INVESTIGATION OF WAIKELE WELL NO. 2401-01, OAHU, HAWAII:

PUMPING TEST, WELL LOGS AND WATER QUALITY

By Paul Eyre

U.S. GEOLOGICAL SURVEY

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INVESTIGATION OF WAIKELE WELL NO. 2401-01, OAHU, HAWAII
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EXECUTIVE SUMMARY

An abandoned Navy well at the Waikele Branch of Naval Magazine Lualualei appears suitable as an additional source of potable water for that installation.

The Naval Magazine Lualualei, Waikele Branch, is presently dependent on water from Oahu Sugar Co. wells. This supply is not always dependable and a backup source is desired.

Results of pumping tests and chemical analyses indicate that the Navy well, No. 2401-01, at the Waikele Branch of the Naval Magazine Lualualei, can supply 400 to 500 gallons per minute of potable water for that installation. The static water level at the well is about 20 feet above mean sea level. A pumping rate of 400 gallons per minute produces a steady drawdown of approximately 40 feet within an hour from the start of pumping. The chloride concentration of the well water is less than 200 milligrams per liter and will probably remain less than 200 milligrams per liter unless the chloride concentration of irrigation water applied to nearby fields (presently about 200 to 500 milligrams per liter) becomes significantly greater.

1.0 INTRODUCTION

A dependable water supply is required for Naval Magazine Lualualei, Waikele Branch.

The water supply for Naval Magazine Lualualei, Waikele Branch, Oahu, Hawaii has been dependent on Oahu Sugar Co.'s water for many years. Because the supply of water from Oahu Sugar Co. is not always dependable, in March 1982, the Pacific Division of the Naval Facilities Engineering Command entered into a cooperative agreement with the U.S. Geological Survey to determine the productivity and water quality of an abandoned Navy well. The well, No. 2401-01, is located in Waikele Gulch near the confluence of Waikele and Kipapa Streams (fig. 1.0-1).

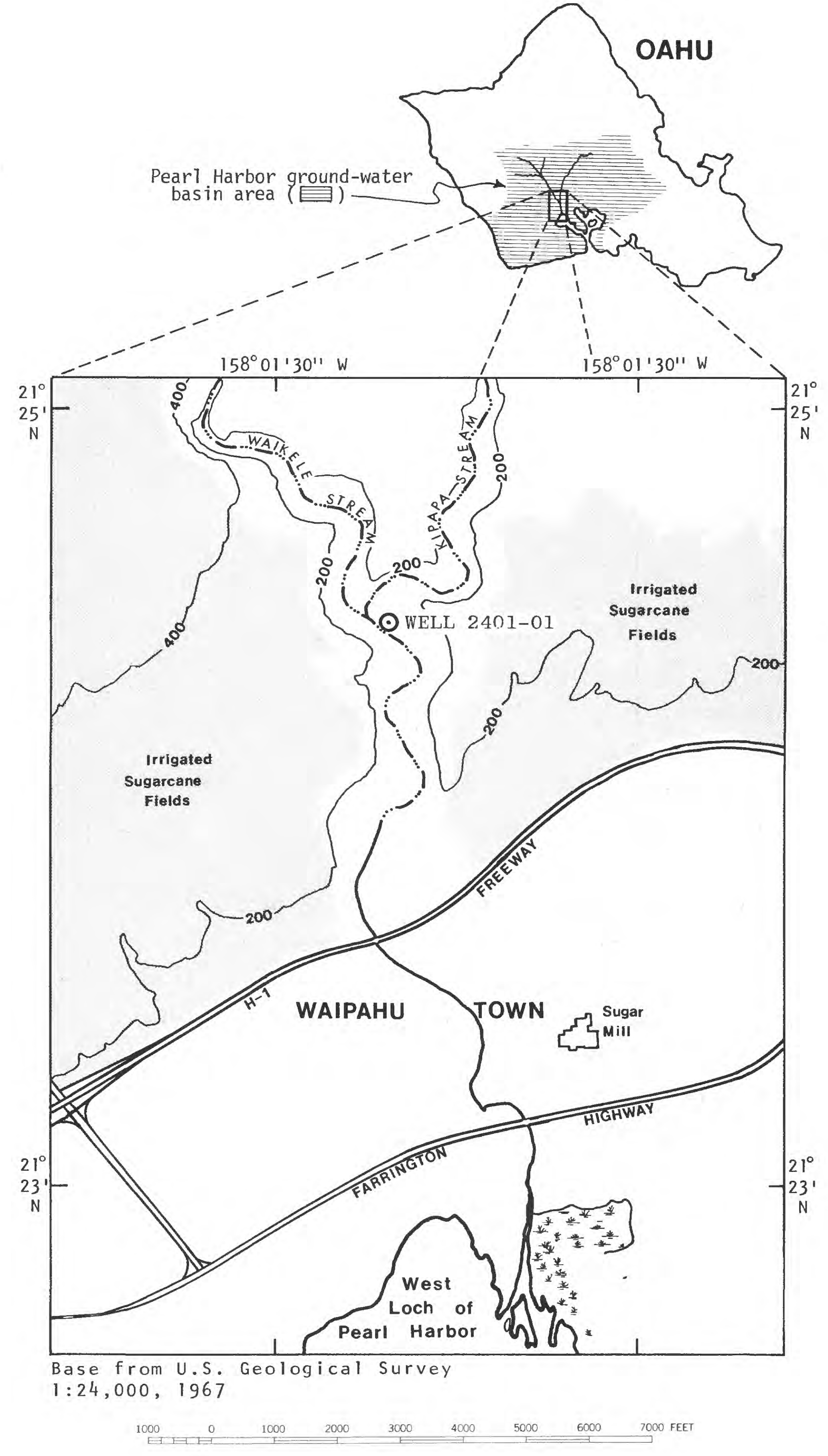


Figure 1.0-1. Location of well 2401-01.

