.182 ± 0.29	0.597
Gross beta	2.99 ± 1.5	2.66
Radium 226	0.0298 ± 0.044	0.0727
Radium 228	0.0916 ± 0.21	0.479
Uranium	0.015 ± 0.004 µg/L	0.101 µg/L

Table 6. Pesticides, herbicides and other volatile organic constituents found to be less than detection limits in water samples from outflow station on April 3,1996 and November 10, 1997, Lake Ngardok, Palau

Organic (total recoverable)	Detection limit (mg/L)	Organic (total recoverable)	Detection limit (mg/L)
Alachlor (Lasso)	0.1	Di (2-ethylhexyl) phthalate	0.6
Aldicarb	0.5	Dinoseb	0.1
Aldicarb Sulfone	0.4	Diquat	0.4
Aldicarb Sulfoxide	0.5	Endothall	9.0
Aldrin	0.1	Endrin	0.01
Aroclor 1016	0.08	Ethylene dibromide (EDB)	0.01
Aroclor 1221	2.0	Glyphosate (Roundup)	6.0
Aroclor 1232	0.5	Heptachlor	0.04
Aroclor 1242	0.3	Heptachlor epoxide	0.02
Aroclor 1248	0.1	Hexachlorocyclopentadiene	0.1
Aroclor 1254	0.1	3-Hydroxycarbofuran	1.0
Aroclor 1260	0.2	Lindane (gamma-BHC)	0.02
Atrazine	0.1	Methoxychlor	0.1
Benzo(a)pyrene	0.02	Methomyl	0.5
Butachlor	0.1	Metolachlor (Dual)	0.1
Carbaryl	1.0	Metribuzin (Sencor)	0.1
Carbofuran	0.9	Oxamyl (Vydate)	1.0
Chlordane	0.2	Pentachlorophenol	0.04
2,4-D	0.1	Picloram (Tordon)	0.1
Dalapon	1.0	Propachlor	0.1
1,2-Dibromo-3-chloropropane	0.02	2,4,5-TP (Silvex)	0.1
Dicamba	0.1	Simazine	0.07
Dieldrin	0.1	Toxaphene	1.0
Di (2-ethylhexyl) adipate	0.6		
Benzene	1.0	2,2-Dichloropropane	1.0
Bromobenzene	1.0	1,1-Dichloropropene	1.0
Bromochloromethane	1.0	*cis*-1,3-Dichloropropene	1.0
Bromodichloromethane	1.0	*trans*-1,3-Dichloropropene	1.0
Bromoform	1.0	Ethylbenzene	1.0
Bromomethane	1.0	Hexachlorobutadiene	1.0
n-Butylbenzene	1.0	Isopropylbenzene (Cumene)	1.0
sec-Butylbenzene	1.0	*p*-Isoropyltoluene (*p*-Cymene)	1.0
tert-Butylbenzene	1.0	Methylene chloride	1.0
Carbon tetrachloride	1.0	Naphthalene	1.0
Chlorobenzene	1.0	*n*-Propylbenzene	1.0
Chloroethane	1.0	Styrene	1.0
Chloroform	1.0	1,1,1,2-Tetrachloroethane	1.0
Chloromethane	1.0	1,1,2,2-Tetrachloroethane	1.0
2-Chlorotoluene	1.0	Tetrachloroethene	1.0
4-Chlorotoluene	1.0	Toluene	1.0
Dibromochloromethane	1.0	1,2,3-Trichlorobenzene	1.0
Dibromomethane	1.0	1,2,4-Trichlorobenzene	1.0
1,2-Dichlorobenzene	1.0	1,1,1-Trichloroethane	1.0
1,3-Dichlorobenzene	1.0	1,1,2-Trichloroethane	1.0
1,4-Dichlorobenzene	1.0	Trichloroethene	1.0
Dichlorodifluoromethane	1.0	Trichlorofluoromethane	1.0
1,1-Dichloroethane	1.0	1,2,3-Trichloropropane	1.0
1,2-Dichloroethane	1.0	1,2,4-Trimethylbenzene	1.0
1,1-Dichloroethene	1.0	1,3,5-Trimethylbenzene	1.0
cis-1,2-Dichloroethene	1.0	Vinyl chloride	1.0
trans-1,2-Dichloroethene	1.0	*m*- & *p*-Xylenes	1.0
1,2-Dichloropropane	1.0	*o*-Xylene	1.0
1,3-Dichloropropane	1.0		

