GROUND-WATER YIELD AND POTENTIAL FOR IRRIGATED AGRICULTURE IN THE AREA OF THE NAVAL MAGAZINE AND RADIO TRANSMITTING FACILITY, LUALUALEI, OAHU, HAWAII

By Patricia J. Shade and Kiyoshi J. Takasaki

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DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
300 Ala Moana Blvd.
Room 6110
Honolulu, Hawaii 96850

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION TABLE

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

Multiply	By	To obtain
Temperature		
degree Celsius (°C)	F = 9/5 °C + 32	degree Fahrenheit (°F)
Length		
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile, statute (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09294	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
acre-foot (acre-ft)	1,233	cubic meter (m^3)
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
Volume Per Unit Time (includes Flow)		
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06308	cubic decimeter per second (dm^3/s)
gallon per day (gal/d)	0.00004381	cubic decimeter per second (dm^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
Miscellaneous		
micromho per centimeter at 25°Celsius (μmho/cm at 25°C)	1.000	microsiemens per centimeter at 25 °Celsius (μS/cm at 25°C)

Ground-water Yield and Potential for Irrigated Agriculture in the Area of the Naval Magazine and Radio Transmitting Facility, Lualualei, Oahu, Hawaii

By Patricia J. Shade and Kiyoshi J. Takasaki

ABSTRACT

It appears likely that an estimated additional two million gallons per day of fresh and slightly brackish water can be developed in Lualualei Valley for the agricultural outleasing project. Several additional wells could be located in the volcanic aquifer which presently produces water of excellent quality. A secondary line of wells designed to develop water from the coralline aquifer would capture the flow not captured by the wells in the volcanic aquifer. The chloride concentration of the water pumped from these wells is expected to range between 500 and 1,500 milligrams per liter.

The amount of acreage devoted to crops would depend primarily on the water quality and quantity requirements of the type of crops cultivated and on the type of irrigation system employed. The remaining acreage could be allocated for pasture to graze beef cattle.

INTRODUCTION

The U.S. Geological Survey, in cooperation with the U.S. Department of the Navy, has evaluated the water resources of Lualualei Valley to determine the extent of agricultural out-leasing that can be supported around the Radio Transmitting Facility and the Naval Magazine. Several thousand acres of land in the valley are suitable for grazing and truck farming if sufficient additional water resources can be developed for irrigation. This study was made to determine the feasibility of such a plan to develop the full potential of 3,700 acres for grazing and crop production.

PHYSICAL SETTING

Climate

The climate in Lualualei Valley is warm and dry. It is virtually a desert with a mean maximum temperature of about 85°F in the summer and about 80°F during the winter (Department of Geography, University of Hawaii, 1973). The mean annual rainfall on the valley floor ranges from 20 to 32 inches, and it increases to 59 inches along the upper slopes near the Waianae crest (fig. 1). The great size of the valley is a result of deep and widespread erosion. It was not carved out during the present condition of such low rainfall. Before the Koolau Volcano became high enough to intercept the northeast tradewind orographic rainfall, the Waianae Range received much higher rainfall (Stearns and Vaksvik, 1935).

Topography and Geology

Lualualei is a broad amphitheater-headed valley on the west side of the Waianae Range, the older of two volcanoes which formed the island of Oahu. Lualualei is in a late stage of valley development. The expansive flat valley floor covers about 14 square miles. Coral reefs and near-shore sediments were deposited on most of the valley floor during higher stands of the sea in the island's geologic history. Extensive erosion has caused Lualualei, and Waianae Valley to the north, to coalesce with only thin discontinuous ridges remaining between them.

A road enters at the head of Lualualei Valley through Kolekole Pass at an altitude of 1,640 feet and winds around Puu Kailio, an erosional remnant which peaks at 1,965 feet (fig. 1). The swarms of dikes and volcanic breccia which compose a large part of Puu Kailio indicate that Puu Kailio is located in the caldera of the Waianae Volcano (Stearns and Vaksvik, 1935). The large size of Lualualei Valley is due in part to extensive erosion of the caldera.

Soils and Vegetation

The soils in the area, according to Foote and others (1972), are sticky, plastic clays with low permeability and high shrink-swell potential. Much of the soil contains enough stones to hinder machine cultivation and has a type E productivity rating not favorable for crop production (Sahara and others, 1972). Although the soils along some of the stream channels may be suitable for crops, these areas are susceptible to flooding, and the risk of complete crop damage eliminates these areas from consideration as truck crop land. All of the above areas have been designated as suitable for grazing (fig. 2).