1.0 INTRODUCTION

1.1 ACKNOWLEDGMENT

Chester Lao, Clarence Murata, and Glenn Masui of the Board of Water Supply, City and County of Honolulu, were instrumental in obtaining and interpreting the geophysical logs used in this study.

1.2 TASKS PERFORMED

Data were collected to determine the productivity of the well and the quality of the well water.

From May 10 through May 28, 1982, the following tasks were performed by personnel of the U.S. Geological Survey, Honolulu Board of Water Supply, the Roscoe Moss Drilling Co., and Towill, Shigeoka, and Associates, Surveyors.

(1) Determine the precise elevation of a local bench mark and the top of the well casing.

(2) Measure ground-water levels.

(3) Collect water samples.

(4) Videotape the well to determine the condition of the casing and open hole.

(5) Obtain a neutron log of the hole. These data indirectly indicate the location of the water-producing zones of the well.

(6) Obtain a specific conductance profile of the well water.

(7) Perform a pumping test to determine the relationship between drawdown and pumping rate. These data are used to estimate the hydraulic conductivity of the aquifer and to determine the depth at which the pump intake should be set.

2.0 HYDROGEOLOGIC SETTING

Wells in this area tap a lens of freshwater floating on sea-water. Water quality depends on the location and depth of a well, and its pumping rate. Irrigation return water may also affect water quality.

The Waikele well, located near the confluence of Waikele and Kipapa Streams, taps the fresh ground-water lens that comprises the Pearl Harbor basal-water body. The Ghyben-Herzberg principle states that such a freshwater lens, floating on seawater, will have a thickness equal to 41 times the head (water-table elevation) of freshwater above sea level. In the vicinity of the Waikele well, the lens thickness is about 800 feet. The principal recharge to the ground-water lens is rainfall in the highlands of the Koolau Range. The lens becomes thicker to the north where rainfall is greater and heads are higher, and thinner to the south where the lens discharges to many pumping wells and natural artesian springs. The thickness of freshwater available to wells is generally less than what the Ghyben-Herzberg factor predicts because the lower part of the lens is occupied by brackish water in transition from freshwater to seawater. Also, pumping at high rates from deep wells may induce deeper and saltier water to move upward.

Another source of saltwater in this area is irrigation return water. The primary land use in this area is the cultivation of sugarcane. Irrigation wells which tap the Pearl Harbor basal-water body produce water ranging from about 150 to 500 mg/L Cl^- (milligrams per liter of chloride), depending primarily on the location and depth of the well, and its pumping rate. One excessively deep battery of wells produces water with 1,500 mg/L Cl. After being applied to the fields, a significant fraction of the irrigation water percolates through the ground and recharges the basal lens.

At the confluence of Waikele and Kipapa Streams, a bed of alluvium approximately 100 feet thick has accumulated. Below this alluvium is a zone of weathered basalt (saprolite) which grades into fresher, more permeable basalt with depth. The low permeability of the alluvium and saprolite results from the process of laterization in a humid environment. Hard rock of high permeability is chemically altered to soft clay of low permeability. Between the valley walls, two ground-water systems exist. In the alluvial-saprolite aquifer, a small ground-water body is recharged by rainfall over the valley, flood waters of Waikele and Kipapa Streams, and possibly by leakage from the streambed itself. The permeable basalt aquifer, which underlies the alluvial-saprolite aquifer, is a part of the Pearl Harbor basal-lens system. This system behaves as previously discussed. Because of the tightness of the alluvial-saprolite aquifer, the head and water quality of the two aquifers remain distinct, although some interflow probably occurs.

3.0 HISTORIC RECORD

3.1 DRILLING RECORD

Waikele well No. 2401-01 was drilled in 1946.

Well 2401-01 was drilled to a depth of 300 feet below the ground surface in 1946. A summary of the well log is shown in figure 3.1-1. The original well record is presented in table 3.1-1.