Table 7. Data from AECOS Inc. station 20, 1.4 miles downstream of Lake Ngardok outflow, Palau

[Data from AECOS Inc., 1997; ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25°C; °C, degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; µg/L, micrograms per liter; --, no data or not applicable]

Date	Time	Instantaneous discharge (ft^3/s)	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Turbidity (NTU)	Disolved oxygen (mg/L)	Total nitrogen, NO^2+NO^3 (µg/L as N)	Total nitrogen (µg/L as N)	Total phosphorus (µg/L as P)
04/03/96	1525	34.6	40	6.1	28.0	3.1	6.0	--	--	--
04/06/96	1540	--	42	6.7	29.0	5.0	6.5	<1	45	11
07/16/96	1535	5.65	41	7.1	27.0	1.1	6.9	<1	62	6

SUMMARY

Because of the increasing population on Koror, the Palau government plans to relocate its capital to Melekeok on Babeldaob Island. Lake Ngardok, near Melekeok, the largest freshwater lake in the Republic of Palau, is being considered as a source of water for the new capital. This report presents the methods and results of measurements of the quantity and quality of water in Lake Ngardok.

A bathymetric survey was done during March and April 1996, to determine the storage capacity of the lake. From analysis of bathymetric data, a capacity of 107 acre-feet was estimated with 24.1 acres of surface area at an elevation of 59.5 feet (mean lake elevation for the period April 1996 to March 1998). Elevation-surface area and elevation-capacity curves summarizing the current relations between elevation, surface area, and storage capacity along with lake-elevation data collected between April 1996 and March 1998 showed that lake capacity fluctuated between 90.0 and 168 acre-feet during this period. Rainfall data collected from July 1996 to March 1998 indicated that lake water levels were correlated to rainfall with lake elevation rising in response to heavy rainfall and then returning to normal levels after a few days. A floating mat of *Hanguana malayana*, a reed-like plant, covers about 58 percent of the surface area of the lake. The vegetation was a source of error reducing the accuracy of the storage capacity computations.

Quality of water was sampled during April 1996 and November 1997, and results indicated that no U.S. Environmental Protection Agency primary drinking water standards were exceeded for the organic and inorganic compounds and radionuclides analyzed. With suitable biological treatment, the lake water could be used for drinking-water purposes. Temperature and dissolved-oxygen measurements at various depths showed stratification of the lake with depth and near anaerobic conditions at the lake bottom. Complete mixing of the lake probably occurs rarely. The low dissolved oxygen (3.2 mg/L) measured at the outflow indicated that the water flowing past the outflow probably comes from the deeper oxygen-depleted depths of the lake.

