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# The Hydrology of the Northern Marshall Islands

by

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## INTRODUCTION

The field work on which this paper is based was carried out in conjunction with an engineering survey of the northern Marshall Islands 3/ by the 71st Engineering Survey Liaison Detachment, General Headquarters, Far East Command. The hydrologic studies, which were made by the U. S. Geological Survey, were part of a comprehensive investigation of atoll features. The field work was done in December 1951 and January, February, and August, 1952 during which time the following atolls were visited: Utirik, Taka, Likiep, Ailuk, Lae, Kwajalein, Ujelang, Wotho, Ujae, Taongi, and Bikar (fig. 1). An average of 4 working days was spent at each atoll. The author wishes to acknowledge the assistance of the Marshallese guides and well diggers who aided in collecting ground-water data. In particular he wishes to express appreciation to his colleagues F. S. MacNeil and F. R. Fosberg, who collected water samples on Utirik and Likiep, and C. G. Johnson, who collected water samples on Taongi and Bikar. The author did not visit Likiep, Taongi, or Bikar. Groundwater data for Eniwetok Atoll were furnished by Harry Ladd of the Geological Survey. Appreciation is expressed also to Dan A. Davis, district geologist of the Ground Water Branch, Geological Survey, at Honolulu, Hawaii, who reviewed the report and made numerous valuable comments and suggestions.

A comprehensive report of hydrologic conditions in the northern Marshalls, including a discussion of the principles of the occurrence of ground water on small oceanic islands, is to be incorporated in an extensive report which will include all phases of the investigation. The main purpose of this paper, therefore, is to present factual data collected in the Marshall Islands rather than to give a discussion of principles.

## CLIMATE

### General Statement

The northern Marshall Islands have a tropical marine climate characterized by uniformity of air pressure, temperature, cloudiness, and humidity. Wind conditions are somewhat more variable, depending upon the season, and precipitation shows considerable variation depending upon the season and latitude. The predominant weather condition is one of moderate easterly trade winds and partly cloudy skys. This is usually broken by relatively brief showers or infrequent thunderstorms. Strong winds and long periods of continuous rain are infrequent, and hurricanes (typhoons) are relatively uncommon.

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1/ Publication authorized by the Director, U. S. Geological Survey.

2/ Geologist, Ground Water Branch, Water Resources Division, U. S. Geological Survey, Agana, Guam.

3/ In this report the "northern Marshall Islands" are considered as comprising Kwajalein Atoll and all atolls north of Kwajalein.

## Statistical Data

Meteorological records are comparatively scarce for the northern Marshall Islands. The only continuous long-term data available that were collected before World War II are from Ujelang for the period 1894 to 1913. Since World War II, data have been collected almost continuously at Eniwetok and Kwajalein. Because of the extremely short period of time spent on each atoll, no significant climatological data were collected during the work reported here.

The meteorological factor that has the most bearing on water supply is precipitation. The presence of the equatorial front, which seasonally may extend as far as 11 degrees north latitude, results in a marked gradation of rainfall from south to north in the northern Marshalls because the southern islands are deeper within the front whereas, to the north, the effect of the front becomes progressively weaker. (See fig. 2.) Comparative rainfall data for Ujelang, Kwajalein, and Eniwetok are shown in table 1.

Other climatic data have been published previously. (See references 1 and 4 at end of paper.)

# TIDES

Tidal data were obtained at each of the atolls visited, by contract personnel of the 71st Engineers. The data were obtained by hourly observations at a staff gage placed in the lagoon. Approximately $2\frac{1}{2}$ days of observations were made at each atoll. Because of the short term of observations and particularly because of the method of observation, the tide data are unreliable for the determination of a datum plane and therefore can be used only for general comparisons.

Tide data for seven of the atolls visited are published by the U. S. Coast and Geodetic Survey in its annual "Tide Tables for the Central and Western Pacific Ocean." These data are based on a primary station established at Kwajalein Island, Kwajalein Atoll. At Kwajalein the mean tide range, as measured in the atoll lagoon, is 3.5 feet; the spring range is 5.0 feet. There are some differences between the ranges at Kwajalein and those of some of the other atolls. The greatest difference from the average is at Ujelang where the mean range is 2.8 feet and the spring range is 3.9 feet.

# WATER SUPPLY

## Rain Water

Rain water is the most important source of fresh water for the Marshellese people. They prefer to use it for all purposes, but during the dry season the available rain water is reserved for drinking purposes and water from wells is used for washing and cooking.

The bulk of the rain water is caught on corrugated iron sheets hung over concrete cisterns or corrugated iron roofs of houses or other buildings. The