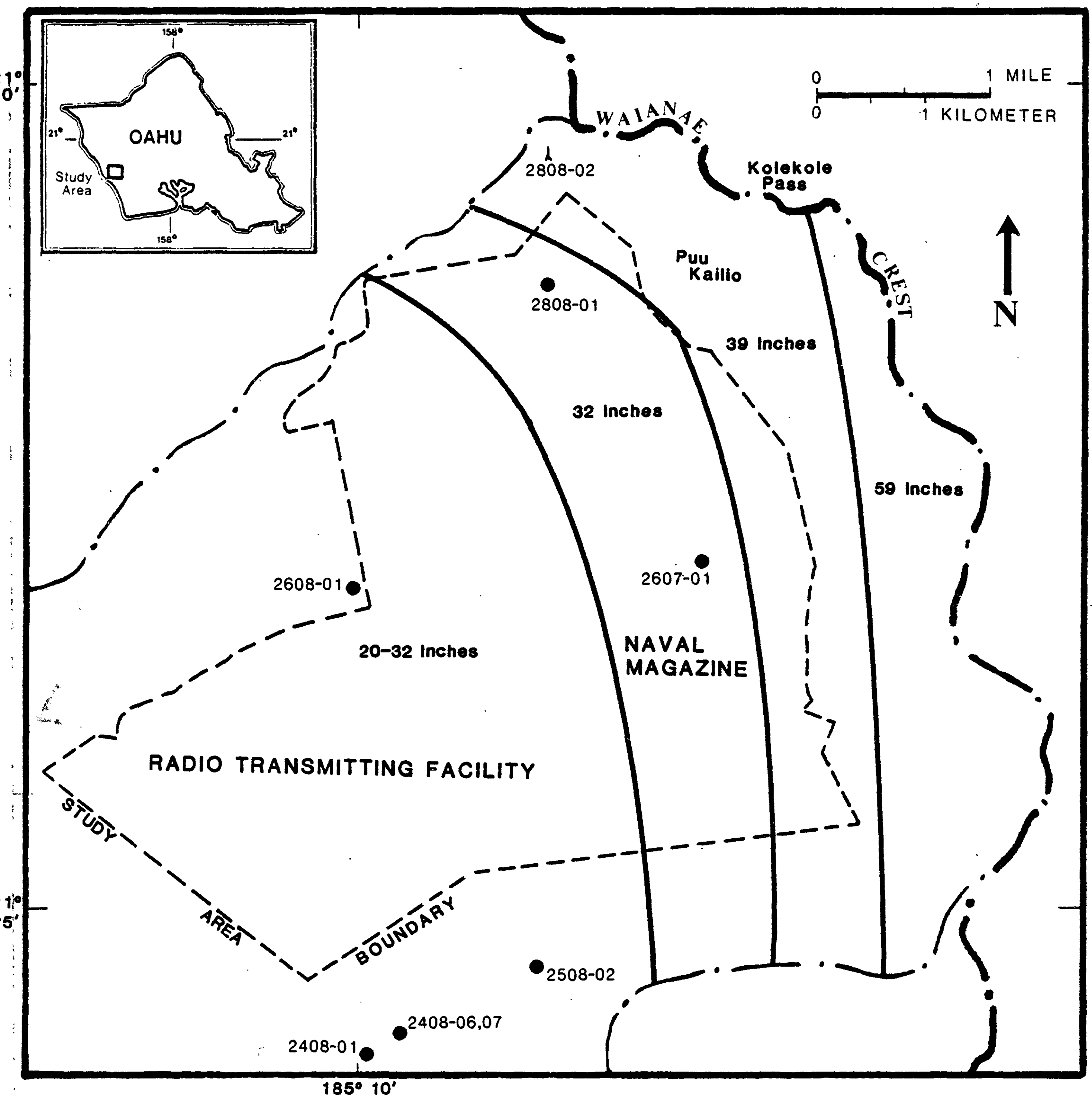


Figure 1. Rainfall distribution bands and well locations in Lualualei Valley.

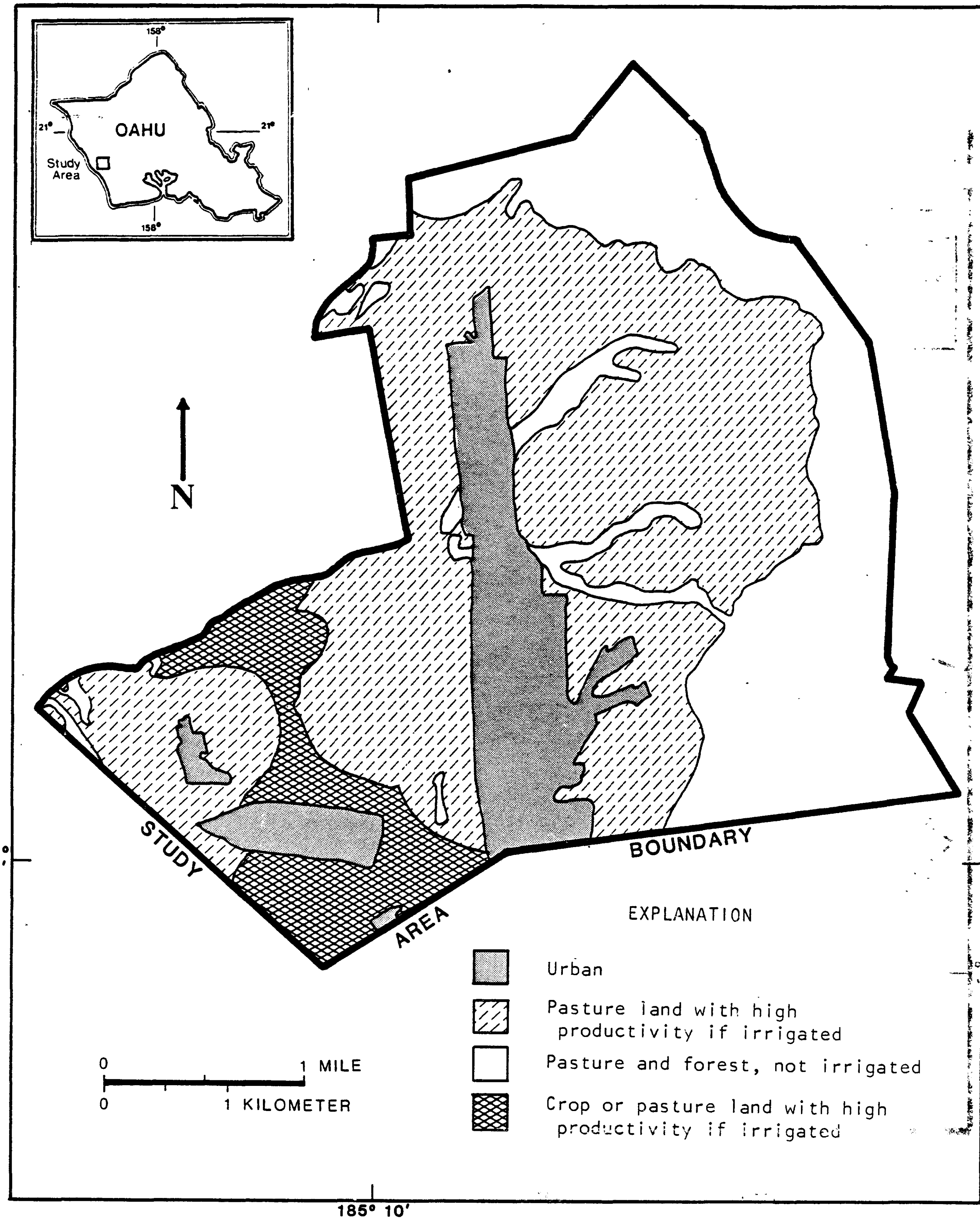


Figure 2. Areas suitable for agriculture and grazing.

Part of the pasture area would have a higher productivity rating (A or B) if it was irrigated. Within this area is about 350 acres that, with irrigation, would also be productive crop land.

The area is so dry that without irrigation only low-moisture-tolerant plants such as kiawe (Prosopis chilensis) and koa haole (Leucaena glauca) can survive. These plants have formed fairly dense stands in bands along the valley floor and lower slopes where the rainfall averages about 24 to 32 in./yr (inches per year). The koa haole is dormant during periods of no rainfall but turns green after the rain returns. The kiawe at lower elevations does not appear to be affected by dry periods. Zones (1961) concludes that transpiration by this plant is principally responsible for the daily fluctuations of the water table that he observed in Waianae Valley just north of Lualualei. Both koa haole and kiawe function as phreatophytes (Zones, 1961) and at low altitude tap much of the modest ground-water flow in the area. Although the quantity of ground water that is transpired was not quantified by Zones (1961), it appears that the ground-water resource could be increased if this phreatophyte vegetation were cleared.

