WATER RESOURCES OF THE ISLAND OF KAHOOLAWE, HAWAII:
PRELIMINARY FINDINGS

By Kiyoshi J. Takasaki

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MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
677 Ala Moana Blvd., Suite 415
Honolulu, Hawaii 96813

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CONVERSION FACTORS AND ABBREVIATIONS

The following table may be used to convert measurements in the inch-pound system to metric units.

Multiply inch-pound units	By	To obtain metric units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile, statute (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

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ABSTRACT

Gages to continuously record rainfall, streamflow, and water levels in a dug well have been installed in the lower reaches of Hakioawa Gulch in the northeast part of Kahoolawe. Although the data from these gages have not been analyzed, preliminary inspection indicates the occurrence of several significant rainfall events between October 1988 and January 1989 that caused considerable flow in the stream channel and a rise in water level and freshening of the water in the dug well. Also evident are serious recurring problems of silting of the control for the stream gage and heavy accumulation of silt in the monitored dug well.

Human activities over the years have had significant impacts on the water resources of Kahoolawe. The most notable activities were the introduction of goats by Captain Cook in 1788, sheep in 1858, and of the phreatophyte kiawe (Prosopis chilensis) in 1900. Browsing by the goats and later grazing by the sheep probably destroyed much of the vegetation cover and promoted soil erosion even before 1900. The loss of vegetation and soil cover probably caused an increase in runoff, which in turn resulted in a decrease of ground water recharge. The introduction of the kiawe is strongly suspected of degrading the freshwater to slightly brackish shallow ground water at low altitudes by inducing saltwater intrusion. Kiawe has been observed to send its roots tens of feet below the ground surface in search of water. Bomb craters and an increase in heavy vehicular traffic resulting from the designation of the island as a target area about 1940 caused a significant increase in wind erosion and further soil loss in the central highlands.

On the basis of results of previous and recent investigations, ground water in Kahoolawe can be classified as basal, probable dike-impounded, and perched. Basal water generally is present as a thin lens of fresh to brackish water floating on saline ground water in dike-free lavas outside the rift zones. Ground water within the rift zone has been designated as probable dike-impounded because of the uncertainty of the dike structure needed to impound water. The 1988 surface geophysical survey shows the presence of a resistive body, believed to represent fresh ground water, that extends to depths ranging from about 160 to 660 feet below sea level in the rift zone. The resistive layer is underlain at these depths by a conductive layer believed to represent saline ground water. If freshwater is present at these depths, the freshwater body may be impounded by dikes to levels 4 to 15 feet above sea level. There is also the possibility that the resistive body represents massive rock of sufficiently low porosity that the bulk resistivity

is dominated by the highly resistive rock matrix rather than the fluid within the rock. If so, saline water rather than freshwater could be present everywhere, and the same resistive anomaly would be observed. Because of the low rainfall, there are no permanent or sizeable perched-water bodies on the island.

INTRODUCTION

The island of Kahoolawe lies approximately seven miles southwest from the leeward shore of East Maui. The island, about 45 square miles in area, is semi-arid. It is about 10 miles long, 5 miles wide and is 1,490 feet above sea level at its highest point, Lua Makika in the northeast part of the island (fig. 1).

Overgrazing in the mid 1800's to early 1900's stripped much of the existing vegetation and exposed the island to severe wind erosion. Although grazing had ceased by World War II and the once large goat population was nearly killed off by the 1980's, attempts to revegetate the island have largely failed and wind erosion generally goes on unabated. Wind erosion has removed much of the soil cover and has laid bare most of the summit area and central highlands.

Since World War II, and continuing into the early 1980's, the entire island was used as a military air and sea target. In the mid 1980's, the Protect Kahoolawe Ohana (PKO), the State of Hawaii, and the U.S. Navy mutually agreed to have the target area reduced to the middle third of the island. The PKO, a native group who have been designated as stewards committed to protect Kahoolawe, was granted visitation rights to the other two-thirds of the island.

The designation of the PKO as stewards to protect Kahoolawe was soon followed by an appropriation by the legislature to the PKO through the State Department of Land and Natural Resources to investigate and to develop soil and water conservation measures. The U.S. Geological Survey was asked to participate in the water-resources investigative phase of the program in cooperation with the State Department of Land and Natural Resources.

The water-resources investigative phase was divided into two parts. One part was to include a review of the available information and a hydrological monitoring program to continuously record streamflow, water levels in wells, and rainfall. The other part of the study was a surface geophysical survey to determine the electrical properties of the rocks at depth and/or the water in them to detect possible occurrence of freshwater.

This report describes the initial activities and presents preliminary findings of the data review and the hydrologic monitoring program completed in late 1988 and early 1989.