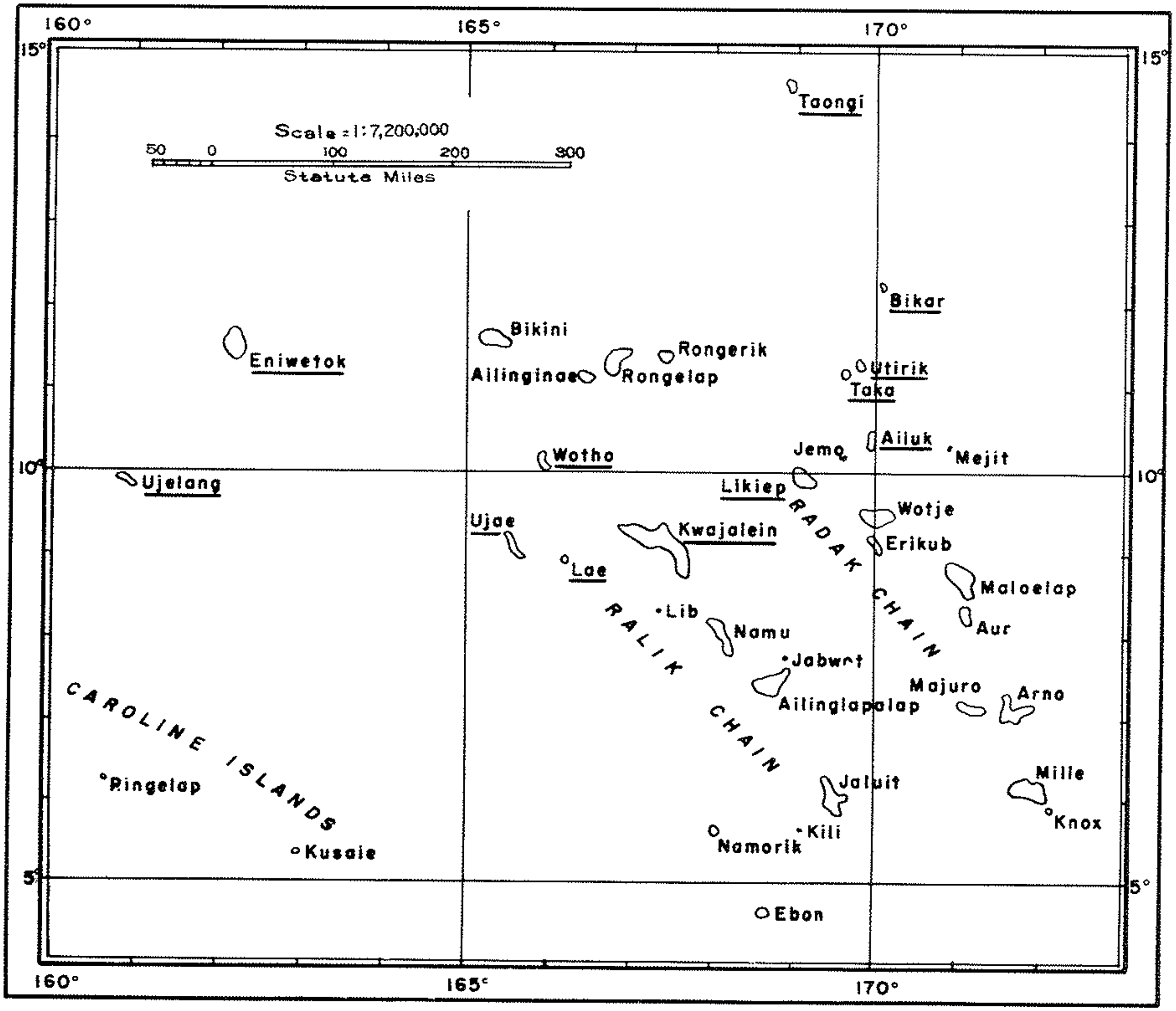


Figure 1. -- Outline map of the Marshall Islands. Islands covered in report are underlined.

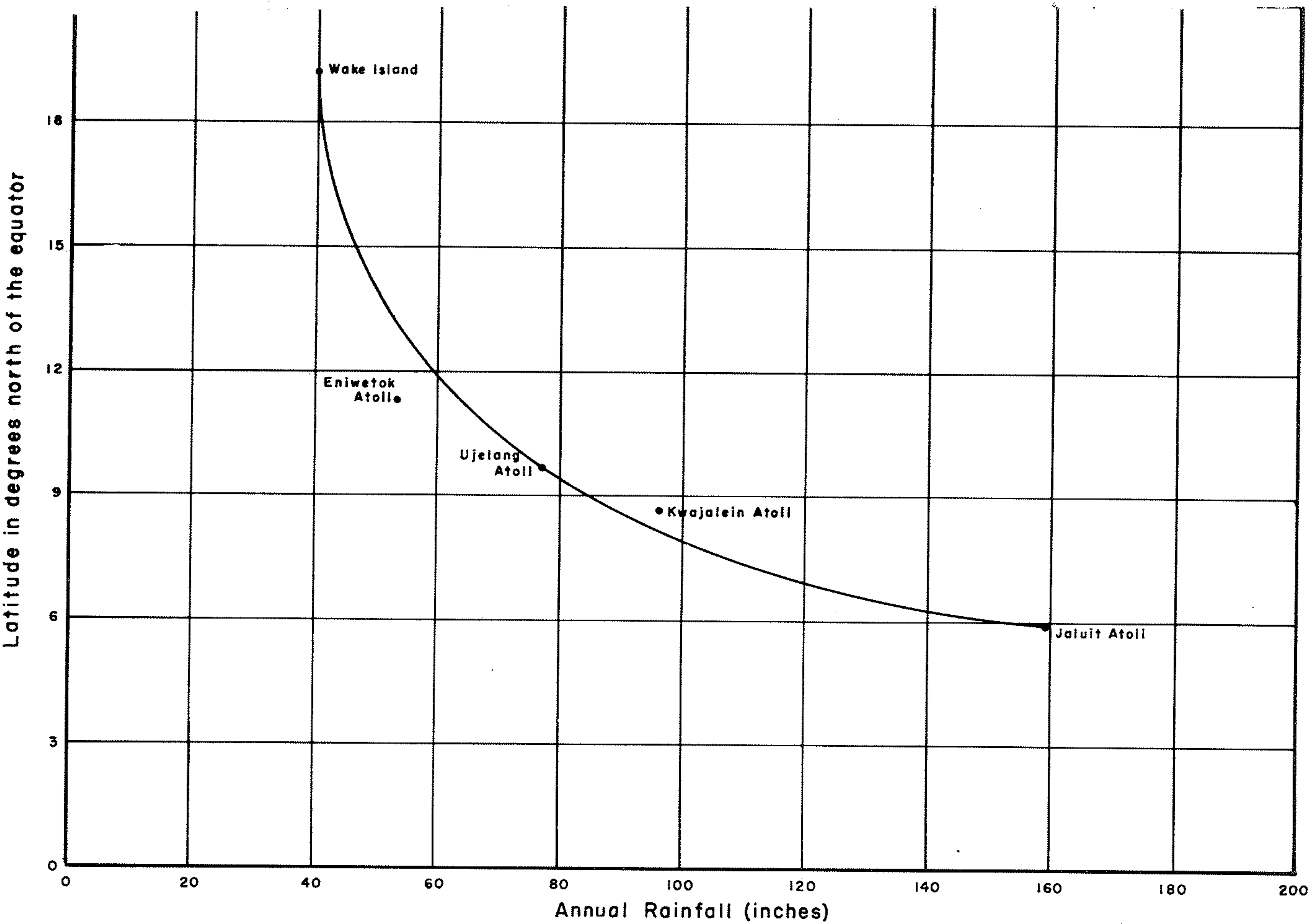


Figure 2.--Variation of rainfall with latitude in the Marshall Islands.