Rainfall-Recharge Relationship

Rainfall in Lualualei was determined from the most recent mean annual rainfall map (Department of Land and Natural Resources, 1982). Rainfall bands were plotted on topographic quad sheets and planimetered. From a water budget prepared for southeast Oahu (Eyre and Shade, U.S. Geological Survey, written commun., 1984), the 30-in./yr rainfall area did not contribute any recharge to the ground-water supply. Because the area of Lualualei Valley that receives 20 to 32 inches of rainfall per year (fig. 1) and the 30-in./yr rainfall area of southeast Oahu have similar topography, geology, rainfall, runoff, temperature, exposure, vegetation, and soils, it was assumed that only the area in Lualualei receiving at least 32 inches of rainfall annually would contribute any recharge to the Lualualei ground-water supply. The mean annual rainfall in this area, which is within and tributary to the study area, is equivalent to 18 Mgal/d (million gallons per day) (fig. 1).

The recharge-rainfall ratios provided by the southeast Oahu water budget and applied to Lualualei are 24 percent in the 59-inch rainfall band, 21 percent in the 39-inch band, and 18 percent in the 32-inch band, resulting in a total of about 4 Mgal/d of recharge. However, because some of this water may be deeply dike-impounded or perhaps perched in small scattered beds in generally low-permeability volcanic rocks; it is likely that only about half of the 4 Mgal/d of recharge can be economically developed.

WATER DEVELOPMENT - PRESENT AND POTENTIAL

Aquifer Limits

The principal aquifers are composed of volcanic and of coralline rocks. Detrital volcanic debris of talus and alluvium composes a minor unimportant aquifer.

Areal extent of the aquifer can best be identified by maps showing these geologic units both on the surface (fig. 3) and projected at sea level (fig. 4). The depths to the top of the ground-water reservoirs are shown by the geologic section (fig. 5). In most of the valley below an altitude of 600 feet, ground water occurs near and below sea level. In areas intruded by dikes at more than 600 feet altitude, ground water is commonly impounded tens to hundreds of feet above sea level.

The areal extent of the coralline aquifer is large, but much of the area is underlain with water of poor quality or water that becomes brackish when pumped at moderate rates. If this aquifer is developed below an altitude of 40 feet or below the 1,000 mg/L (milligram per liter) chloride concentration in figure 4, the wells are likely to yield brackish water. Below this altitude or below this concentration line, the discharge of ground water by transpiration becomes progressively larger and the resulting quality of ground water more brackish. The upper limit for development of water in the coralline aquifer is considered to be the intersection of the coralline rocks and of the talus and alluvium projected at sea level as shown in figure 4.

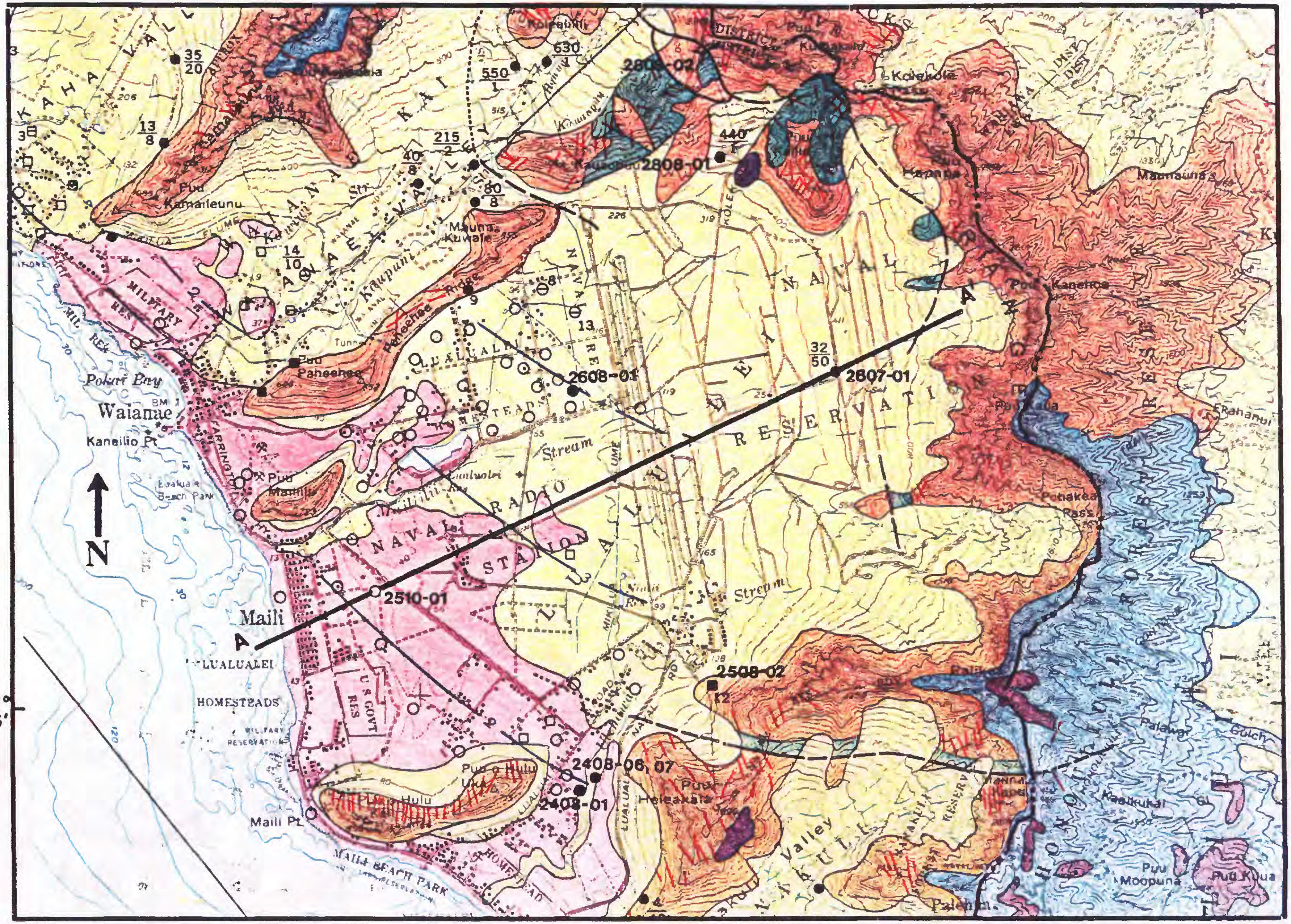


Figure 3. Generalized geologic map of Lualualei Valley showing locations of wells, altitude of water levels, and specific capacities of wells (Geology after Stearns, 1939; hydrology after Takasaki, 1971).