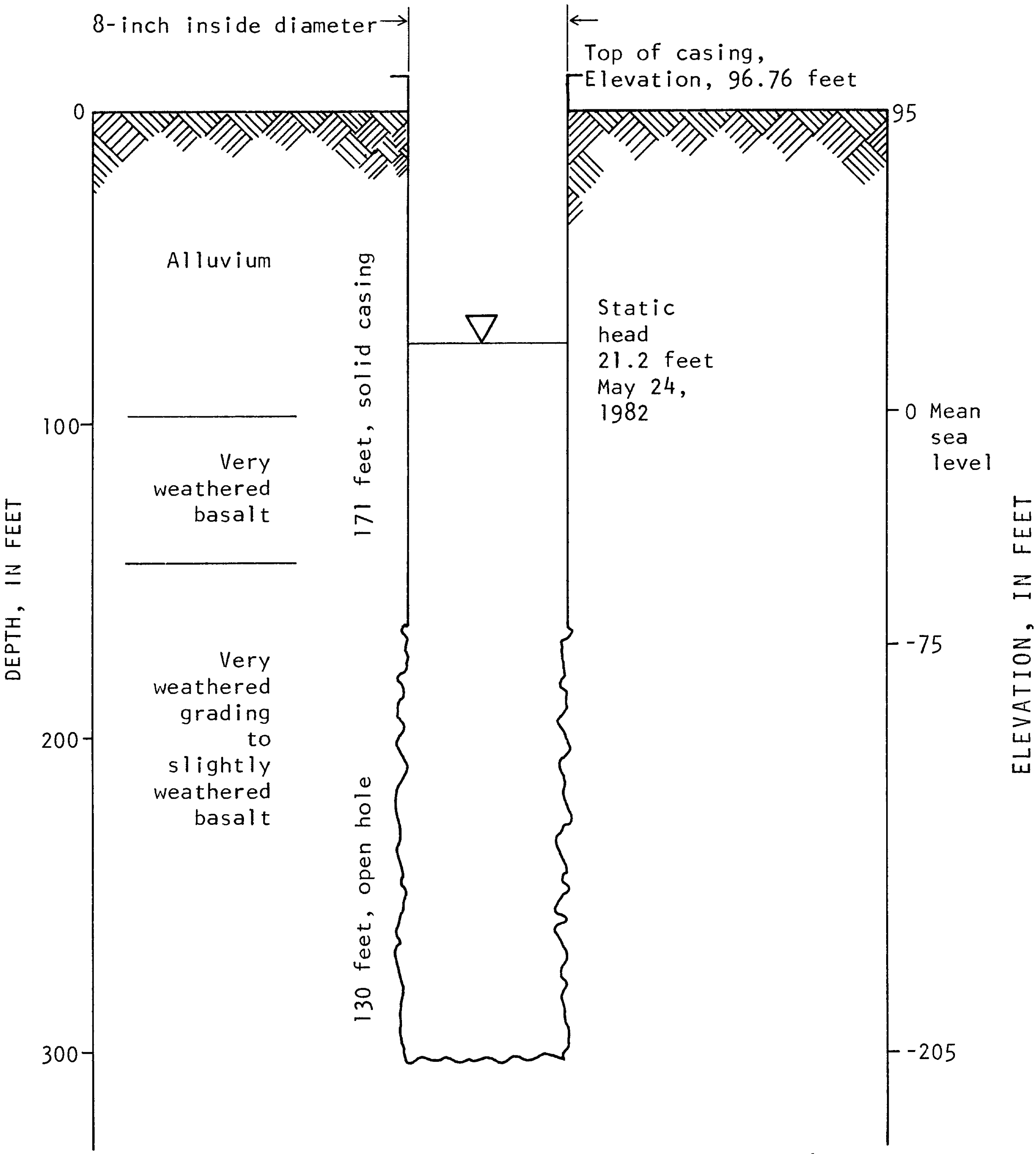


Figure 3.1-1. Dimensions and log of Waikele well, 2401-01.

Table 3.1-1. Well record of well 2401-01 (Well 251-1)
(From U.S. Geological Survey files)

Location:	In Waikele gulch about 600 ft below confluence of Waikele and Kipapa Streams and 1.4 mi northwest of Waipahu.
Owner:	U.S. Navy.
Drilled:	May 1946 by W. M. Mullin.
Elevation:	96 ft.
Diameter:	8 in. (i.d.).
Depth:	300 ft.
Casing:	171 ft galvanize steel pipe.
Head:	Mar. 28, 1946, 40.6 ft elev. when well was 200 ft deep.
	Apr. 1, 1946, 40.7 ft elev. when well was 200 ft deep.
	Apr. 11, 1946, 40.6 ft elev. when well was 200 ft deep.
	May 6, 1946, 18.2 ft elev. when well was finished (300 ft).
Chloride:	Mar. 18, 1946, 73 mg/L when well was 200 ft deep.
	May 6, 1946, 308 mg/L when well was finished (300 ft).
Use:	Well to be abandoned because of high salinity.
Bench Mark:	Top of iron base of pump; altitude, 97.1 ft.

Table 3.1-1. Well record of well 2401-01 (Well 251-1)--Continued

Log

Description of material	Depth (ft)
Clay and boulders	0-7
Clay	7-15
Clay and boulders	15-17
Brown clay and boulders	17-46
Sticky clay and small boulders	46-55
Very sticky brown clay and small boulders	55-80
Dark brown clay	80-98
Hard mud rock	98-100
Hard mud rock and red rock	100-105
Brown clay	105-116
Mud rock with layers of blue rock	116-119
Brown clay	119-125
Mud rock and clay	125-130
Brown clay	130-134
Hard red rock	134-137
Medium hard red rock	137-146
Very hard red rock	146-157
Very hard mud rock	157-160
Medium hard mud rock	160-162
Very hard lava rock	162-167
Hard lava rock	167-173
Red clay	173-175
Very hard lava rock	175-190
Hard lava rock	190-195
Mud rock and lava rock, mixed	195-200
Soft lava rock with streaks of hard rock	200-215
Hard lava rock	215-250
Soft lava rock with hard streaks	250-254
Reddish lava rock	254-258
Very hard reddish lava rock	258-274
Hard lava rock	274-300

3.0 HISTORIC RECORD

3.2 PERFORMANCE RECORD

The well was infrequently used owing to high chloride concentration and the availability of Oahu Sugar Co. water.

As indicated in the well record (table 3.1-1), in 1946 the chloride concentration in the alluvial-saprolite aquifer was about 70 mg/L. The productivity of the well was probably low at this depth. When the well was deepened to 300 feet, the chloride concentration rose to 300 mg/L. Apparently, it was believed that the well had entered the brackish transition zone underlying the freshwater lens, therefore, the well was not put into production. Subsequent testing in 1946 produced a chloride concentration of 400 mg/L, which declined to about 200 mg/L when the well was pumped. Similar results occurred during a 1954 pumping test.