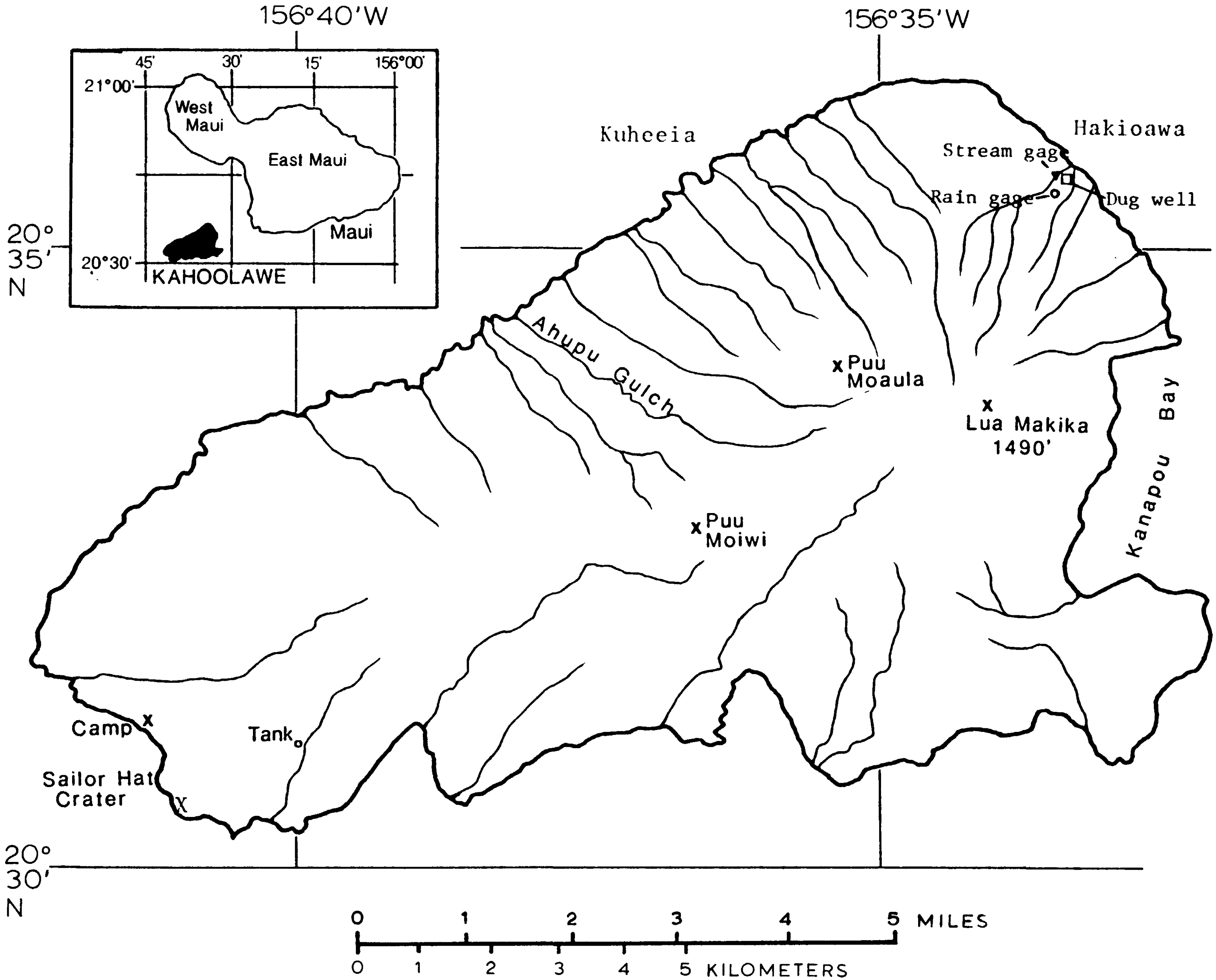

Figure 1. Island of Kahoolawe showing stream channels, selected geographic features, and data-collection sites.

Previous Investigations

The first systematic investigation of the geology and water resources of Kahoolawe was made by Harold T. Stearns, who spent nine days on the island in March 1939. This effort was followed by an electrical resistivity survey by G.R. MacCarthy and a petrographic study by Gordon A. Macdonald, in December 1939. All of these studies were made by the Geological Survey in cooperation with the Territory of Hawaii. The results of the surveys were published as a bulletin of the Territorial Division of Hydrography (Stearns, 1940). Much of the ensuing discussions in this report of findings on the geology and hydrology of Kahoolawe is based on the 1940 bulletin and Stearns' field notes taken in 1939.

A gravity survey of Kahoolawe was made in the spring of 1964 by the University of Hawaii (Furumoto, 1965). The survey indicated a region of high positive anomaly at the eastern end of the island where the surface geology indicates a center of volcanic activity (fig. 2).

In 1971, and again in 1973, experimental plantings were established in Kahoolawe in a cooperative reforestation effort by the U.S. Navy and the State Department of Land and Natural Resources. The Forest Service and the Soil Conservation Service of the U.S. Department of Agriculture also participated. Inspection of these trial plantings was reported in November 1974 in a joint progress report of the U.S. Forest Service and the Hawaii State Division of Forestry (Forest Service, 1974). Shortleaf ironwood and tamarisk trees were recommended and planted each year in mid-December and during January in order to take advantage of early winter rains.