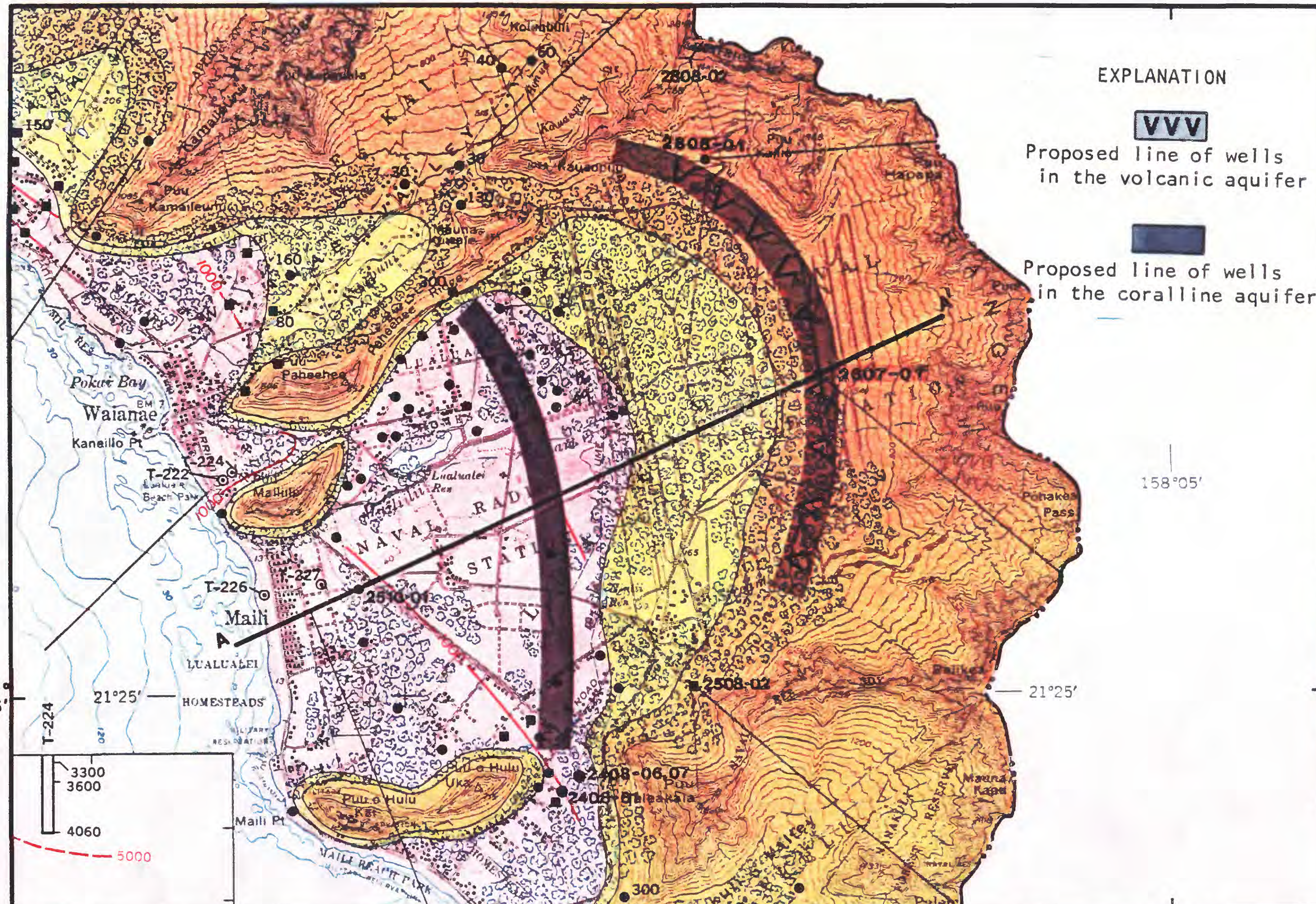


Figure 4. Lualualei Valley showing probable distribution of rocks at sea level, areas of kiawe growth, and lines of equal chloride concentration.

EXPLANATION

Calcareous sedimentary materials
Includes coral, coral rubble, and beach sand

Noncalcareous sedimentary materials
Includes alluvium and talus

Cinder

Lava flows of upper member of the Waianae Volcanic Series

Breccia

Lava flows of lower and middle members of the Waianae Volcanic Series

Dikes

Contact

Fault
Dashed where inferred; dotted where concealed

Length and direction of tunnel in Waianae Volcanic Series

$\frac{40}{8}$ Well — 13 Shaft
Tapping rocks of Waianae Volcanic Series

$\frac{14}{10}$ Well — 3 Shaft or dug well
Tapping alluvium

Well — Shaft or dug well
Tapping calcareous sedimentary material

Wells, shafts, and dug wells
Upper number, where present by well symbol, is altitude of water level, in feet above mean sea level. Lower number, where present by well symbol, is specific capacity, in gallons per minute per foot of drawdown. Single number, where present by well or shaft or dug well symbols, is altitude of water level, in feet above mean sea level

4
Water-level contour
Shows altitude of water level in calcareous sedimentary material. Contour interval 1 foot

Drainage divide and boundary of study area

Kiawe growth

Inferred contact

Drainage divide

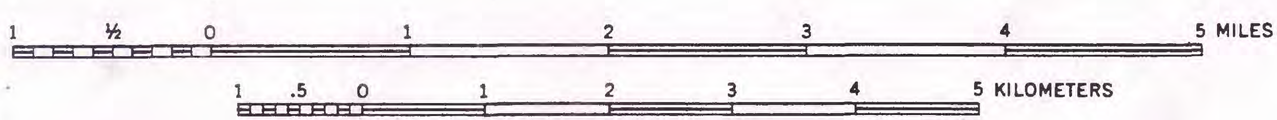
300 Well — 150 Shaft or dug well — Tunnel
Number is chloride content of water in well, shaft, or dug well tapping alluvium or basalt, in milligrams per liter

T-204
Test well and number

500
Line of equal chloride content of water in wells tapping calcareous sedimentary material
Interval 200 and 500 milligrams per liter

Chemical analyses tables. Constituents in milligrams per liter

SOURCE
Dissolved solids residue at 180°C
Sodium plus Potassium (Na+K)
Calcium (Ca)
Magnesium (Mg)
Bicarbonate (HCO_3)
Sulfate (SO_4)
Chloride (Cl)
Nitrate (NO_3)
Year of sampling