In the 1954 test, a pumping rate of 150 gal/min (gallons per minute) produced a drawdown of 5.5 feet. This amount of drawdown is greater than would be expected from an aquifer composed of unweathered flank flows from the Koolau mountain. The drawdown indicates that the permeability of the aquifer has been reduced by weathering (laterization) owing to its location in a stream valley.

4.0 ELEVATION SURVEY

The elevation of the point from which water levels were measured (top of the well casing) was precisely surveyed and is 96.76 feet above mean sea level.

The surveying company of Towill, Shigeoka, and Associates determined the elevation of the measuring point (top of well casing) to be 96.76 feet above mean sea level (msl). The survey was carried from the City and County monument at the intersection of Honowai and Haaa Streets in the town of Waipahu. A local reference mark near the well was made with a spike in a power pole located about 15 feet from the well. The elevation of this reference mark is 98.59 feet above msl.

The bench mark referenced in the original well record agrees with this survey, thus historic head data can be used with confidence.

5.0 GEOPHYSICAL LOGS

On May 12, 1982, stagnant oily water was bailed from the well until the water became clear then a video camera was sent down the well. On May 18, 1982, personnel from the Honolulu Board of Water Supply logged the hole with neutron and specific conductance probes. These logs are shown in figures 5.2-1 and 5.3-1.

5.1 VIDEO CAMERA LOG

The video log confirmed the dimensions of the hole and casing presented in the original well log of 1946. The casing appeared in good condition although it showed signs of rust or scale from a depth of 154 to 170 feet, and the open hole appeared stable. An object shaped like a pipe bridged the hole near a depth of 300 feet.

Moisture was observed on the side of the casing at a depth of 20 feet. Significantly more moisture was observed at depths greater than 56 feet. A depth of 56 feet corresponds to the water table in the alluvial-saprolite aquifer as noted for the March and April heads presented in the original well record (table 3.1-1).

The camera leaned against the side of the hole during its descent and ascent, which indicates that the hole is slightly off plumb.

5.0 GEOPHYSICAL LOGS

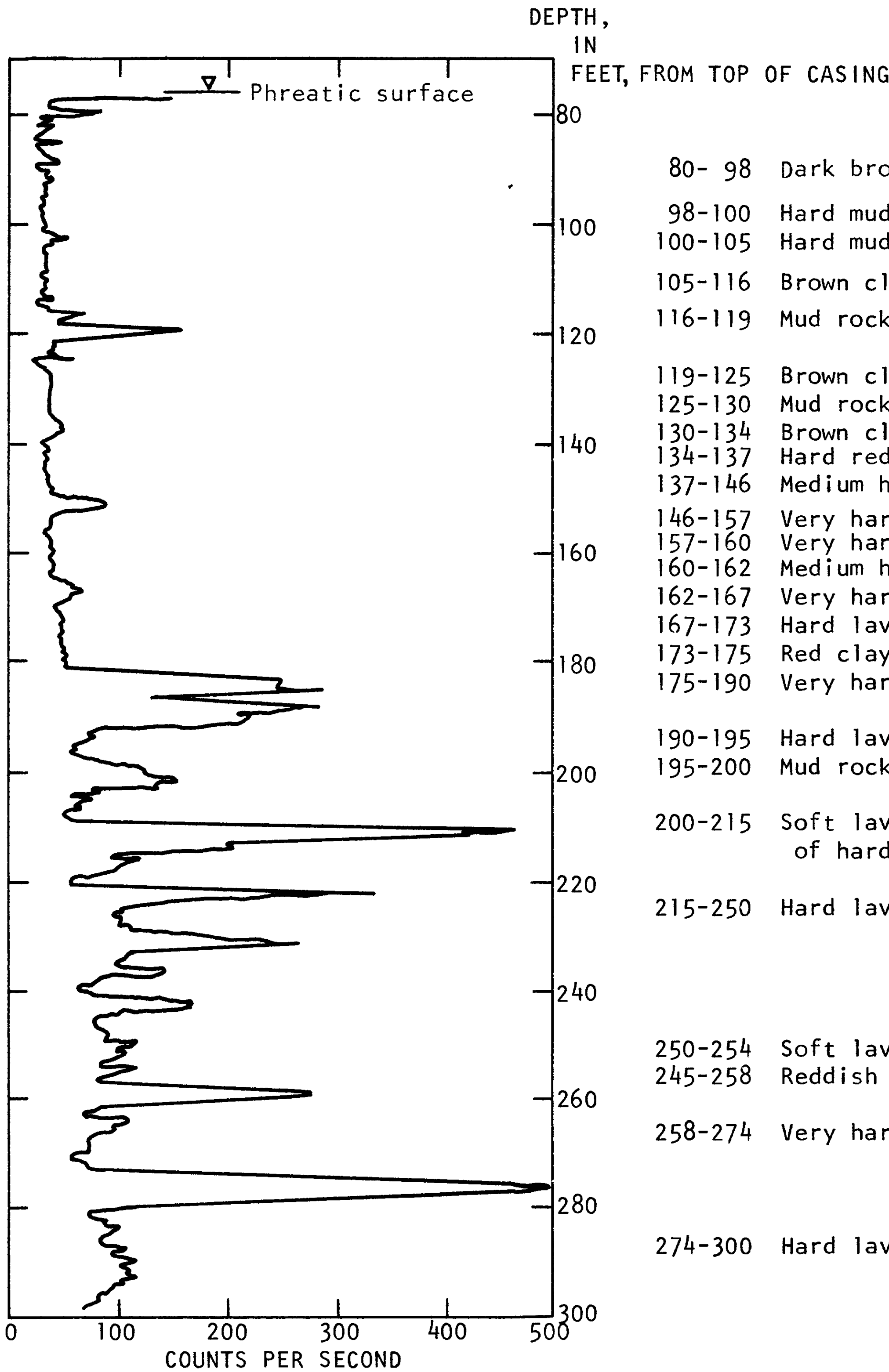
5.2 NEUTRON LOG

The neutron log indicated the location of water-producing zones in the hole.