Table 1.--Comparative precipitation data for Eniwetok, Ujelang, and Kwajalein Atolls, Marshall Islands.

Eniwetok Atoll. Length of record: 5 years, 1944-1946, 1949-1953.

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean monthly | 0.80 | 0.71 | 2.63 | 2.54 | 6.22 | 2.47 | 5.54 | 6.38 | 6.00 | 9.18 | 4.61 | 2.31 | 49.39 |
| Minimum monthly | 0.12 | 0.39 | 0.39 | 0.22 | 1.40 | 1.06 | 2.34 | 3.00 | 2.79 | 5.19 | 2.51 | 0.79 | |
| Maximum monthly | 1.57 | 1.30 | 6.21 | 10.71 | 14.89 | 7.72 | 12.89 | 9.05 | 12.85 | 14.15 | 6.56 | 3.77 | |

Kwajalein Atoll. Length of record: 8 years, 1944-1953

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean monthly | 3.97 | 2.20 | 7.39 | 3.87 | 8.44 | 7.39 | 7.67 | 9.14 | 10.78 | 11.80 | 11.25 | 11.76 | 95.66 |
| Minimum monthly | 1.16 | 0.61 | 0.59 | 0.43 | 4.25 | 2.26 | 2.54 | 4.45 | 5.04 | 3.02 | 4.40 | 5.10 | |
| Maximum monthly | 15.66 | 5.13 | 24.33 | 9.40 | 15.88 | 13.02 | 13.20 | 16.95 | 17.38 | 20.10 | 16.76 | 30.33 | |

Ujelang Atoll. Length of record: 16 years, 1894-1913.

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean monthly | 2.1 | 1.8 | 2.6 | 5.2 | 6.6 | 7.1 | 8.4 | 8.5 | 10.3 | 10.4 | 9.6 | 4.8 | 77.4 |
| Minimum monthly | 0.7 | 0.3 | 0.4 | 0.6 | 0.8 | 0.8 | 2.9 | 3.4 | 6.1 | 5.6 | 3.0 | 1.9 | |
| Maximum monthly | 7.3 | 6.6 | 10.6 | 14.2 | 14.3 | 23.2 | 18.5 | 14.1 | 16.3 | 14.3 | 24.3 | 8.5 | |

water is stored in the cisterns and in oil drums. Where corrugated iron is not available, rain water is obtained by collecting the water that falls on coconut palms, or occasionally, Pandanus trees. The water caught on trees is stored in drums or any other available receptacle, such as paint cans or wash basins.

No determined effort is made by the Marshallese people to insure a year-round supply of rain water. Extensive roof areas are unguttered and some of the cisterns are fed by catchment areas that are not large enough to supply the maximum amount of water that could be handled by the cistern. If maximum use were made of existing facilities there would be much less likelihood of the exhaustion of rain-water supplies that now occurs frequently during the dry season.

No samples of rain water were caught on a surface previously tested to make sure it was free of salt. Samples obtained directly from cisterns ranged in chloride content from 20 parts per million on Lae to 60 parts per million on Wotho. The total hardness of these two samples was 80 and 70 parts per million, respectively. A sample obtained on Lae from an oil drum fed from catchment on a palm tree had a chloride content of 60 parts per million and a total hardness of 40 parts per million.

## Ground Water

Physical nature.--The only source of fresh water on any island in the northern Marshalls is the rain that falls directly on that island. Part of the rainfall evaporates or is transpired by plants, and the remainder, because of the high permeability of the island sediments, seeps directly into the ground. There is no significant surface runoff. The fresh water, which is about 40/41 as heavy as salt water, floats on the surface of the salt water roughly in the shape of a dome, the edges of which coincide with the edges of the island. The fresh water displaces a volume of salt water equal to its own weight and depresses the fresh-salt-water interface below sea level under the island. Under ideal conditions in a homogeneous island, because of the 40/41 weight relationship of fresh to salt water, the interface extends about 40 times as far below sea level as the dome stands above sea level. Actually, the shape of the fresh-water body varies, depending upon local geologic conditions, and the 40-to-1 depth ratio is modified by a transition zone of variable thickness in which there is a mixture of fresh and salt water. This double-convex fresh-water body floating on sea water is known as the Ghyben-Herzberg lens. It is the only source of potable ground water in the northern Marshall Islands.

The average height of fresh water above mean sea level in the northern Marshall islands is less than 1 foot. At well 7, on Lae Island, Lae Atoll, which is about 1,035 feet from the lagoon shore, the mean height of water above mean sea level was found to be 1.41 feet. This figure is based on the determination of mean sea level by tide gage. Unfortunately, the tide-gage determinations were such that the accuracy of the calculated heights of levels in the well is highly questionable. Theoretically, therefore, the depth of fresh water below sea level in the islands of the atolls generally is not more than about 40 feet at the deepest point, tapering to zero at the edges of the lenses. Because of the mixing effect in the zone of transition, however, only the upper part of the lens is fresh enough for human consumption.