CONTOUR INTERVAL 80 FEET

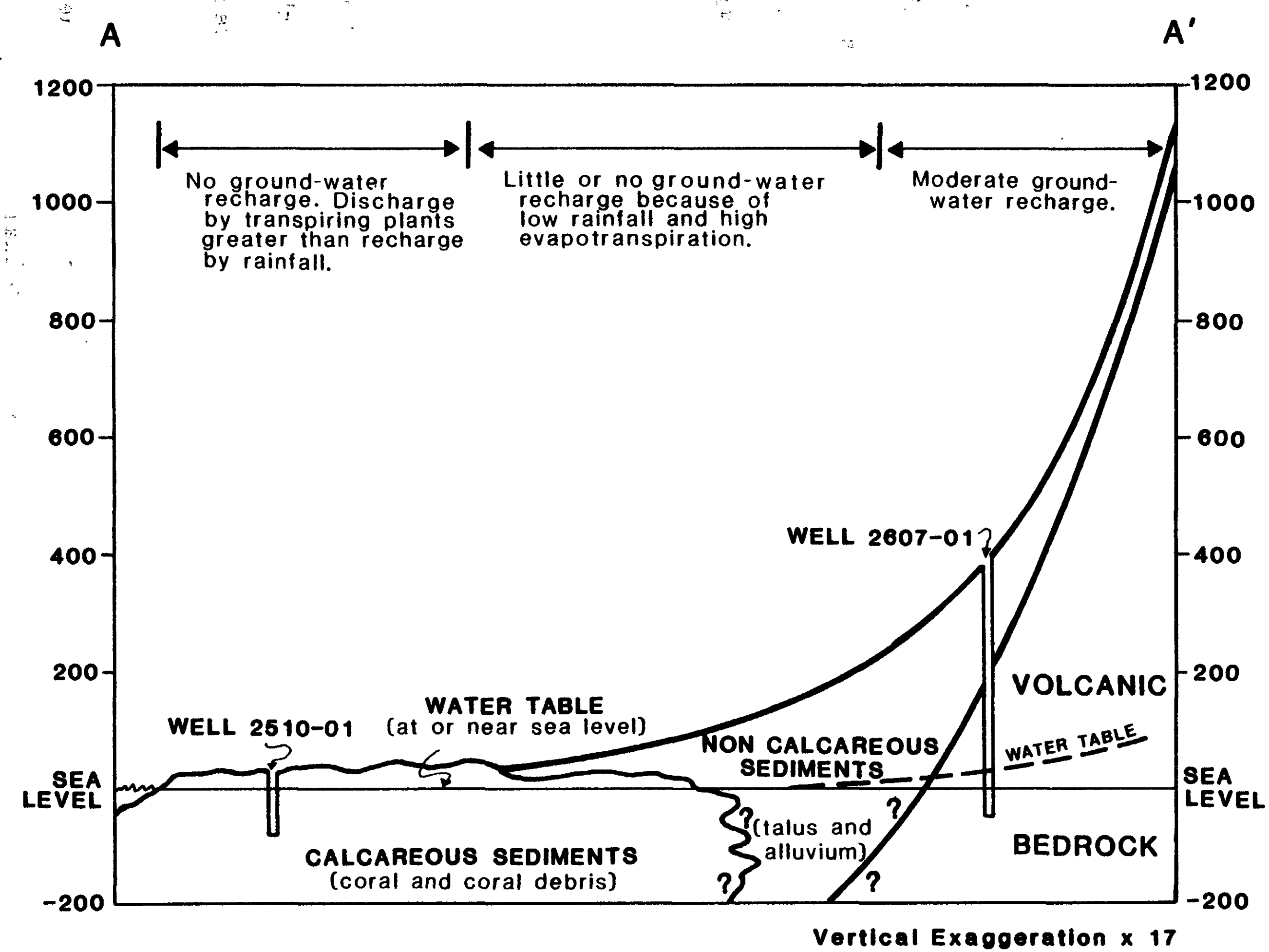


Figure 5. Generalized geologic cross-section along line A - A' through Lualualei Valley.

The lower limit for development of the volcanic aquifer is the volcanic aquifer boundary projected at sea level (fig. 4). In geologic-section A - A' (fig. 5), this altitude is shown at about 280 feet. There is no definite upper limit. The upper limit for the development of ground water that occurs near and below sea level depends on how deep the developer is willing to drill.

The areal extent of dike-intruded reservoirs impounded hundreds of feet above sea level is difficult to define. However, a general rule usually applies. If such a reservoir is close to the land surface and is developable by wells or tunnels, it leaks, and this leakage is manifested as spring discharge or as a marsh. No such manifestation of any significance exists other than the springs that existed prior to the development of the Navy tunnel.

Dike Water and Estimates of Storage

The Navy Lualualei tunnel (2808-02) was completed at the site of several springs that once fed a perennial stream. The springs and the stream have gone dry since the construction of the Navy tunnel. Total discharge of the springs and stream was reported to be about 0.38 Mgal/d, or about the current base flow of the Navy tunnel.

There are no other springs, perennial streams, or any other indications of dike-water leakage of any significance in Lualualei Valley. In the absence of such indications, any new development of dike water at high levels becomes highly conjectural. Until such time that water levels can be better determined by test drilling or possibly by geophysical techniques, new development of dike water at high altitudes, above 1,000 feet, would be risky.

In a study by the U.S. Geological Survey (Takasaki and Mink, 1981), storage of dike water above sea level in the Waianae Range was estimated at 100 billion gallons. From similar methods of estimating storage using 5 square miles as the area underlain by dike water, the 300-foot altitude as the mean top of stored water, and a mean specific yield of 0.03, the storage in upper Lualualei Valley was estimated at 9 billion gallons.

Two estimates were made of the reduction in dike-water storage caused by the construction of the Navy tunnel. The empirical equation

$$Q_t = Q_o e^{bt}$$

where:

Q_t = base flow at time, t

Q_o = initial flow

t = time in days

b = recession constant

gives a good approximation of the recession curve derived from data obtained during the depletion of storage. One estimate was made using only three measurements made in successive months in 1938 when the tunnel was allowed to deplete freely. Another estimate was made by comparing the hydrologic properties of the nearby County tunnel in Waianae and the Makaha Tunnel, with those of the Navy tunnel.