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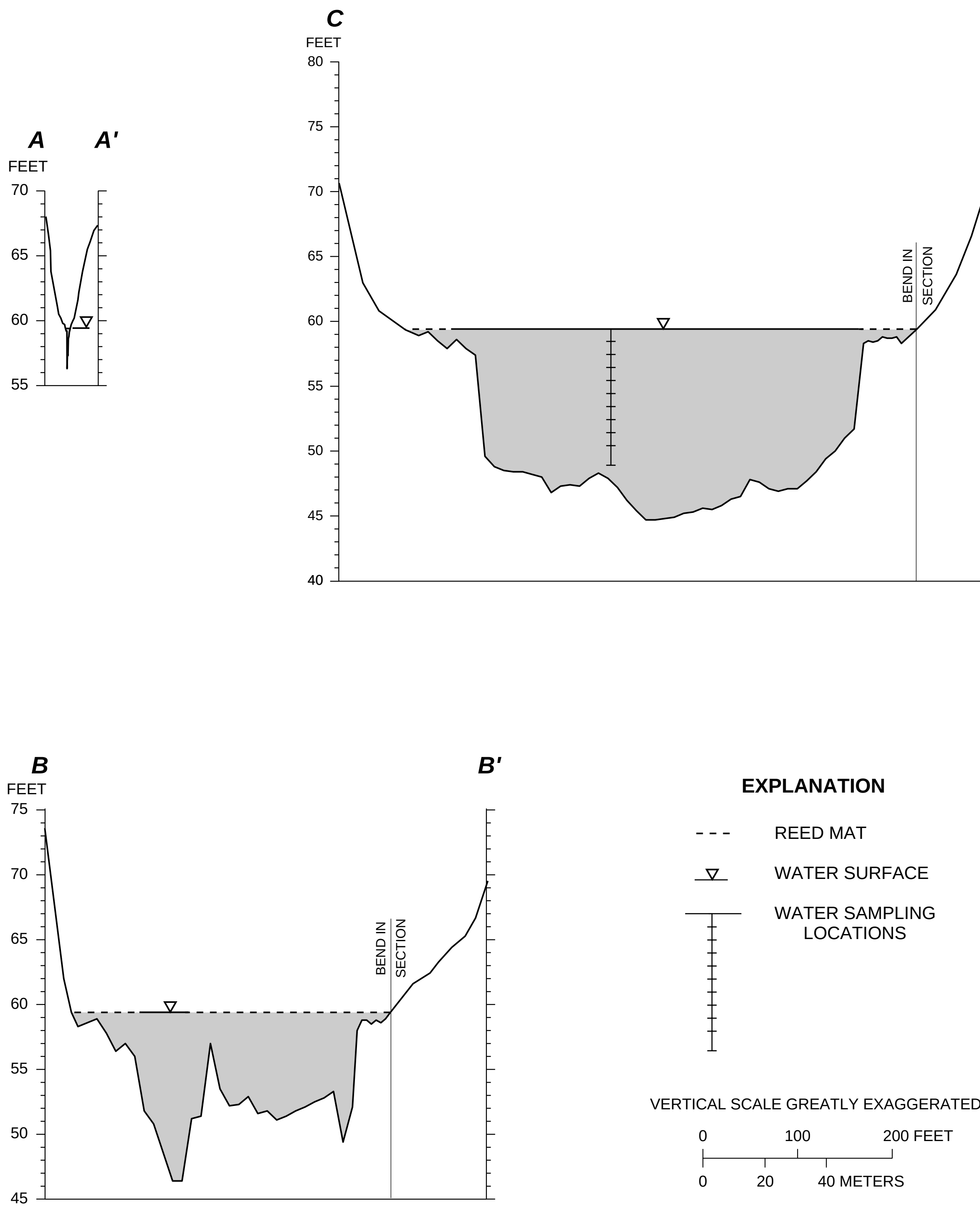
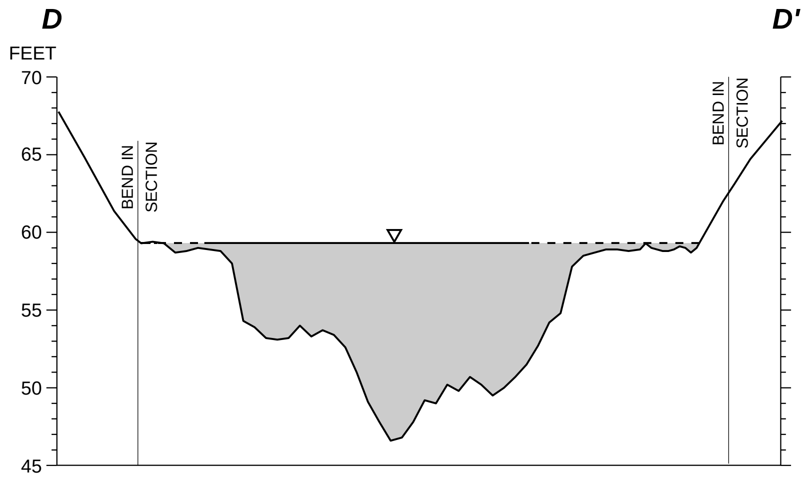


Figure 4. Bed elevation at cross sections, Lake Ngardok, Palau, 1996 (datum is mean sea level).