Fresh water is miscible with salt water, and the Ghyben-Herzberg lens will not form or will be destroyed unless certain prerequisites of permeability, water-level fluctuation, and precipitation are fulfilled. The permeability of the soil and rocks constituting the island must be great enough to allow the fresh water to infiltrate rapidly enough to maintain a positive hydrostatic pressure against the salt water, but must not be so great as to allow free mixing of the fresh and salt water. The islands in the northern Marshalls consist mostly of sand overlying rubble deposits, both of which have a degree of permeability that is conducive to the formation of a Ghyben-Herzberg lens. The windward side of many of the islands, however, is composed of coarse-grained materials ranging in size up to boulders, and because of the high permeability of these materials the lens may not be developed as well on the windward side as it is on the leeward side or in the central part of an island. At Taka Island, Taka Atoll, water from well 6, which is on the windward side of the island, had a chloride content of 6,480 parts per million, whereas water from wells 1 and 7, on the leeward side, had chloride contents of 840 and 2,480 parts per million, respectively. This condition existed in spite of the fact that well 6, at 400 feet, is farther from the windward shore than wells laand 7, at 300 and 55 feet respectively, are from the lagoon shore.

The second prerequisite for a functioning Ghyben-Herzberg lens is that tidal and seasonal fluctuations in the ground-water level be small, thereby reducing the mixing of fresh and salt water. The magnitude of the tidal fluctuations in the ground-water body at a given point in an island is inversely proportional to the distance to the shoreline and directly proportional to the permeability of the soil and rocks constituting the island. A comparison of tidal fluctuations in the ocean and in the ground-water body in four islands indicates that the ocean tides are damped by approximately nine-tenths as they move through the land (see table 2). Presumably in smaller islands there would be considerably less damping of the ocean tides. Inasmuch as each atoll was visited only once it was not possible to obtain any data concerning the magnitude of seasonal or annual fluctuations of the levels of the fresh-water lens.

The third prerequisite for the existence of a Ghyben-Herzberg lens is that the precipitation be sufficient to provide adequate infiltration of water to the ground-water body after losses due to evaporation and transpiration are deducted. It is estimated that less than half and perhaps only about a quarter of the rainfall is available after evapo-transpiration losses are deducted. The infiltration areas are small, owing to the size of the islands, and, in addition as shown in figure 2, the precipitation in the northernmost Marshall Islands is light. The total recharge to the ground-water lens, therefore, is so small in the northernmost islands that a permanent Ghyben-Herzberg lens probably does not exist on any island north of the latitude of Eniwetok Atoll. South of Eniwetok infiltration from rainfall is adequate to maintain a permanent lens if the island is at least 0.1 square mile in area. This area is great enough to provide sufficient catchment area, and adequate width for the damping of tidal fluctuations. During the rainy season smaller islands south of Eniwetok and larger islands north of Eniwetok may receive enough precipitation to build up small fresh-water lenses, but these lenses deteriorate or are destroyed during the dry season because of the lack of sufficient water from precipitation to maintain them against natural discharge and mixing with the ocean water.

Table 2.--Comparison of tidal fluctuations in the ocean and in the ground-water lens of four islands in the northern Marshall Islands.

| Island | Well number | Distance to lagoon shore (feet) | Maximum tidal range in well (feet) | Mean tidal range in well (feet) | Maximum tidal range in ocean (feet) | Mean tidal range in ocean (feet) | Ratio of mean tidal range in well to mean tidal range in ocean | Period of observation (days) | Chloride content of well water (ppm) |
|---|---|---|---|---|---|---|---|---|---|
| Ailuk | 1 | 115 | 0.62 | 0.32 | 5.8 | 4.0 | 0.08 | 5 | 272 |
| Lae | 7 | 1,035 | .22 | .16 | 3.5 | 2.1 | .08 | 3 | 15 |
| Ujelang | 2 | 140 | .23 | .20 | 3.0 | 1.7 | .12 | 3 | 100 |
| Wotho | 4 | 330 | .26 | .22 | 5.1 | 4.8 | .05 | 1.5 | 130 |

Quality of water.--The extent of development of the Ghyben-Herzberg lens controls the quality of the ground water found in the islands of the northern Marshalls. Where there is a combination of such factors as low rainfall and small island area (conditions inimical to the development of a Ghyben-Herzberg lens) as is found for example on Bogallua Island, Eniwetok Atoll, the ground water is very similar to sea water in composition. On a larger island such as Lae Island, Lae Atoll, however, where the precipitation is considerably greater, the ground water in the central part of the island is comparable, in certain dissolved constituents, to water obtained by rain catchment. Between these extremes may be found ground water having varying chemical characteristics, depending upon the development of the Ghyben-Herzberg lens and the location with respect to the shoreline. (See table 3.)

All the 53 ground-water samples tested in the northern Marshalls had a total hardness of more than 200 parts per million 1/ and 50 exceeded 300 parts per million. The relation of total hardness to distance from the shoreline was not the same in every island. Two examples are shown in figures 3 and 4. At Ailuk Island, Ailuk Atoll, the total hardness varied inversely with distance from the lagoon shore, whereas at Lae Island, Lae Atoll, the total hardness of the samples tested remained approximately uniform and showed no relation to distance from the shoreline. 2/ The increase in total hardness at Ailuk toward the lagoon shore is apparently due to contamination by sea water mixing with the ground water. At Ailuk the calcium hardness of the ground water remained relatively constant, regardless of distance to the shoreline, whereas at Lae the calcium hardness seemed to decrease toward the shore (figs. 3 and 4). The increase in total hardness at Ailuk, where the calcium hardness remained constant, and the decrease in calcium hardness at Lae, where the total hardness remained constant, must be accounted for by an increase in magnesium hardness.

The chloride content of the ground water varies widely, depending upon the amount of contamination by sea water. The chloride content of sea water is approximately 18,000 to 20,000 parts per million, whereas that of rain water theoretically is zero. The rain water, however, dissolves salt crystals floating in the air and deposited on the vegetation and soil. Therefore, a "base" chloride content is always present regardless of whether the ground water has been contaminated by sea water. The lowest chloride determination obtained, 15 parts per million, was at well 7 in Lae Island (see table 3), and this may be considered as the base chloride content in the northern Marshalls until and unless a lower determination is obtained. The highest value obtained was for a well on Bogallua Island, Eniwetok Atoll, where the chloride content of a well sampled was 19,300 parts per million (see table 3). Chloride of about this magnitude, of course, is present in the ground water of most of the small islands in the northern Marshalls on which fresh-water lenses have not formed. In places the ground water on the main islands in Likiep, Lae, Ailuk,

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1/ Water having a hardness of less than 50 or 60 parts per million is generally rated as soft. Where the hardness is 200 or 300 parts per million it is common practice in the United States to soften water for household use.