According to Hirashima (1971), the initial discharge, Q_o, when the tunnel was nearly full recedes to some stable discharge, Q_t, after the dewatering. Q_t is the base flow; t is the time in days for Q_o to recede to Q_t; and b is the recession constant governed by the characteristics of the storage reservoir. Total discharge for the period t is equal to:

$$\frac{Q_o - Q_t}{b}$$

Water released or depleted from storage is then equal to:

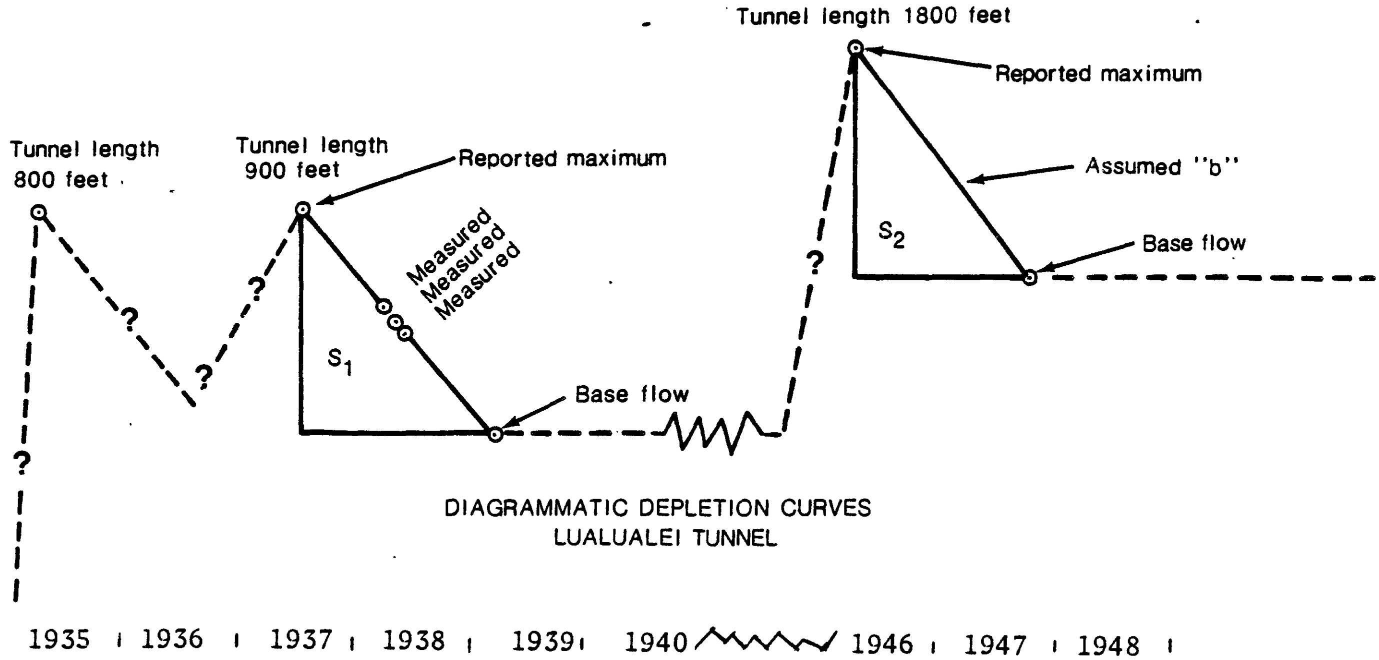
$$\frac{Q_o - Q_t}{b} - Q_t t$$

Calculations for the above estimates are given in figure 6.

Storage depletion calculated by using measured tunnel-flow was 170 million gallons and that made by comparing hydrologic properties was 630 million gallons. The estimates thus made show depletion of storage by the Navy tunnel to range from 2 to 7 percent of the total storage in upper Lualualei Valley.

Present Development

Presently two wells (2808-01, 2607-01) and a tunnel (2808-02) tap the volcanic aquifer in upper Lualualei Valley. The wells were not in use in 1984. The tunnel, with a base flow yield of about 0.38 Mgal/d, is the principal source of water for the Radio Transmitting Facility and the Naval Magazine.



Solve for S_1 (Storage depletion)

$Q_t = Q_o e^{bt}$ Equation of depletion curve

$t = 540$ days

$Q_o = 0.45$ Mgal/d initial flow

$Q_t = 0.20$ Mgal/d Base flow at t

$\text{Log } Q_t = \log Q_o + b(\log e)t$

$-0.69897 = -0.34679 + b(0.4343)(540)$

$$-b = \frac{-0.69897 + 0.34679}{(522)(0.4343)}$$

$b = 0.00150$

$$\text{Total discharge} = \frac{0.45 - 0.20}{0.00150} = 166 \text{ Mgal}$$

S_1 = Total discharge - Base flow x 540 days

$S_1 = 166 - 108 = 58$ Mgal

Solve for S_2

$t = 540$ days

$Q_o = 0.8$ Mgal/d

$Q_t = 0.35$ Mgal/d

$\text{Log } Q_t = \log Q_o + b(\log e)t$

$-0.45593 = -0.09691 + b(0.4343)(540)$

$$-b = \frac{-0.45593 + 0.09691}{(0.4343)(540)}$$

$b = 0.00150$

$$\text{Total discharge} = \frac{0.8 - 0.35}{0.00150} = 300 \text{ Mgal}$$

$S_2 = 300 - 0.35 \times 540$

$S_2 = 111$ Mgal

Total Storage Depletion $= S_1 + S_2 = 169$ Mgal

If b for Lualualei tunnel is made comparable to b calculated for Waianae City and County and Makaha tunnels, then total storage depletion is:

$$\text{Total discharge} = \frac{0.45 - 0.20}{0.00075} = 333 \text{ Mgal}$$

then $S_1 = 333 - 108 = 225$

$$\text{Total discharge} = \frac{0.8 - 0.35}{0.00075} = 600 \text{ Mgal}$$

then $S_2 = 600 - 189 = 411$

Total Storage Depletion $= S_1 + S_2 = 225 + 411 = 636$ Mgal

Figure 6. Calculations for the reduction in dike-water storage.

Sustainable production yields for the wells can be estimated from previous pumping tests. In 1957, well 2808-01 was test pumped at a rate of 80 gal/min (gallons per minute) with a drawdown of 150 feet. However, with the pump intake at a depth of 160 feet, it would be more desirable to pump at a lower rate. An optimal rate can be determined by a pump test. A rough rate can be estimated by using the specific capacity of 0.53 gal/min/ft (gallons per minute per foot) of drawdown that was determined by the test in 1957. For example, a drawdown of about 95 feet will result from pumping at a rate of 50 gal/min. For planning purposes 100,000 gal/d (gallons per day) is an estimate of the maximum production from this well.

At well 2607-01, a pumping test in 1960 indicated a drawdown of 5 feet when pumping 250 gal/min, or a specific capacity of 50 gal/min/ft. A long-duration pumping test at a higher rate would provide a more accurate estimate of the well yield. The estimated production from this well is 250,000 gal/d.