Peaks on the neutron log indicate zones of low porosity. In Hawaiian basalt aquifers, the contacts between the zones of low porosity (hard rock) and adjacent zones are generally the areas through which most of the water flows. The neutron log, interpreted with the aid of the geologic log, indicates that the productive zones of the hole are located in the high-porosity sections on either side of the major peaks (see fig. 5.2-1.).

The width of a peak, measured at half of the peak's amplitude, represents accurately the thickness of the hard layers; however, the log cannot determine the relative productivity of the high porosity zones or whether there are other producing zones that are not adjacent to major peaks. A comparison of steel tape and logger readings indicate that the logger may be reading 1 foot less than the actual depth.

The neutron log shows that the transition from saprolite to slightly weathered basalt occurs abruptly at about 180 feet. Although saprolite has a relatively high porosity, its permeability is low owing to its clay content.



80- 98	Dark brown clay
98-100	Hard mud rock
100-105	Hard mud rock and red rock
105-116	Brown clay
116-119	Mud rock with layers of blue rock
119-125	Brown clay
125-130	Mud rock and clay
130-134	Brown clay
134-137	Hard red rock
137-146	Medium hard red rock
146-157	Very hard red rock
157-160	Very hard mud rock
160-162	Medium hard mud rock
162-167	Very hard lava rock
167-173	Hard lava rock
173-175	Red clay
175-190	Very hard lava rock
190-195	Hard lava rock
195-200	Mud rock and lava rocks mixed
200-215	Soft lava rock with streaks of hard rock
215-250	Hard lava rock
250-254	Soft lava rock with hard streaks
245-258	Reddish lava rock
258-274	Very hard reddish lava rock
274-300	Hard lava rock

Figure 5.2-1. Neutron and geologic logs for Waikele well 2401-01.

5.0 GEOPHYSICAL LOGS

5.3 SPECIFIC CONDUCTANCE LOG

The specific conductance log indicates the salinity of the water in the well.

Figure 5.3-1 presents a profile of the specific conductance of the well water. The top 94 feet of water in the Waikele well is inside a solid casing and may or may not represent the quality of the ground water outside the casing. This water has a chloride concentration of 70 to 100 mg/L. The relatively freshwater inside the casing probably results from rainwater, Waikele and Kipapa flood water, and the alluvial-saprolite aquifer water seeping through the casing.

Water below the casing has a chloride concentration of about 150 mg/L. This more brackish water (150 mg/L Cl^-) results probably from relatively high-chloride irrigation-return water mixing with fresh ground water. Other studies of the Pearl Harbor basal-water body (for example, Mink and Kumagai, 1971) show that this layer of slightly brackish water can be up to 300 feet thick before it grades into the fresher ground water. At greater depth, the freshwater grades into the underlying seawater upon which the freshwater floats.