2/ Ailuk and Lae are used as type examples because the most satisfactory well distribution was obtained on these islands.

Wotho, Eniwetok, and Ujae atolls was found to contain less than 250 parts per million of chloride, and on Utirik, Ujelang, and Kwajalein Atolls to contain less than 500 parts per million of chloride. Such waters are definitely potable and contain considerably less dissolved mineral matter than is present in public water supplies in parts of Guam and in certain other islands in the Pacific.

On some of the larger islands the chloride content of the ground water was found to be controlled by the distance of the point of sampling from the shoreline. On both Ailuk and Lae Islands there was an inverse relationship between chloride content and distance to Lagoon shore (fig. 5). On other islands, notably Wotho Island, Wotho Atoll, and Lado Island, Likiep Atoll, however, no such relationship was observed.

As would be expected in islands composed almost exclusively of limestone or limestone derivatives, the ground water is slightly alkaline (see fig. 6). The average pH of 50 samples tested was 7.4. Of the total, 45 had a pH between 7.0 and 8.0 and 39, between 7.2 and 7.6. Two of the samples had a pH of 6.7, which is slightly on the acid side. Both samples were obtained from pits on Lae Island dug in taro plots where the soil was a mucky peat containing much decaying vegetal matter. Two of the samples had a pH of 8.3. This, however, was due to the influence of sea water. The two samples were obtained from wells on Sibylla Island, Taongi Atoll, where the ground water had salinities corresponding to 65 and 85 percent of that of ocean water, which may be expected to have a pH ranging from 8.1 to 8.3. One sample, with a pH of 8.2, was from a well on Engebi Island, Eniwetok Atoll. The high pH value probably was caused by the concrete lining in the well. This effect of concrete, which evidently still is curing, was noted also in several samples of rain water collected from concrete cisterns. Five such samples showed pH values ranging from 8.0 to 8.5, whereas one sample of rain water that had been stored in a discarded oil drum had a pH of 7.4.

The temperature of the ground water in the northern Marshall Islands averaged 81° Fahrenheit. This is 1 degree less than the mean annual air temperature (based on records for Ujelang Atoll). No relationship between temperature of the ground water and latitude of the atoll was observed.

Use.--Ground water is used by the Marshallese people for all domestic purposes. Although rain water is preferred, ground water is used for washing and cooking during the dry season and for drinking purposes when the rain cisterns are completely empty.

All the ground water is obtained from dug wells. Most of the wells are less than 10 feet deep and penetrate about 1 foot below the water table. Many of the wells are cased with limestone blocks or discarded oil drums, but some of the very shallow ones are not cased at all. None of the wells was reported to antedate the German period of control and it is unlikely that the Marshallese people were aware of the presence of fresh water under their islands before the German period. Even today on Lae Island, where there is an excellent Ghyben-Herzberg lens, some of the Marshallese were skeptical of the widespread existence of fresh water beneath the island. They showed considerable surprise when a well dug through the boulder rampart near the ocean side of the island yielded fresh water.

Table 3.--Chemical analyses of water from selected wells in the northern Marshall Islands
(Analyses by U. S. Geological Survey. Dissolved constituents in parts per million)

| Island<br>Well no.<br>Atoll | Ailuk<br>1<br>Ailuk | Engebi<br>1<br>Eniwetok | Engebi<br>2<br>Eniwetok | Engebi<br>3<br>Eniwetok | Engebi<br>4<br>Eniwetok | Runit<br>1<br>Eniwetok | Biijiki<br>1<br>Eniwetok | Bogallua<br>1<br>Eniwetok | Lae<br>1<br>Lae | Lae<br>7<br>Lae | Wotho<br>4<br>Wotho | Wotho<br>7<br>Wotho | Wotho<br>8<br>Wotho |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance from shore (ft.) | 115 | 925 | 410 | 710 | 250 | 175 | 65 | 40 | 345 | 1,035 | 330 | 210 | 490 |
| Area of island (sq. mi.) | .19 | .38 | .38 | .38 | .38 | .13 | .08 | .03 | .21 | .21 | .09 | .09 | .09 |
| Specific conductance (micromhos at 25°C) | 1,390 | 1,470 | 1,630 | 1,040 | 8,070 | 14,800 | 14,200 | 42,500 | 354 | 589 | 786 | 824 | 872 |
| Dissolved solids | 767 | a800 | a890 | a570 | a5,200 | a10,200 | a9,800 | a31,900 | 201 | 406 | 421 | 546 | 473 |
| Hardness (total, as $CaCO_3$) | 464 | 432 | 324 | 388 | 1,000 | 1,920 | 1,800 | 6,400 | 148 | 380 | 370 | 380 | 310 |
| Silica | --- | 14 | 9.4 | 8.5 | 9.9 | 9.0 | 8.5 | 4.1 | --- | --- | --- | --- | --- |
| Iron | .02 | .07 | .27 | .11 | --- | --- | --- | --- | .02 | .02 | .02 | .02 | .03 |
| Calcium | 30 | --- | --- | --- | --- | --- | --- | --- | 41 | 145 | 54 | 40 | 50 |
| Magnesium | 54 | --- | --- | --- | --- | --- | --- | --- | 11 | 2.7 | 28 | 80 | 24 |
| Sodium | --- | 31 | 46 | 77 | 1,500 | 2,850 | 2,700 | 10,600 | --- | --- | --- | --- | --- |
| Potassium | --- | 8.0 | 6.0 | 5.4 | 48 | 70 | 70 | 200 | --- | --- | --- | --- | --- |
| Sulfate | 81 | 62 | 83 | 40 | 17 | 43 | 36 | 132 | 12 | 9.1 | 17 | 54 | 30 |
| Chloride | 272 | 222 | 326 | 88 | 2,680 | 5,200 | 4,860 | 19,300 | 44 | 15 | 130 | 156 | 129 |
| Nitrate | --- | 50 | .3 | 46 | 12 | 10 | 10 | 2.0 | --- | --- | --- | --- | --- |
| Phosphate | --- | .2 | .0 | .0 | .0 | .1 | .1 | .2 | --- | --- | --- | --- | --- |
| pH | 8.0 | 7.4 | 7.7 | 7.3 | 8.2 | 7.6 | --- | 7.8 | 7.4 | 6.7 | 7.2 | 7.2 | --- |
| Temperature (°F) | 78 | 79 | 77 | 79 | 79 | 75 | 77 | 82 | 79 | 80 | 81 | 81 | 82 |

a Calculated from specific conductance.