In 1979, three hydrologists of the U.S. Geological Survey made a reconnaissance of selected areas of the island (C.J. Ewart, U.S. Geological Survey, written communication, 1979). Their principal objective was to investigate the source and quality of water in two pools then believed to be spring-fed and perennial. The reconnaissance indicated that the pools were not spring-fed but were maintained by infrequent rains. During this study rainfall data were collected and a rain-gage network was recommended.

A group of visiting scientists systematically collected and studied more than 200 rock samples in 1986. They reported some unusual geochemical features, probably of hydrothermal origin, that are not normally observed in Hawaiian volcanic rocks (Fodor and others, 1987).

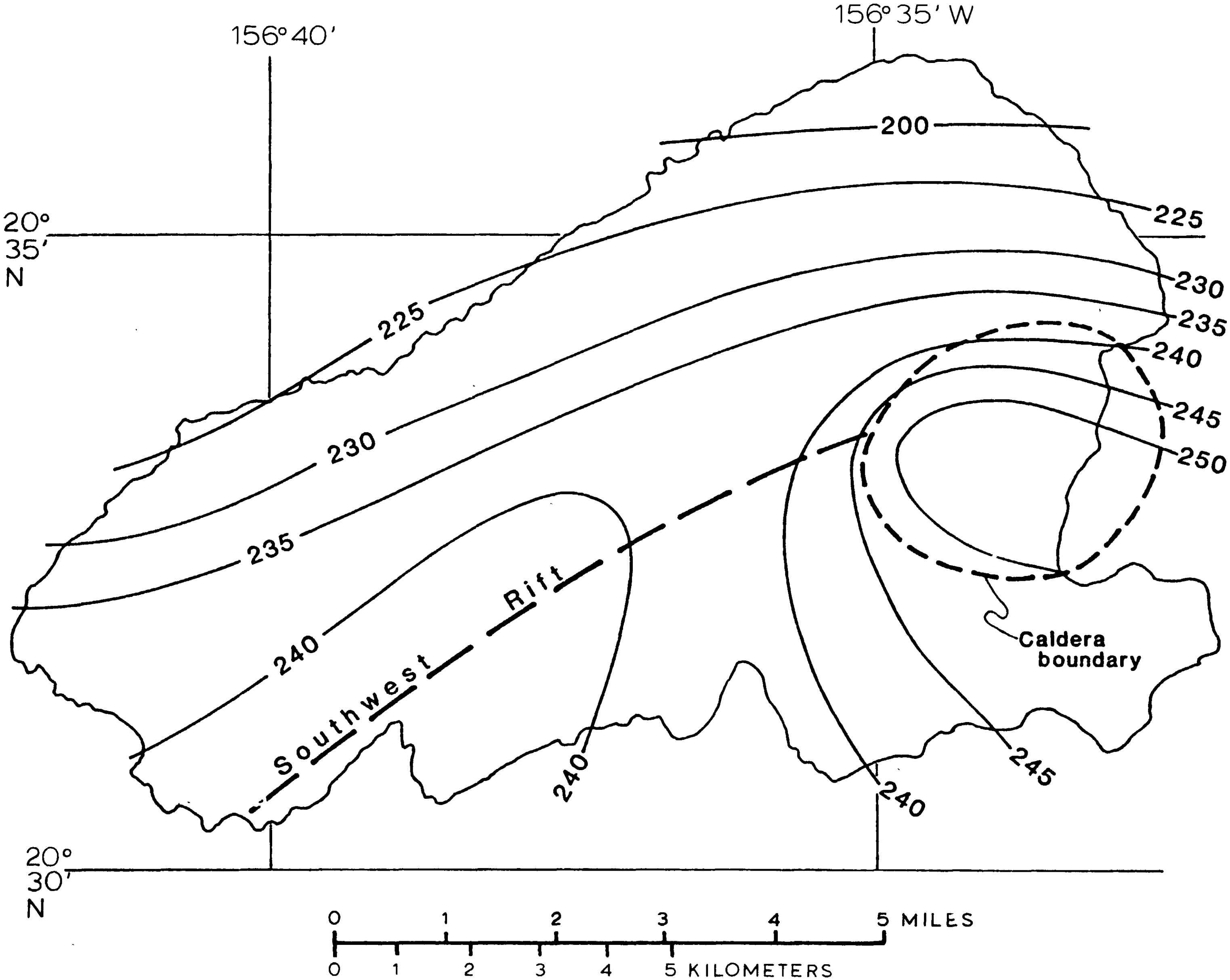

Figure 2. Bouguer anomaly map of the island of Kahoolawe. Values in milligals (after Furumoto, 1965). Caldera boundary and rift zone delineation (after Stearns, 1940).