Data from the Board of Water Supply shaft 2508-02, now abandoned, show that a production rate of 340,000 gal/d caused saltwater intrusion. The pump sump is too deep for the shaft to sustain such a heavy draft. Mink (1978) indicated that in 1939 an average of 110,000 gal/d was pumped for about one year. The chloride concentration remained around 300 mg/L and the head above mean sea level decreased about 3 feet to 8.6 feet. A production rate of 110,000 gal/d appears to be the maximum that can be pumped while keeping the chloride concentration reasonably low, at about 300 mg/L.

Additional Development

The average flow of freshwater through the volcanic aquifer in the upper reaches of Lualualei Valley is about 1 Mgal/d per linear shoreline mile or a total of 5 Mgal/d. Present development is about 375,000 gal/d from the Navy tunnel in the north part of the valley. The unused flow not tapped by the tunnel moves from the volcanic aquifer to the talus and alluvial aquifer, then to the coralline aquifer. Ground-water discharge in the sedimentary aquifers is by transpiration, which is small at mid-altitudes and subsequently becomes the principal discharge at lower altitudes underlain by the coralline aquifer.

Optimal development would be to capture as much of the discharge as possible from the volcanic aquifer before it reaches the sedimentary and coralline aquifers where it is transpired. This can be best accomplished by a line of wells in a zone from 1,000 to 1,500 feet landward of the projection of the volcanic aquifer at sea level (fig. 4). In the geologic-section shown in figure 5, this zone would be at an altitude between 320 to 360 feet. The wells would be located along this zone below and one-half mile west of the Navy tunnel, then every half mile to the southeast for a total of 6 wells. The need for closer placement of additional wells can be determined after the drilling of the wells. Well 2607-01 can be considered as one well of the series. Should the planned wells average out to roughly the capacity of well 2607-01, the yield from the 6 wells would total between 1.5 to 2.0 Mgal/d. The water pumped from these wells is expected to have a chloride concentration similar to that of well 2607-01, less than 100 mg/L. The yield from the Navy tunnel should not be perceptibly affected.

A secondary line of wells designed to develop water from the coralline aquifer can be drilled in a zone 1,000 to 2,000 feet seaward of the projection of coralline rocks at sea level (fig. 4). In the geologic section, this zone would be between an altitude of 60 to 80 feet. In areas of sparse kiawe growth, such as in the Ammunition Depot, the wells can be sited lower to an altitude of about 40 feet.

These wells would capture the discharge not tapped by the wells in the volcanic aquifer. If the depth of these wells exceeds 25 feet below sea level, the wells would likely yield salt water. The chloride concentration of the water pumped from these wells is expected to be between 500 to 1,500 mg/L. The production from individual wells tapping the coralline aquifer will be determined by the water quality, particularly with respect to the intended water use and to any increase in chloride concentration from increased pumping.

WATER QUALITY

The Committee on Water Quality Criteria (1972) has set contaminant level standards for various chemicals in drinking water. There are some differences in satisfactory levels depending on the type of water system, community or non-community, and depending on the measurement technique. Generally for sulfates and chlorides the maximum concentration limit is 250 mg/L and for nitrate (as N) the limit is 10 mg/L. A general drinking water recommended limit for dissolved solids concentration is 500 mg/L. There is a general classification of hardness concentrations: 0 to 60 mg/L is soft; 60 to 180 mg/L is moderately hard; 180 to 240 mg/L is hard; and greater than 240 mg/L is very hard. The dissolved solids and hardness criteria basically relate to taste, aesthetic preferences and industrial requirements rather than to human health requirements.

At well 2607-01 during a pump test in 1958, at a rate of 123 gal/min (gallon per minute), samples indicated that the chloride concentration ranged from 36 to 39 mg/L, hardness from 61 to 66 mg/L, dissolved solids from 230 to 298 mg/L, and sulfate from 4.5 to 5.2 mg/L. A 1972 sample showed that the sulfate concentration was 8.5 mg/L, chloride concentration was 45 mg/L, and nitrate concentration was 4.3 mg/L. This well produces water of excellent quality.

Several samples from well 2808-01 indicated high sulfate, hardness and dissolved solids content, but the chloride concentration was below 200 mg/L. With a light continuous draft, about 100,000 gal/d or less, a dilution of 3 parts tunnel water to one part well water would be required to reduce hardness and sulfate levels to meet Drinking Water Standards. Continuous pumping may flush the sulfates from the volcanic rocks, causing the sulfate concentration to decline over time.

At the Navy tunnel 2808-02, several samples indicated hardness ranging from 41 to 68 mg/L, dissolved solids from 150 to 238 mg/L, sulfate concentration between 1 and 5.3 mg/L, chloride concentration between 20 and 50 mg/L and pH between 7.3 and 8.39. This is another source of good quality water.

Several other sources of water in the valley have been abandoned, but they could be re-established for agricultural purposes depending on the water quality requirements. Samples taken from the Board of Water Supply shaft 2508-02 in 1973 and 1976 indicated chloride concentrations from 280 to 295 mg/L. Data from 1954 show chloride concentration of 520 mg/L, dissolved solids of 1,618 mg/L, and a sulfate concentration of 51 mg/L. Samples taken in 1939 show considerably lower dissolved solids, from about 670 to 950 mg/L, and chloride concentrations from 250 to 560 mg/L. A sample taken in 1971 indicated a chloride concentration of 280 mg/L, a nitrate concentration of 8.5 mg/L, a sulfate concentration of 22 mg/L and a pH of 7.8.

Water from well 2608-01 was used for irrigation and limited data in U.S. Geological Survey files indicate that chloride concentrations were between 605 and 638 mg/L.

The coralline aquifer wells 2408-01, 2408-06, and 2408-07 have chloride concentrations in the range of 1,200 to 2,000 mg/L. These concentrations are generally indicative of the chloride concentration throughout this area.

The foregoing discussed in general terms the relative concentrations of chloride, sulfate, and nitrate in the ground water of the study area. In future studies consideration will be given also to effects of chloride, sulfate and heavy metals on fish and wildlife resources or on expanded human use.

POTENTIAL FOR GROUND WATER USE

Based on the additional production of 2 Mgal/d, several water-use plans can be proposed. From an analysis of the soils in the study area of 4,100 acres (Foote and others, 1972 and Sahara and others, 1972) 77 percent of the area, about 3,170 acres, is best suited for grazing because much of the soil contains too many stones for machine cultivation, the slope of the land is too steep for truck farming, and part of the area is susceptible to flooding (fig. 2). Of this 3,170 acres, 2,040 acres, with irrigation, have a high productivity rating for pasture (Sahara and others, 1972). About 350 acres within the above 3,170 acre pasture area, with irrigation, would have a high crop productivity rating (Sahara and others, 1972). One potential land use would be to devote the entire 3,170 acres to grazing beef cattle.