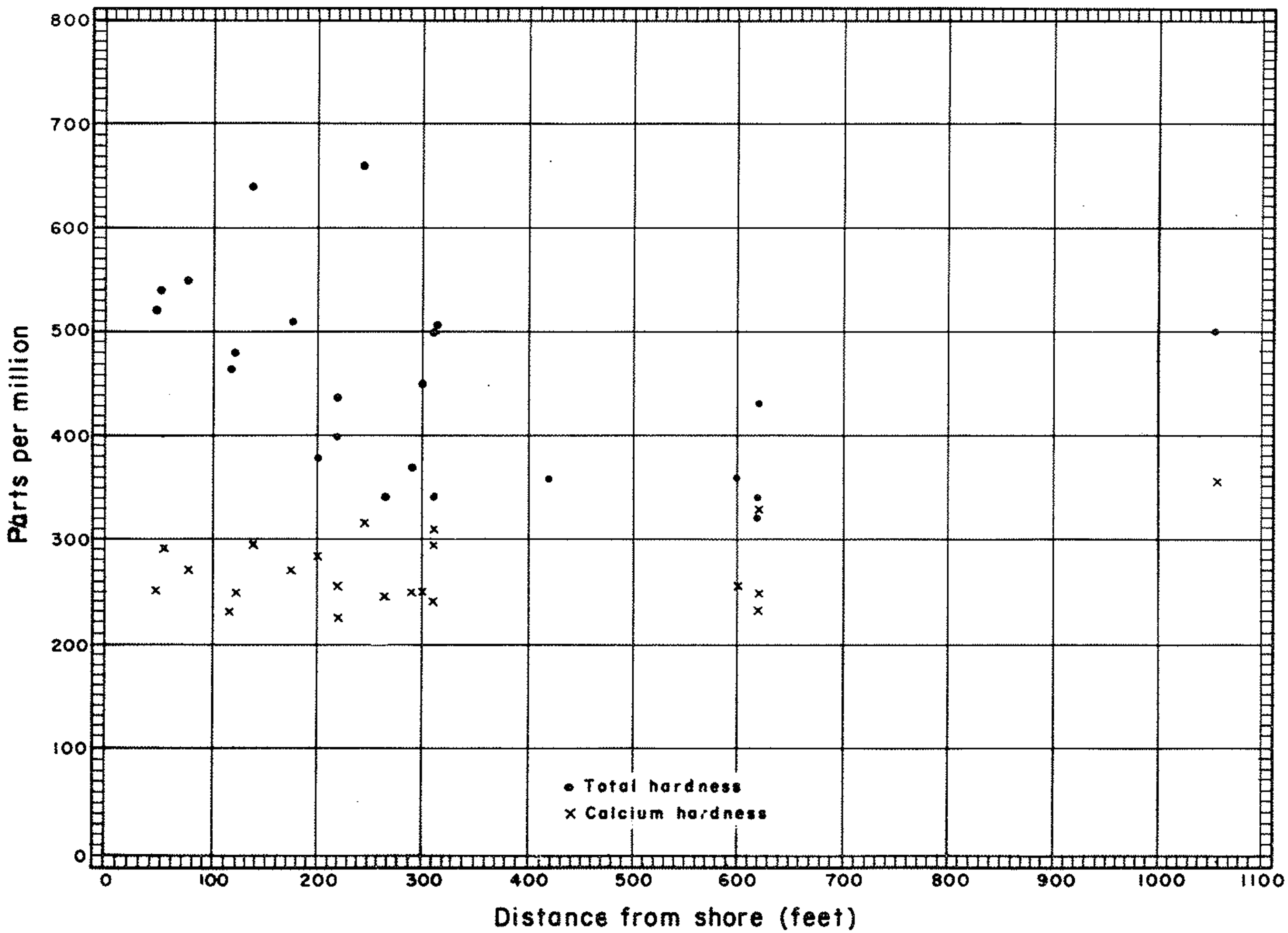


Figure 3.--Relation of total hardness and calcium hardness to distance from shoreline in the ground water of Ailuk Island, Ailuk Atoll, Marshall Islands.