MAN'S IMPACT ON THE WATER RESOURCES

The following information in chronological order is a synopsis of some of the human activities that have had a significant impact on the water resources of Kahoolawe.

Year	Activity	Resulting effect	Impact on water resources
1788	Introduction of goats by Captain Cook	Browsing by the goats destroyed much of the vegetation cover and promoted soil erosion	It caused an increase in runoff and subsequent decrease in ground-water recharge.
1858	Island was leased to sheep ranchers who moved several thousand sheep to the island	This caused further loss of vegetation cover by grazing and in turn caused more erosion	It intensified runoff and resulted in subsequent decrease in ground-water recharge.
1900	Kiawe (Prosopis chilensis), a close relative of the mesquite and a phreatophyte, was introduced to the island	This caused an increase in transpiration from a greater root depth. This degrades the shallow freshwater bodies at the low altitudes near the coast	Potable stock water from wells declined significantly after 1900, and by 1919, all existing well water became too salty for stock use.
1910	Most of the ranching activities were terminated	There was some recovery of vegetation cover in wind-sheltered low lying areas	There was some decrease in runoff and increase in ground-water recharge.
1918	Big sheep and goat kill took place	Recovery of vegetation and grass cover in inland slopes	Do.

Year	Activity	Resulting effect	Impact on water resources
1918	The lack of funds to restore island led to leasing land for the continuation of ranching	This caused further loss of vegetation cover by the grazing	There probably was an increase in runoff and a decrease in ground-water recharge.
1939	Ranching was continued. Reported livestock; 500 cattle, 200 wild sheep, 25 goats, 17 horses, 3 mules and 500 turkeys	There was some subdued restoration of grasslands	There probably was little change.
About 1941	Entire island was designated as practice target area for the U.S. Navy	The bomb craters and increase in vehicle traffic caused significant increase in wind erosion in central highlands	There was an increase in runoff, especially in central highlands, resulting in decrease in ground-water recharge there.
1980's	The bombing was reduced to the middle third of island. There was replanting in central highlands by the U.S. Navy. The goat population was reduced significantly	There was an increase in trees in central highlands which subdued effects of wind erosion	There was some decrease in runoff and probably some increase in ground-water recharge.
1988	The Protect Kahoolawe Ohana program to restore the island was begun. Electrical resistivity survey was completed. Hydrologic monitoring program was started.	Under study	Under study.

THE ROCKS AND THEIR HYDROLOGIC PROPERTIES

The geologic history and rocks of Kahoolawe were discussed by Stearns (1940) in a report that also included a chapter by G.A. Macdonald on the petrology of the island. Much of the discussion that follows is extracted from or based on their work.

Kahoolawe is an extinct volcano about 45 square miles in area. The bulk of the island consists of shield-building basaltic lava flows that emanated from three rift zones. In the late stages of mountain building, a three-mile-wide caldera formed in the eastern part of the island and a graben formed along the principal or southwest rift zone. Subsequent lava flows ponded in the caldera and graben. Continued flows, some alkalic, filled and overflowed the caldera and graben. These flows were accompanied by pyroclastic activity. A period of quiescence and erosion followed, after which some post-erosional volcanic activity occurred. Stearns (1940) and Macdonald and others (1983, p. 403) observed that Kahoolawe lies on the extension of the southwest rift zone of Haleakala on Maui and noted that volcanism on Maui may be related to the post erosional volcanism of Kahoolawe.

The most permeable lavas are the shield-building basaltic lava flows that make up the bulk of the island. These rocks underlie a veneer of post-caldera alkalic basalts that overflowed the caldera and graben, and covered the basaltic lava flows. The least permeable of the lavas are the basaltic and alkalic basalts that ponded in the caldera and in the reported graben along the principal southwest rift zone (fig. 3). The permeability of the alkalic basalts that overflowed the caldera and graben is somewhere between that of the basaltic lavas and the caldera-filling alkalic basalts. The least permeable of the volcanic rocks are the dikes that acted as feeder conduits for the lavas. Most of the dikes intruded the primitive basalts in the rift zones and where they do, they may act as underground dams and impound water in the basalt.

The pyroclastic rocks are very permeable when unweathered and generally poorly permeable when thoroughly weathered, as those on Kahoolawe appear to be. Weathered pyroclastic rocks may act as perching members for short-lived perched-water bodies. The pyroclastic rocks make up only a small fraction of the total rock volume and do not significantly influence the overall hydrology.

Most of the sedimentary rocks consist of alluvium and talus or their combination in the lower reaches of stream valleys. Like the pyroclastic rocks, these sediments are somewhat permeable when unconsolidated and unweathered, and poorly permeable when consolidated or thoroughly weathered. The sediments are important local aquifers and contain basal water near the shore. There is little or no emerged coral limestone on the island.