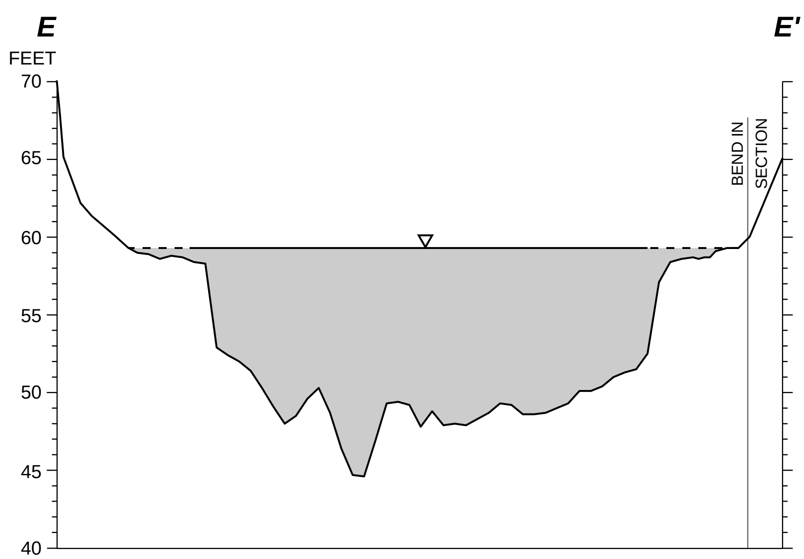


Figure 4. Bed elevation at cross sections, Lake Ngerdok, Palau, 1996 (datum is mean sea level)--*Continued*.