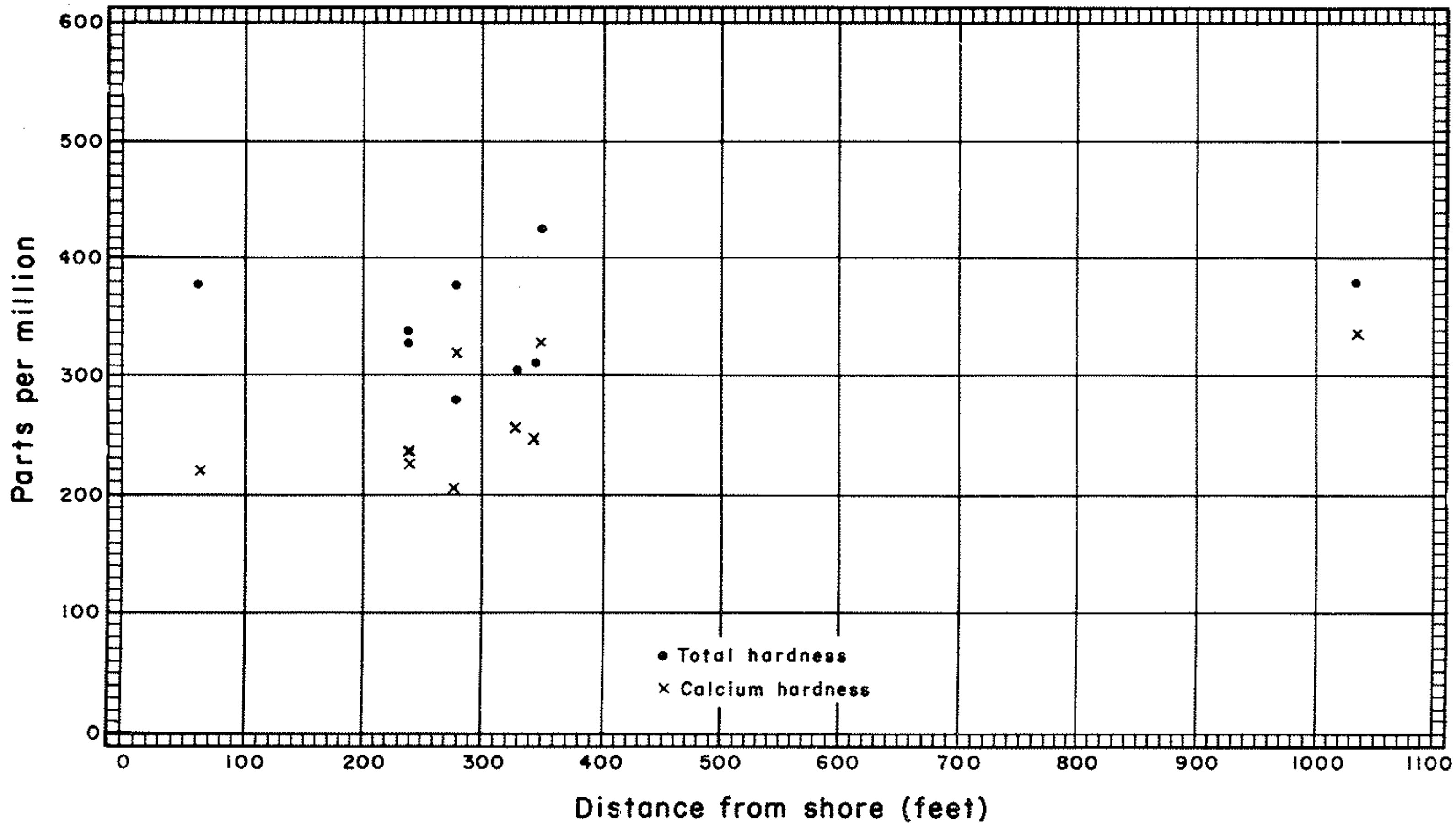


Figure 4.--Relation of total hardness and calcium hardness to distance from shoreline in the ground water of Lae Island, Lae Atoll, Marshall Islands.