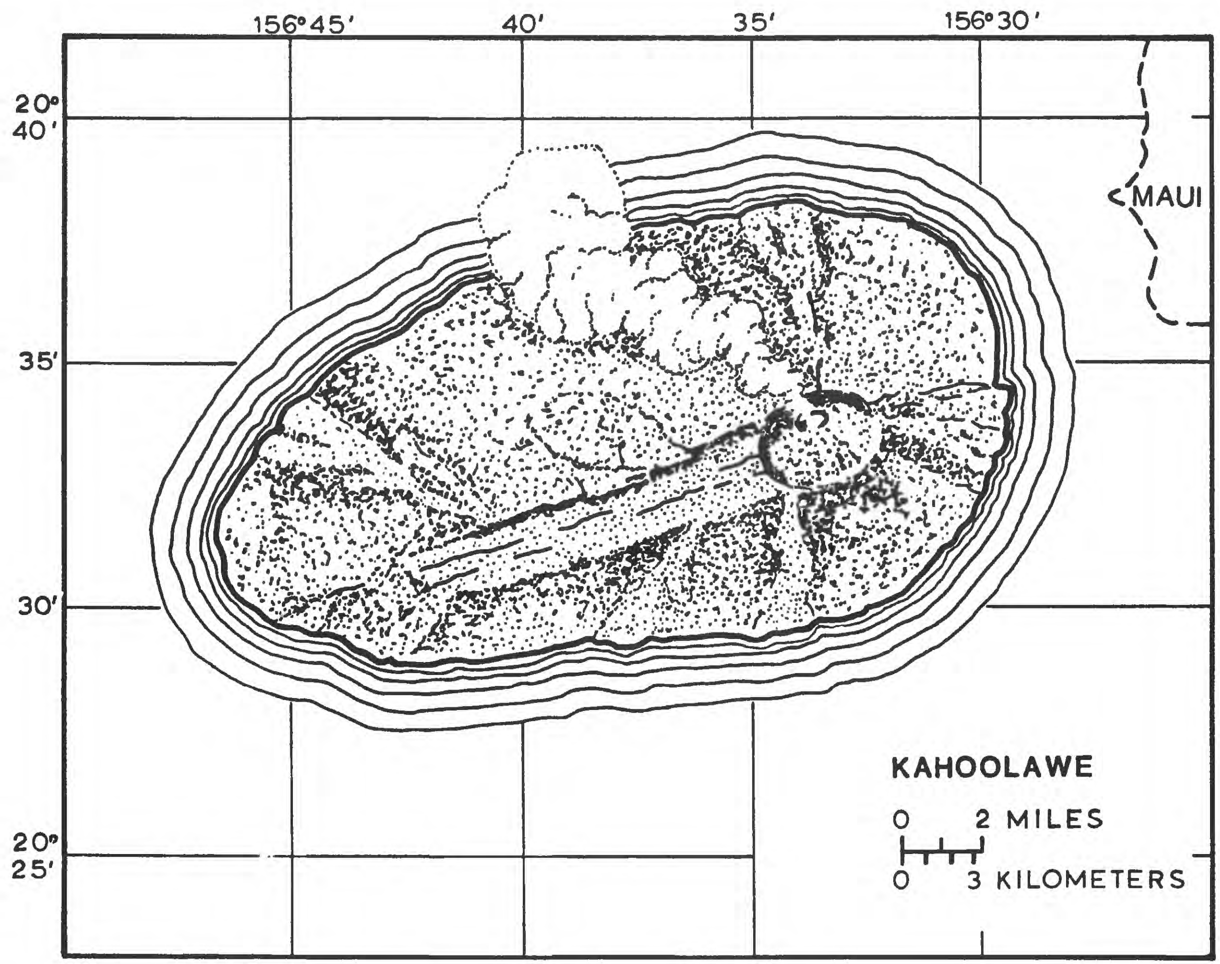

Figure 3. Kahoolawe during its collapse phase with a summit caldera and a graben along the southwest rift zone (after Stearns, 1940).

RAINFALL

Kahoolawe, located a short distance to the lee of Mount Haleakala, Maui, receives an average rainfall of about 20 inches per year. This quantity is probably less than what falls on the unsheltered open ocean near the Hawaiian Islands. Most of the rain falls between the months of November and April, when sporadic southern (Kona) storms prevail.

SURFACE GEOPHYSICAL SURVEY

In order to determine the occurrence of fresh ground water on the island, a surface geophysical survey was made in 1988. The survey consisted of several traverses (Kauahikaua, 1989). The survey showed the presence of a thick resistive body, believed to represent fresh ground water underlain by a conductive layer, believed to represent saline ground water. There is also the possibility that the resistivity body represents massive rock of sufficiently low porosity that the bulk resistivity is dominated by the highly resistive rock matrix rather than the fluid within the rock.

STREAMS

In order to assess the magnitude of the flow of streams and the characteristics of low flows following periods of rain on Kahoolawe, the installation of two recording stream gages was planned. In late October 1988, a continous recording stream-gage station equipped with an artificial control was installed to record the low flows in Hakioawa Gulch. In 1989, a recording crest-stage gage with natural control will be installed in the southwestern part of the island.