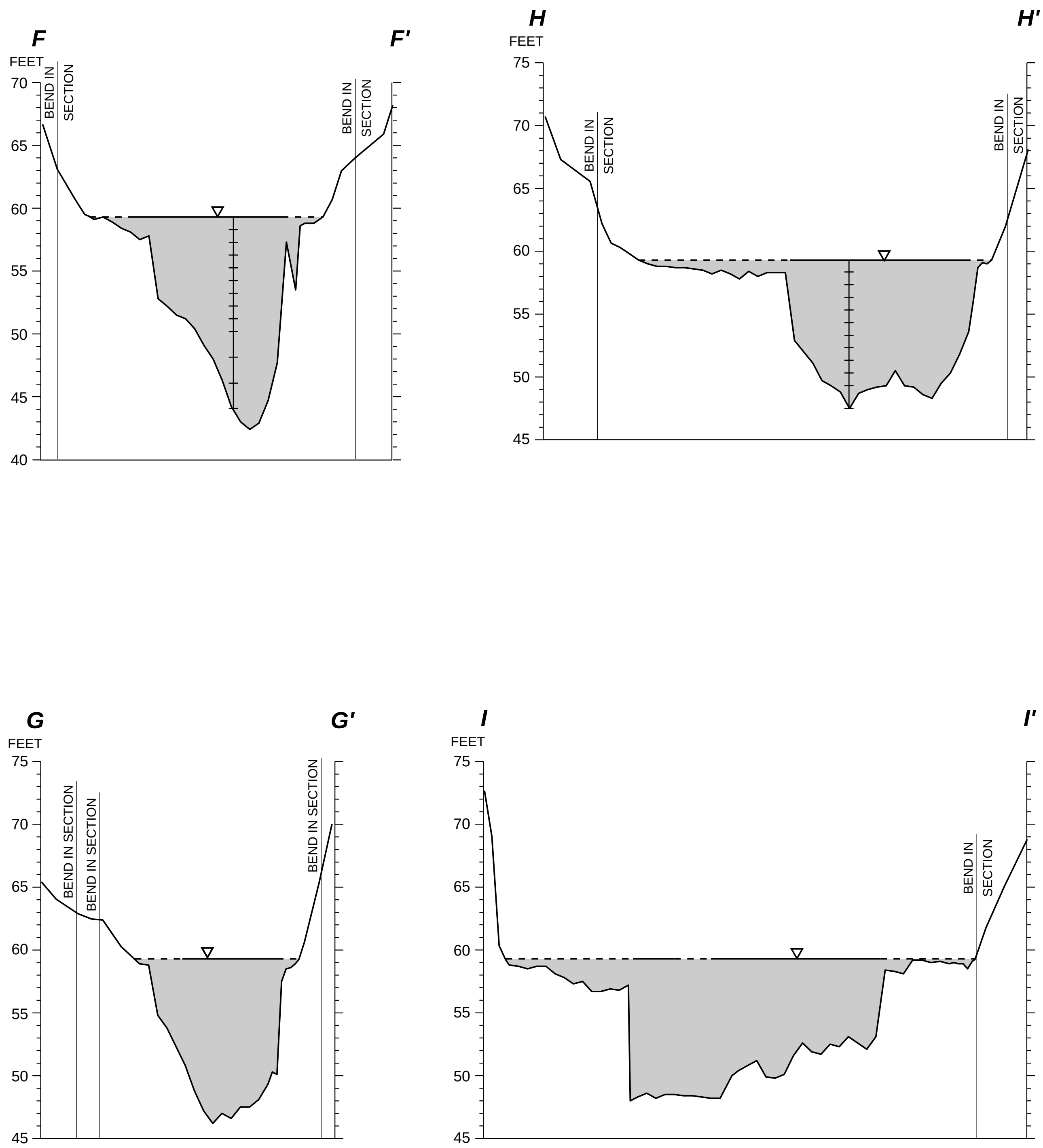


Figure 4. Bed elevation at cross sections, Lake Ngardok, Palau, 1996 (datum is mean sea level)--*Continued*.