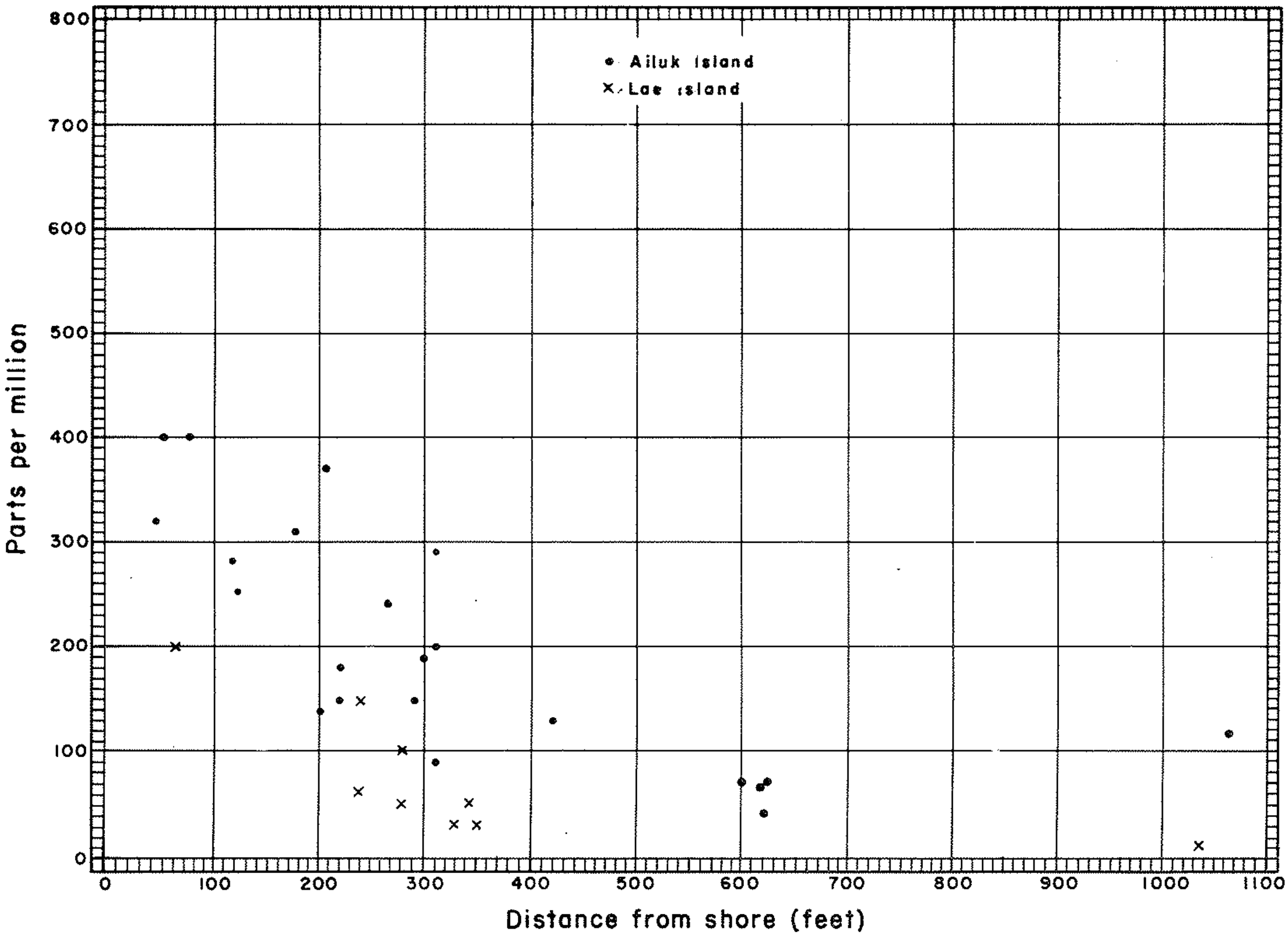


Figure 5.--Relation of chloride content to distance from shoreline in the ground water of Ailuk Island, Ailuk Atoll, and Lae Island, Lae Atoll, Marshal Islands.

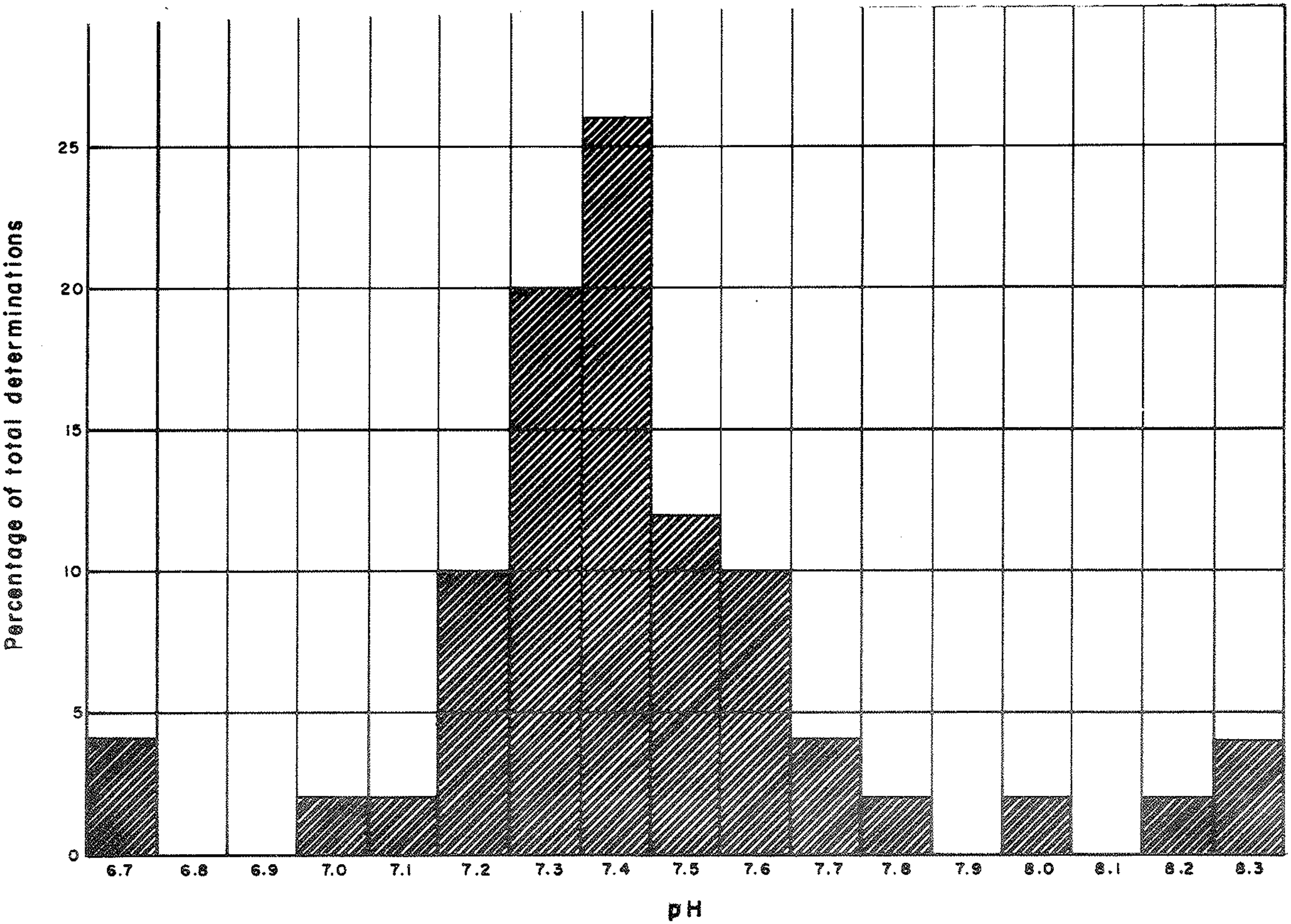


Figure 6.-- Histogram of 50 pH determinations of ground water in the Marshall Islands.

## REFERENCES


1. Bryan, E. H., Jr., 1946, A geographic summary of Micronesia and notes on the climate of Micronesia: U. S. Commercial Company Econ. Survey, Honolulu.

2. Cox, Doak C., 1951, The hydrology of Arno Atoll, Marshall Islands: Atoll Research Bull. 8, December.

3. Ohrt, Frederick, 1947, Water development and salt water intrusion on Pacific islands: Am. Water Works Assoc. Jour., v. 39, no. 10, October.

4. U. S. Weather Bureau and Air Weather Service, U. S. A. F., 1948, Weather conditions in the Marshall Islands, with special emphasis on the Eniwetok area, Special Study No. 40, February.

5. Wentworth, Chester K., 1947, Factors in the behavior of ground water in a Ghyben-Herzberg system: Pacific Sci., v. 1, no. 3, July.