The stream gage with the artificial control was installed about 1,000 feet from the shore in Hakioawa Gulch. A recording rain gage and a water-level recorder in an existing dug well were also installed within 200 feet of the Hakioawa stream gage in late October 1988 (figure 1). When the Hakioawa site was visited for maintenance on January 17, 1989, it was discovered that the clock for the recording rain gage had stopped on January 3 and the clock on the stream gage recorder had stopped on January 12, 1989. The water-level record in the dug well was good for the period October 26, 1988 to January 17, 1989. The streamflow and rainfall records are good for the period when the clocks were operating. The clocks were replaced and the recorders were returned to service.

It was discovered that a recurring silting problem exists at the stream gage because of fine sediment that accumulates in the gulches between rains. The streamflow records show that flows of different magnitudes occurred on November 4, December 6, and 16, in 1988. Because of the silting, flow rates cannot yet be determined until some indirect measurements are made. Rainfall in Hakioawa on the days the stream flowed were 4.56 inches on November 4, 6.62

inches on December 6, and 2.09 inches on December 16, 1988. There was no discernible flow in the gulch on December 18 even though the rain gage showed a rainfall of 1.64 inches. The total rainfall between November 4 and December 18, 1988, was 15.66 inches.

Streamflow following rains is flashy and short-lived. With better streamflow measurements, a relation between rainfall and streamflow durations and magnitudes probably can be established.

GROUND WATER

The geologic framework of Kahoolawe is similar to that of the other Hawaiian Islands. Consequently, the mode of occurrence of ground water probably is similar to that on the other islands in that size, development and permanency of the ground-water bodies differ owing to differences in the size of the islands and the amounts of rain that falls on them. Because of the sparse rainfall and relatively small size of Kahoolawe, ground-water bodies there are not extensive and some, like perched-water bodies, are short-lived as well.

The areas underlain by basal and probable dike-impounded ground-water bodies are delineated in figure 4 on the basis of the results of previous investigations and the geophysical survey in 1988. Perched-water bodies, mostly ephemeral, occur above and are separated from both basal and dike-impounded water bodies.

The following briefly describes the occurrence of the ground water in Kahoolawe.

Basal Water

Basal water occurs near sea level in dike-free lava flows and in sediments in the mouths of valleys as thin lenses of fresh to brackish water that float on saline ground water. The results of the electrical resistivity survey by MacCarthy (in Stearns, 1940) indicate that the lens is thin even in the interior part. Owing to the steeply sloping land surface, basal water is not subject to losses by evapotranspiration except in the coastal areas where the water table is shallow and can be tapped by the roots of trees. There is strong indication that the introduction of the kiawe in 1900 has greatly increased transpiration in coastal areas and has as a consequence, degraded these near-shore water bodies that were reported as potable for stock before 1900. The degradation probably is the result of intrusion of saline water caused by transpiration of freshwater by the kiawe plants.