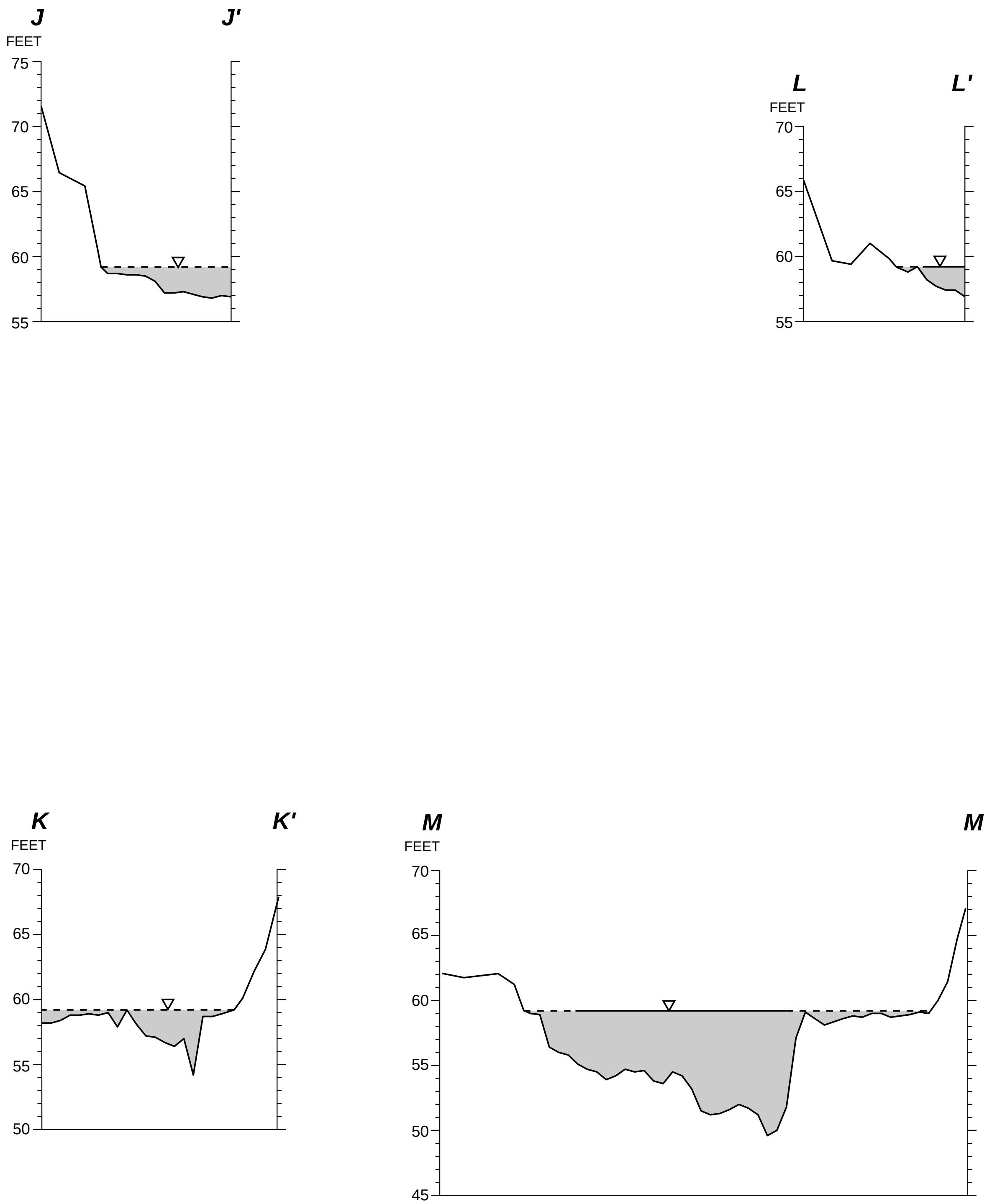
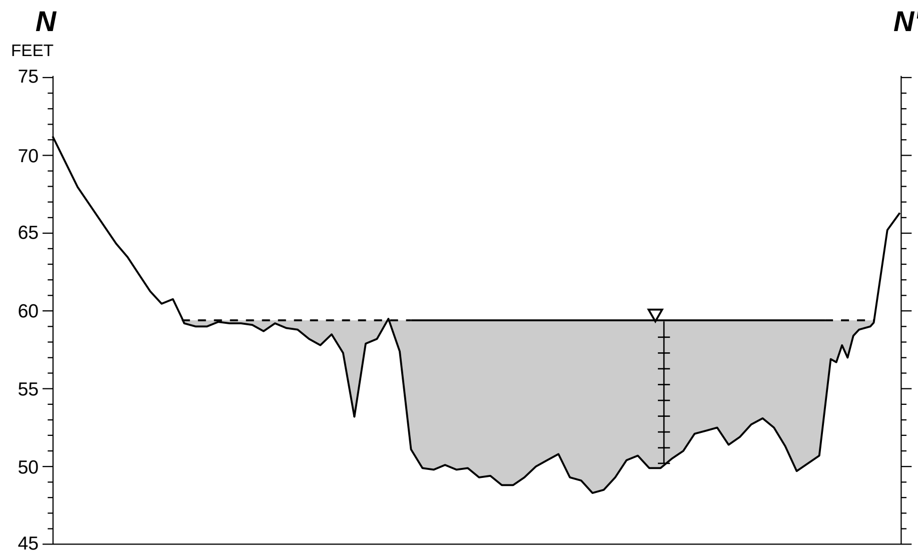


Figure 4. Bed elevation at cross sections, Lake Ngardok, Palau, 1996 (datum is mean sea level)--*Continued*.