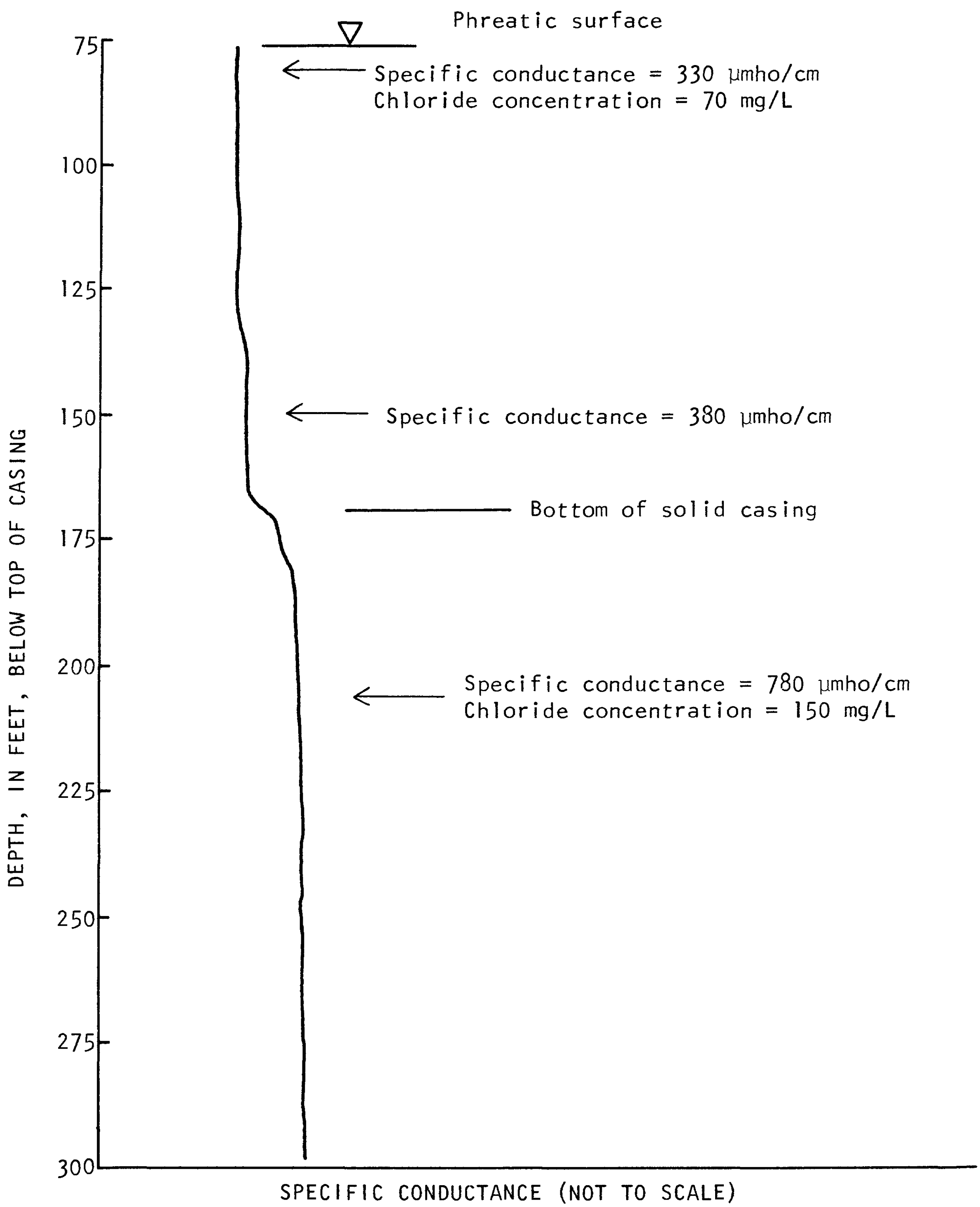


Figure 5.3-1. Specific conductance log of water in Waikele well, May 18, 1982.

6.0 WATER QUALITY

6.1 CHANGES IN WATER QUALITY

The chloride concentration of the well water declines when the well is pumped.

In 1946, at the start of a 2-day pumping test, the chloride concentration of water from the Waikele well was 400 mg/L. At the end of the test, the chloride concentration was 220 mg/L. A 4-day test, pumping about 150 gal/min in 1954, started with about 300 mg/L Cl^- and ended with 200 mg/L Cl^-. The 4-day test of May 1982 started with 160 mg/L Cl^- and ended with 110 mg/L Cl^- (fig. 6.1-1). These data indicate that the ground-water quality has improved since 1946 and that water with a chloride concentration of 220 mg/L or less can be expected from this well.

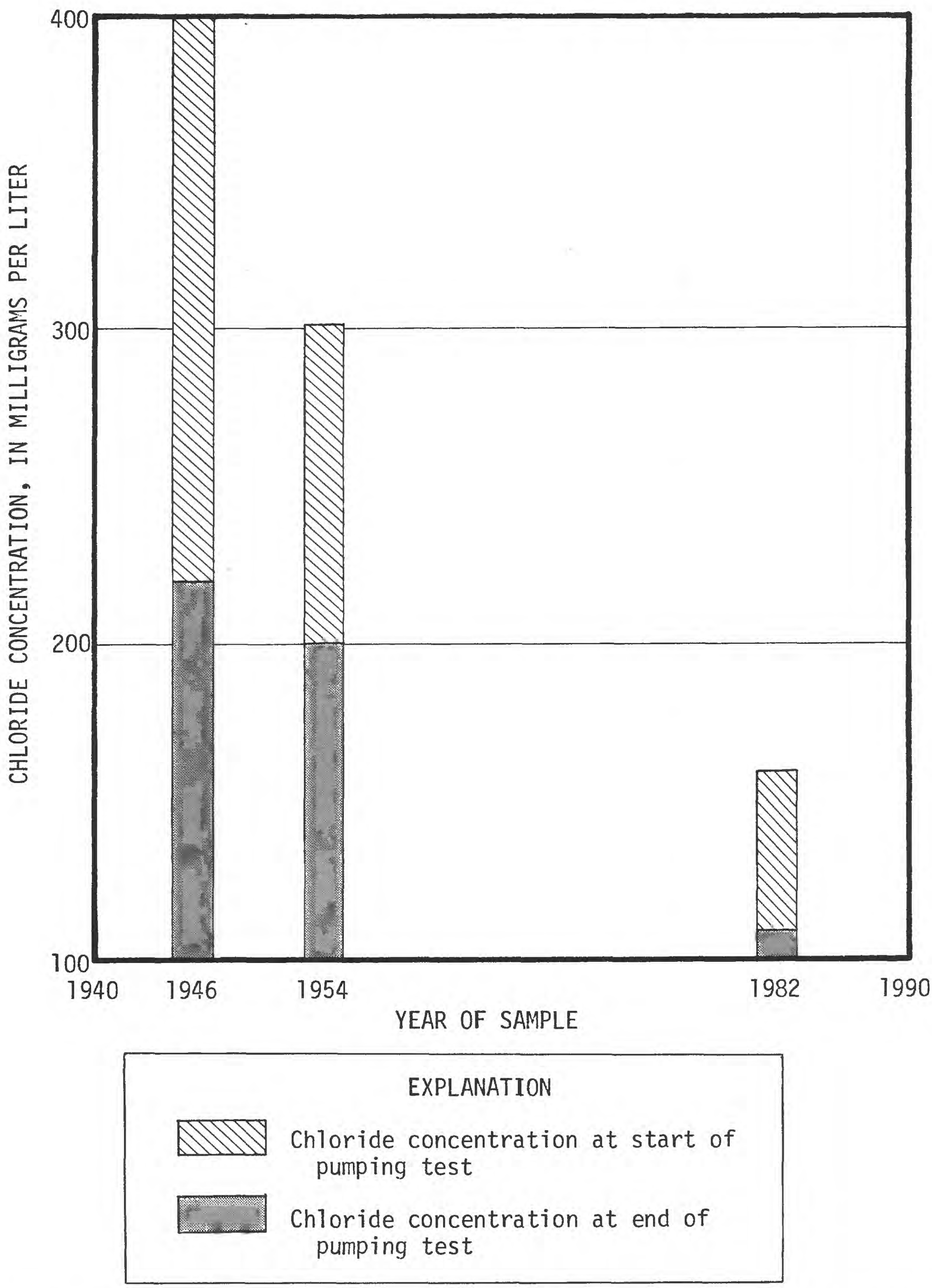


Figure 6.1-1. Record of chloride concentration in Waikele well water.