According to Dr. James Nolan, an animal science professor at the University of Hawaii (oral commun., 1984), beef cattle are the only suitable livestock for the area because dairy cattle could not live on the rugged terrain and there is no market for goats. For beef cattle there is a limit of one animal per 10 acres, and about 15 gallons of water per day per animal is necessary under average conditions. However, when there is no rain and the vegetation is dry, then 20 to 25 acres per animal are required. If an average of 20 acres and 20 gallons of water per day per animal is assumed, then 3,170 acres could support about 160 head of beef cattle. Beef cattle can tolerate a slightly higher chloride concentration in the water, about 300 mg/L maximum, but for planning purposes, human potability requirements are assumed. The drinking-water requirements for a herd of 160 animals would be 3,200 gal/d or 0.0032 Mgal/d.

Of the 3,170 acres of pasture, 2,040 acres would have a high productivity rating with irrigation (Sahara and others, 1972). However, with an estimated irrigation requirement of 2,000 gallons per acre per day (oral commun., University of Hawaii Cooperative Extension Service, 1985) only about 1,000 acres could be irrigated with the additional development of 2 Mgal/d. Therefore, in this scenario the entire 3,170 acres could be used for pasture, but less than half of it could be irrigated. The water requirement for 160 head of beef cattle and irrigation of about 1,000 acres would be 2 Mgal/d.

Another approach would be to use the 2 Mgal/d by growing only low-water-use crops such as pineapple. The pineapple plantation near Wahiawa presently uses 1,000 gallons per acre per day with their drip irrigation system. Assuming a water requirement of 1,000 gallons per acre per day, perhaps 2,000 acres of pineapple could be farmed. However, because of the low crop productivity ratings of much of the soils in Lualualei and flood hazards in some areas, only about 350 acres could be put into pineapple production. This scenario would require 0.3 Mgal/d.

With both of the above scenarios the possibility exists that part of the 2 Mgal/d to be developed would have to be mixed to meet salt-tolerance requirements of pineapple or beef cattle. Table 1 (from McKee and Wolf, 1963) classifies irrigation water by ranges of chloride concentration, specific conductance and dissolved solids concentration. The large ranges in each class and the overlap between classes reflects the variations in plant salt tolerances that occur due to different soils, climates, and farming practices. It appears that most plants can be grown when the chloride concentration of the irrigation water is below 250 mg/L, although some plants under some conditions have been affected when the chloride concentration was greater than 70 mg/L. In Class II, table 1 indicates that some plants will be affected when the chloride concentration of the irrigation water approaches 710 mg/L. Class III indicates greater than 710 mg/L is injurious to most plants.

Table 1.--Classification of irrigation water

(Source: McKee and Wolf, 1963)

	Chloride (mg/L)	Specific conductance (microsiemens/cm)	Dissolved solids (mg/L)
Class I			
Excellent to good, or suitable for most plants under most conditions	<70 to <250	<500 to <1,000	<350 to <700
Class II			
Good to injurious harmful to some under certain conditions of soil, climate practices	70 to 710	500 to 3,000	350 to 2,100
Class III			
Injurious to unsatisfactory, unsuitable under most conditions	>213 to >710	>2,500 to >3,000	>,500 to >2,100

The literature indicates considerable variation in the limits set for each class for the above variables. Thus there is some overlap in the ranges presented.

The National Academy of Sciences (1974) addressed the problem of irrigating with saline water and stated that, in general, almost any crop can tolerate irrigation water containing dissolved solids less than 600 mg/L. Many crops can tolerate water with dissolved solids from 500 to 1,500 mg/L if there is adequate leaching and drainage. Water with 1,000 to 2,000 mg/L dissolved solids, can be used to irrigate moderately salt-tolerant crops if they are watered frequently. High yields from highly tolerant crops such as sugar beets, Bermuda grass, cotton and barley have been achieved using water with dissolved solids concentrations of 3,000 to 5,000 mg/L.

It is apparent that the salt-tolerance of crops to be grown will affect water-use decisions and development. For example, if the Board of Water Supply shaft is opened and the chloride and dissolved solid concentrations average about 300 mg/L and 1,600 mg/L, respectively, the water could be used to irrigate, possibly on a drip system without being mixed with fresh water, crops that have a moderate or high salt tolerance, such as asparagus, garden beets, and spinach or grasses such as bermuda or zoysia (McCall, 1980). With a shaft production rate of 110,000 gal/d and estimating a water consumption rate of about 10,000 gallons per acre per day using drip irrigation, about 11 acres could be allocated for vegetable production using this source. Foliage burn may be eliminated with drip irrigation; however, hole-clogging due to salt deposits may be a problem.

The shaft water might also be mixed with fresher water developed by the proposed band of wells in the volcanic aquifer. Mixing at appropriate proportions may eliminate the problems mentioned and allow the use of 110,000 gal/d at relatively minimal expense as compared with construction costs of new wells.

Other crops such as Manoa lettuce, mustard cabbage, and most vegetables are only moderately or slightly salt tolerant and would require 7,000 to 10,000 gallons per acre per day using sprinkler irrigation (Dr. Woo, Agriculture Engineering, University of Hawaii, oral commun., 1984). If drip irrigation were used perhaps the above vegetables would require 7,000 to 8,000 gallons per acre per day. Depending on the method of irrigation, 200 to 285 acres could be farmed with the additional 2 Mgal/d. This is considerably less acreage for crops than was originally proposed (2,400 acres) by the Navy for the outleasing project; however, it is within the 350 acres that have a high crop productivity rating with irrigation.

Another approach would be a combination of grazing and crop production, estimating an allocation of 190 acres for crop production assuming between 8,000 and 10,000 gallons per acre per day depending on the crop type and irrigation method, and 2,980 acres (non-irrigated) for 150 head of beef cattle at 3,000 gal/d. The total water use would then range between about 1.52 and 1.9 Mgal/day using 3,170 acres.

If staffing levels remain constant, the present water source (2808-02) will be adequate to supply the personnel and operating requirements of the Radio Transmitting Facility and the Naval Magazine. The estimate of 2 Mgal/d of additional water could be allocated to the agricultural outleasing program.

WELL-NUMBERING SYSTEM

The well-numbering system for Oahu is based on latitude and longitude. The island is divided into rectangles by the 1-minute parallels and meridians. Each rectangle is located by a four-digit number which is minutes of latitude followed by minutes of longitude.

Within each rectangle, the wells are numbered serially according to the time drilled. Each well has the four-digit number that identifies the rectangle, followed by a two-digit serial number. Because Oahu encompasses an area less than 1 degree of latitude or longitude, there are no duplications in the 1-minute rectangular grid system.

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