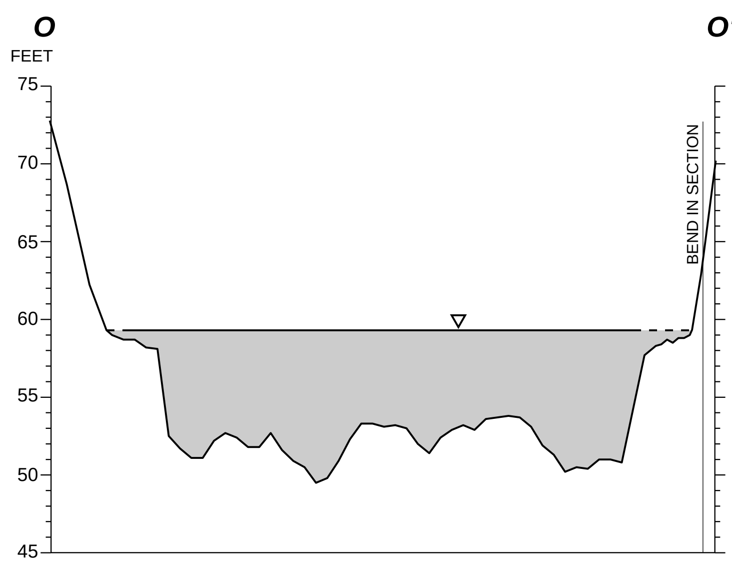
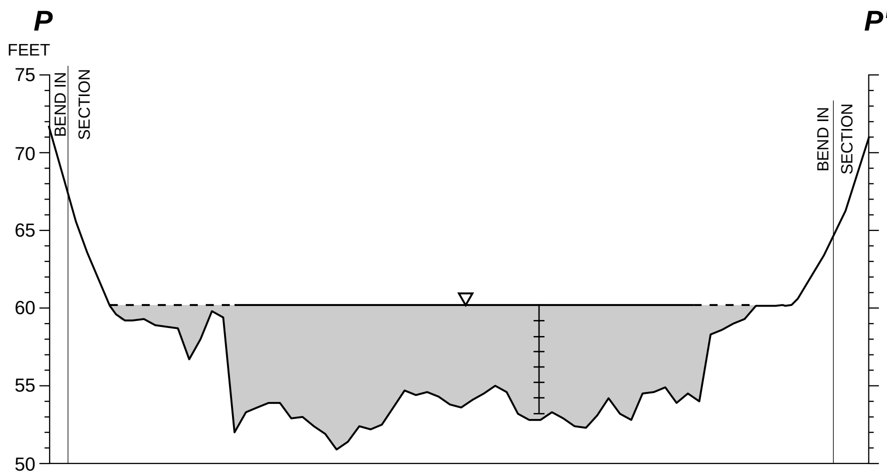


Figure 4. Bed elevation at cross sections, Lake Ngardok, Palau, 1996 (datum is mean sea level)--*Continued*.



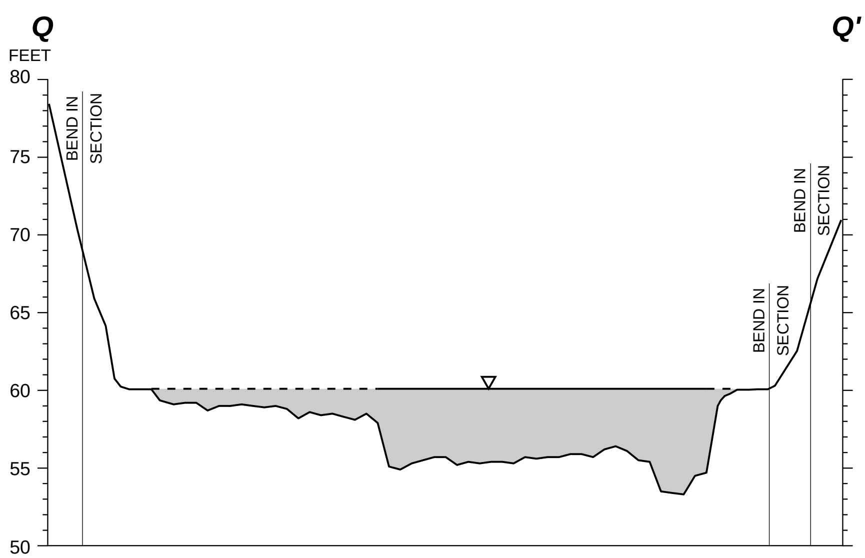


Figure 4. Bed elevation at cross sections, Lake Ngardok, Palau, 1996 (datum is mean sea level)--*Continued*.