The data presented in figure 6.1-1 show that the chloride concentration of the well water declines when the well is pumped. This freshening results when the fresher water in the aquifer is drawn to the pumping well. Pumping from the basalt aquifer may also induce some flow of fresher water from the overlying alluvial-saprolite aquifer. Figure 6.1-2 represents a possible distribution of water types encountered by the well.

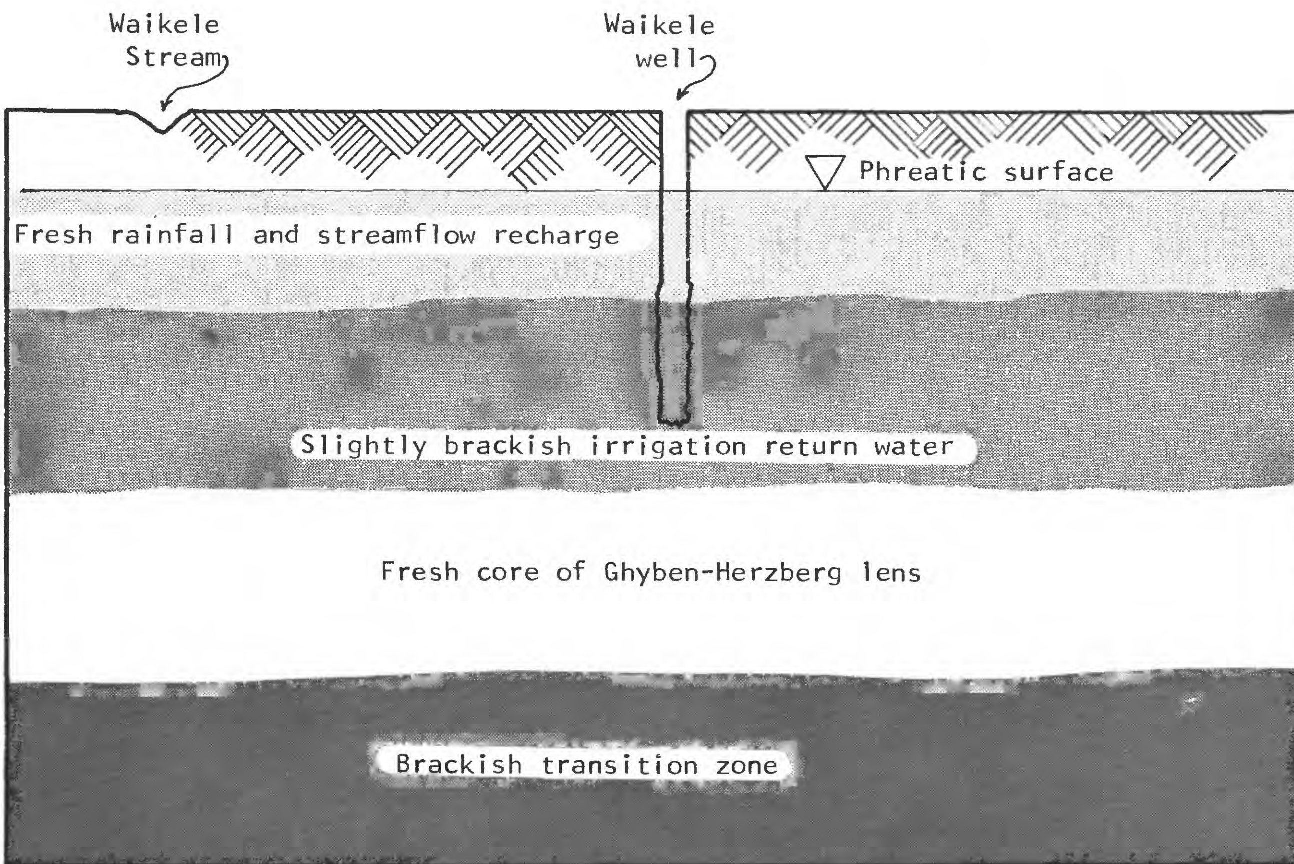


Figure 6.1-2. Possible distribution of water types at the Waikele well.

6.0 WATER QUALITY

6.2 ANALYSIS OF CHEMICAL CONCENTRATIONS

Water samples at the start and end of the pumping test were analyzed by the U.S. Geological Survey Central Laboratory for inorganic chemical species. The Navy's Environmental/Industrial Laboratory performed analyses required by the Environmental Protection Agency. All analyses indicate that the water is potable but additional chemical analyses may be desired.

Environmental Protection Agency (1980) Regulations (effective August 27, 1980) require that the concentrations of certain inorganic and organic species in drinking water be less than a maximum contaminant level. The analyses listed in table 6.2-1 show that for the chemical species analyzed, the water from the Navy Waikele well meets the Environmental Protection Agency requirements.

The concentrations of nitrogen and sulfate from U.S. Geological Survey analyses (table 6.2-2) indicate that irrigation return water has mixed with the fresh ground water of this area (Tenorio and others, 1969). This observation reinforces the concept that the greater part of the chloride concentration of the well water results from irrigation return water rather than seawater upconing or intrusion.