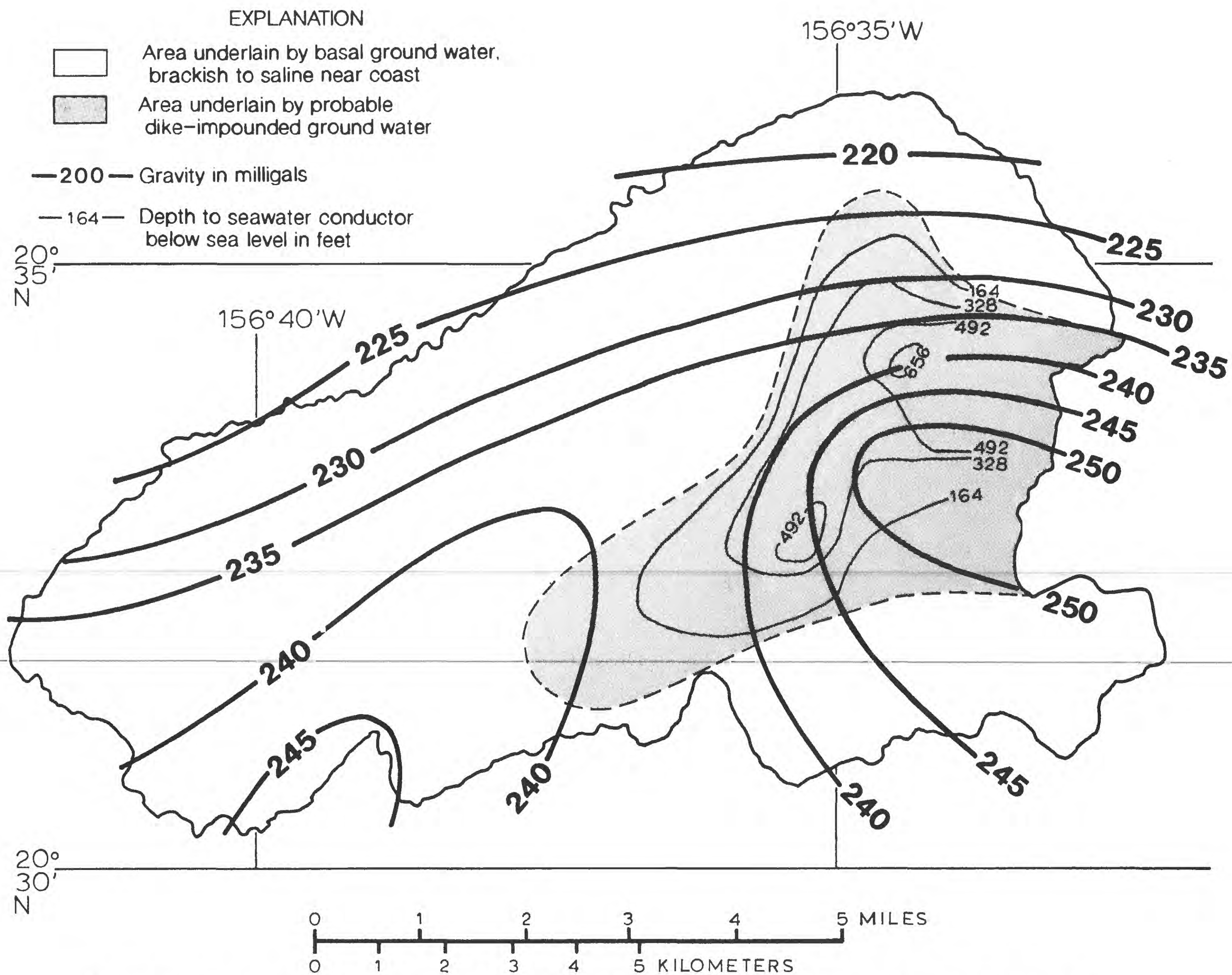

Figure 4. Areas underlain by basal and probable dike-impounded water in relation to the gravity and electrical geophysical anomalies. (Electrical geophysical anomaly after Kauahikaua, 1989; Gravity anomaly after Furumoto, 1965).

An examination of the water-level records obtained from a recording gage of the well in Hakioawa Gulch indicates that the well is so filled with silt that it is not freely connected to the underlying alluvial aquifer. The wide range in chloride concentration of water in the well over the last 50 years and the lack of tidal and transpiration-caused fluctuation of water levels also support the belief that the water level in the well does not represent the behavior of the water level in the underlying alluvial aquifer.

The following table shows the chloride concentration of the Hakioawa well for the period 1939 to 1989.

Date	Chloride concentration in milligrams per liter	Field temperature in degrees Centigrade	Sampled by
3-11-39	12,600	--	H.T. Stearns
7-7-82	10,300	--	Glenn Bauer, Honolulu, Hawaii
1-21-87	1,300	24.0	U.S. Geological Survey
10-20-88	16,000		Do.
10-26-88	18,000		Do.
*1-7-89	1,200	23.0	Do.

*After a total of 15 inches of rain in Hakioawa Gulch in November and December of 1988. Note that the well was sampled in January 1987 when the chloride concentration was 1,300 mg/L.

Glenn Bauer, a ground-water hydrologist of the Honolulu Board of Water Supply, visited the island in 1982 and collected a water sample from the Hakioawa dug well. The sample was analyzed by the Board's laboratory for the following ions:

Ion	Concentration in milligrams per liter
Sodium, Na	5,174
Potassium, K	200
Calcium, Ca	353
Magnesium, Mg	771
Chloride, Cl	10,300

It is likely that much of the basal water in the alluvium of other shallow valleys is discharged by transpiration by deep-rooted phreatophytes such as the kiawe. At a pan evaporation rate estimated at 70 to 90 inches per year, the rate of transpiration probably ranges between 0.10 to 0.25 inches of water per day depending on the season and the distribution of kiawe growth. At these rates, the freshwater lens developed after rains in low-lying areas is quickly dissipated.

Freshwater lenses in lava flows underlying areas at depths beyond the root zone of plants are probably more stable. They are, however, also likely to be dissipated at low altitudes by transpiration from the root zone of the kiawe.

Basal water in small quantities suitable for livestock consumption probably can be developed if losses by transpiration can be reduced either by destroying the deep-rooted kiawe growth at low altitudes or by siting wells at higher altitudes where the water table lies below the root-zone of the kiawe. The wells sited in or near stream channels are more likely to be successful because the areas underlying the stream channels likely receive the most recharge.