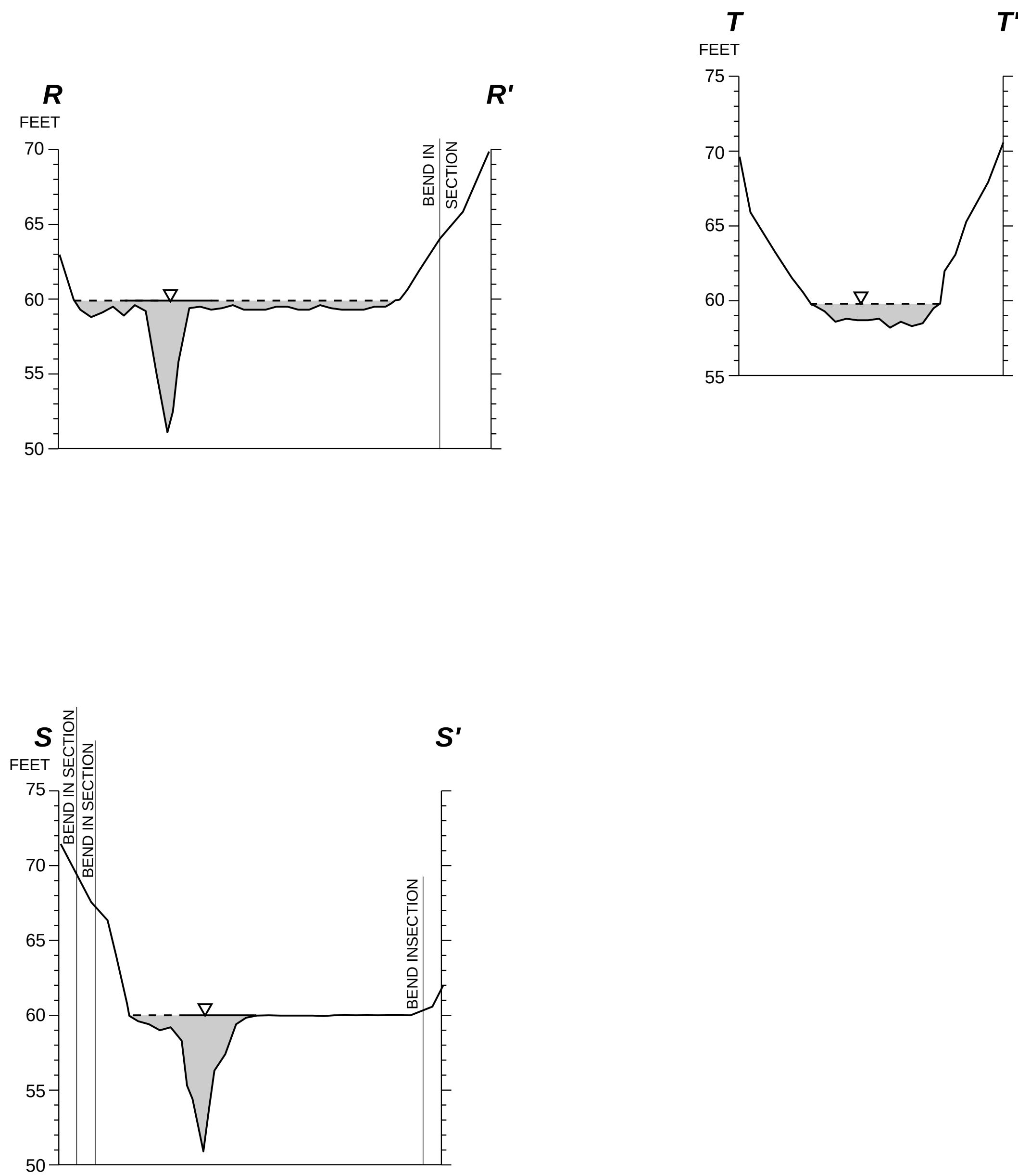


Figure 4. Bed elevation at cross sections, Lake Ngardok, Palau, 1996 (datum is mean sea level)--*Continued*.

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