Probable Dike-Impounded Water

The area delineated as underlain by probable dike-impounded water was drawn to be parallel to and to contain areas believed to lie in the rift zones. This area includes that showing the highest gravity anomalies and the greatest depth to a seawater conductor as estimated by electrical geophysical surveys (fig. 4). The gravity highs usually indicate centers or zones of volcanic activity that occur in the rift zones. The great depth to the conductive layer believed to represent seawater could indicate depression of saline ground water by a body of high standing freshwater such as dike-impounded water in permeable lavas. Alternately, brackish or saline water could be present but contained in massive rock of sufficiently low porosity that the bulk resistivity is dominated by the highly resistive nature of the rock matrix rather than by the salinity of the fluid in the rock. If the latter is true, such rock may be ponded caldera flows.

The number of dikes typically decreases upward toward the land surface in a rift zone. A density of two dikes for each 10 feet or 200 dikes for each 1,000 feet of rise has been suggested by Wentworth and MacDonald (1953) as characteristic of a dike zone two miles wide. Thus, in a generally uneroded rift zone such as in Kahoolawe, dikes are sparse at shallow depths. Using the estimate suggested by Wentworth and MacDonald for Kahoolawe, it is not likely that there are sufficient dikes at shallow depths capable of impounding ground water above sea level in the low-lying areas. The likelihood of impoundment above sea level increases in the higher altitudes because the number of dike instrusions above sea level is more abundant at the higher altitudes than at the lower levels.

The surface geophysical survey completed in early 1989 showed the presence of a conductive layer thought to represent saline ground water at depths ranging from about 160 to 660 feet below sea level in the rift-zone area in the northeastern part of the island. If this anomaly represents a dike-impounded ground-water body that depresses saline ground water to these depths, it would require that the water levels of the fresher part range from 4 to 15 feet above sea level and its thickness ranges from 160 to 660 feet. There is, however, little evidence of any discharge from the freshwater body anywhere on the island. It is possible that discharge from the dike-impounded aquifer is so small that it is not readily detectable.

Perched Water

There are no surface indications of any sizeable perched-water bodies on the island. Two seeps reported flowing less than a half a pint a minute near Kanopou Bay probably represent discharge from perched-water bodies. The rainfall is likely too low to maintain these water bodies permanently, even though the geologic structures are favorable for their occurrence.

SUMMARY OF PRELIMINARY FINDINGS

The chronological information of man's activities that have impacted the water resources on Kahoolawe was mostly from Stearns (1940) and from his field notes, available at the Hawaii District of the U.S. Geological Survey. This information is presented in the body of the report.

The geologic framework of Kahoolawe is similar to that of the other Hawaiian Islands. Consequently, the mode of occurrence of ground water is similar to that on the other islands. Because of the sparse rainfall and small size of Kahoolawe, ground-water bodies are not extensive and natural discharges from them are not readily perceptible. On the basis of results of previous and recent investigations, ground water in Kahoolawe can be classified as basal, probable dike-impounded, and perched.

Basal ground water occurs as a thin lens of fresh to brackish water floating on saline ground water in dike-free lavas and in sedimentary deposits outside the rift zones. The chloride concentration of the water from a dug well in Hakioawa Gulch ranged from 1,200 to 18,000 mg/L over a period of 50 years. The well is badly silted, so the quality of the well water is not representative of the quality of the ground-water body being tapped. Because of silting, the water level and quality of the well water fluctuates widely with rainfall.

The occurrence of dike-impounded ground water was deemed probable when the surface geophysical survey completed in early 1989 showed the presence of a conductive layer thought to represent saline ground water at depths ranging from about 160 to 660 feet below sea level. If this anomaly represents freshwater that depresses saline ground water to these depths, the water level of the freshwater would range from 4 to 15 feet above sea level.

There are no surface indications of any sizeable perched-water bodies on the island.

NEED FOR ADDITIONAL INVESTIGATIONS

As an initial effort to understand better the water resources of Kahoolawe, recording gages were installed in the lower reaches of Hakioawa Gulch late in 1988 to monitor rainfall, streamflow and ground-water level. Similar gages need to be installed in other gulches on the island. In 1989, an additional stream gage will be installed in the southwestern part of the island. This will require the drilling of an observation well.

Test holes that tap the sedimentary or volcanic aquifer at various altitudes higher than 35 feet in the gulches need to be considered. Water from test holes drilled to depths beyond the reach of the roots of the kiawe will be indicative of the quality of the basal water in the lower reaches of gulches not affected by transpiration. Because the ground water underlying the gulches probably will be fresher than ground water underlying the facet slopes between the gulches as a result of test holes might be more favorable if sited in the gulches.

A test hole is needed within the anomaly indicated by the surface geophysical survey in order to confirm the probable existence of an impounded freshwater body. Selection of the test-hole site requires consideration of factors other than the magnitude of the anomaly, because the greatest anomaly lies in the caldera where the lavas are ponded and their permeability extremely low.

Data from a stream gage in Hakioawa Gulch indicates that streamflow there following rains is flashy and short-lived. This is probably the same for other parts of the island. With better streamflow measurements, a relation between rainfall and streamflow durations and magnitudes probably can be established. It was also discovered that a recurring silting problem exists at the stream gage because of fine sediment that accumulates in the gulches between rains.

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