Because of the recent pesticide contamination of ground water in the Kunia area, about 5 miles northwest of the Waikele well, there is reason to analyze the water in the Waikele well for the pesticides DBCP and EDB as well. On a regional scale, ground water flows roughly north to south in this area and contamination from the Kunia area could reach Waikele.

Table 6.2-1. Chemical analyses performed by the Naval PWC Environmental/Industrial Laboratory, Pearl Harbor

Sample No. 2-21-DW41
Sample station: Navmag, Waikele well
Date of sample: May 27, 1982

Analysis requested	Maximum contaminant limits (mg/L)	Lab results (mg/L)
	Inorganic analyses	
Arsenic --------	0.05	<0.005
Barium ---------	1.0	<.02
Cadmium --------	.01	<.003
Chromium -------	.05	<.005
Lead -----------	.05	<.005
Mercury --------	.002	<.0002
Selenium -------	.01	<.005
Silver ---------	.05	<.005
Fluoride -------		.12
Nitrate as N ---	10	4.16
Turbidity ------	1.0	.07
	Organic analysis	
Endrin ---------	.0002	ND[1/]
Lindane --------	.004	ND
Methoxychlor ---	.10	ND
Toxaphene ------	.005	ND

[1/] Not detected.

Table 6.2-2. Chemical analyses of samples collected at start and end of pumping test*

[U.S. Geological Survey]

*Concentrations are of dissolved constituents

	Starting Sample May 24, 1982	Ending Sample May 28, 1982
Temperature (°C)	24.5	24.5
pH	6.8	7.1
Specific conductance (μmho)	710	580
Total dissolved solids	433	378
Chloride (mg/L)	160	110
Alkalinity (mg/L as $CaCO_3$)	64	82
Hardness (mg/L as $CaCO_3$)	220	180
Noncarbonate hardness (mg/L as $CaCO_3$)	160	100
Nitrate + nitrite (mg/L as N)	2.1	4.0
Sulfate (mg/L)	57	37
Sodium (mg/L)	55	48
Sodium adsorption ratio	1.9	1.8
Percent sodium	34	36
Potassium (mg/L)	2.5	2.3
Calcium (mg/L)	24	20
Magnesium (mg/L)	40	32
Silica (mg/L)	47	62
Fluoride (mg/L)	< .1	< .1

Table 6.2-3. Ion balance of chemical analyses

Cations	(mg/L)	(meq/L)	Anions	(mg/L)	(meq/L)
			Ion balance (starting sample)		
Potassium, dissolved --	2.5	0.064	Chloride, dissolved ----	160	4.514
Calcium, dissolved ----	24	1.198	Sulfate, dissolved -----	57	1.187
Magnesium, dissolved --	40	3.290	Alk tot lab. $CaCO_3$ -----	64	1.279
Sodium, dissolved -----	55	2.393	Nitr Dis NO_2+$N_0$3 as N --	2.1	0.150
	Total	6.945		Total	7.130
		Percent difference = -1.31			
			Ion balance (ending sample)		
Potassium, dissolved --	2.3	0.059	Chloride, dissolved ----	110	3.103
Calcium, dissolved ----	20	0.998	Sulfate, dissolved -----	37	0.770
Magnesium, dissolved --	32	2.632	Alk tot lab. $CaCO_3$ -----	82	1.638
Sodium, dissolved -----	48	2.088	Nitr dis NO_2+NO_3 as N --	4.0	0.286
	Total	5.777		Total	5.797
		Percent difference = -0.17			

7.0 PUMPING TEST

The Navy Waikele well was pumped at controlled rates for four days in order to determine the productivity of the well and the hydraulic conductivity of the aquifer. The well can produce water at a rate of 400-500 gal/min without drawing down the water level to the bottom of the casing. The permeability of the aquifer is about 50 ft/d (feet per day).

7.1 HYDRAULIC SETUP FOR THE PUMPING TEST

Hardware that could pump a maximum of 1,000 gal/min was assembled.

A three-stage 8-inch pump bowl and intake assembly were positioned 200 feet below the ground surface at the end of a 4-inch pump column. The pump column was attached to a vertical turbine, mounted on top of the casing, driven by a 91-horsepower diesel engine. Flow rate was measured with a totalizing meter and was adjusted by throttling the diesel engine.

7.0 PUMPING TEST

7.2 STEP-DRAWDOWN PUMPING TEST

The well was pumped sequentially at seven rates, from 75 to 520 gal/min, and the depth to water was measured at each rate. Drawdown increased from 2.9 to 64 feet as the pumping rate increased.

From May 12 to May 24, 1982, prior to the start of the pumping test, water levels at the Waikele well were measured several times. The static head at the well fluctuated between 20.8 to 21.2 feet above mean sea level during this time. At 0940, May 24, 1982, the pumping test began with a rate of 75 gal/min. This rate was held for half an hour with frequent water-level measurements being made. This procedure was repeated at successively greater pumping rates until the maximum obtainable rate was achieved, 520 gal/min. In this case, the maximum obtainable rate was limited by the efficiency of the diesel engine.

The data obtained from the test are presented in figure 7.2-1. At rates of up to 400 gal/min, a steady water level was achieved within half an hour. At 520 gal/min, the depth to water was 136 feet (drawdown = 59 ft) initially but reached the steady level about 141 feet within the next 24 hours of steady pumping. The engine could not maintain a rate of 520 gal/min for much more than one day. After about a day, the pumping rate steadily declined and the water level rose accordingly.

After 4 days of pumping at approximately 500 gal/min the test was terminated. The water level in the well fully recovered approximately 40 minutes after the pump was shut off.

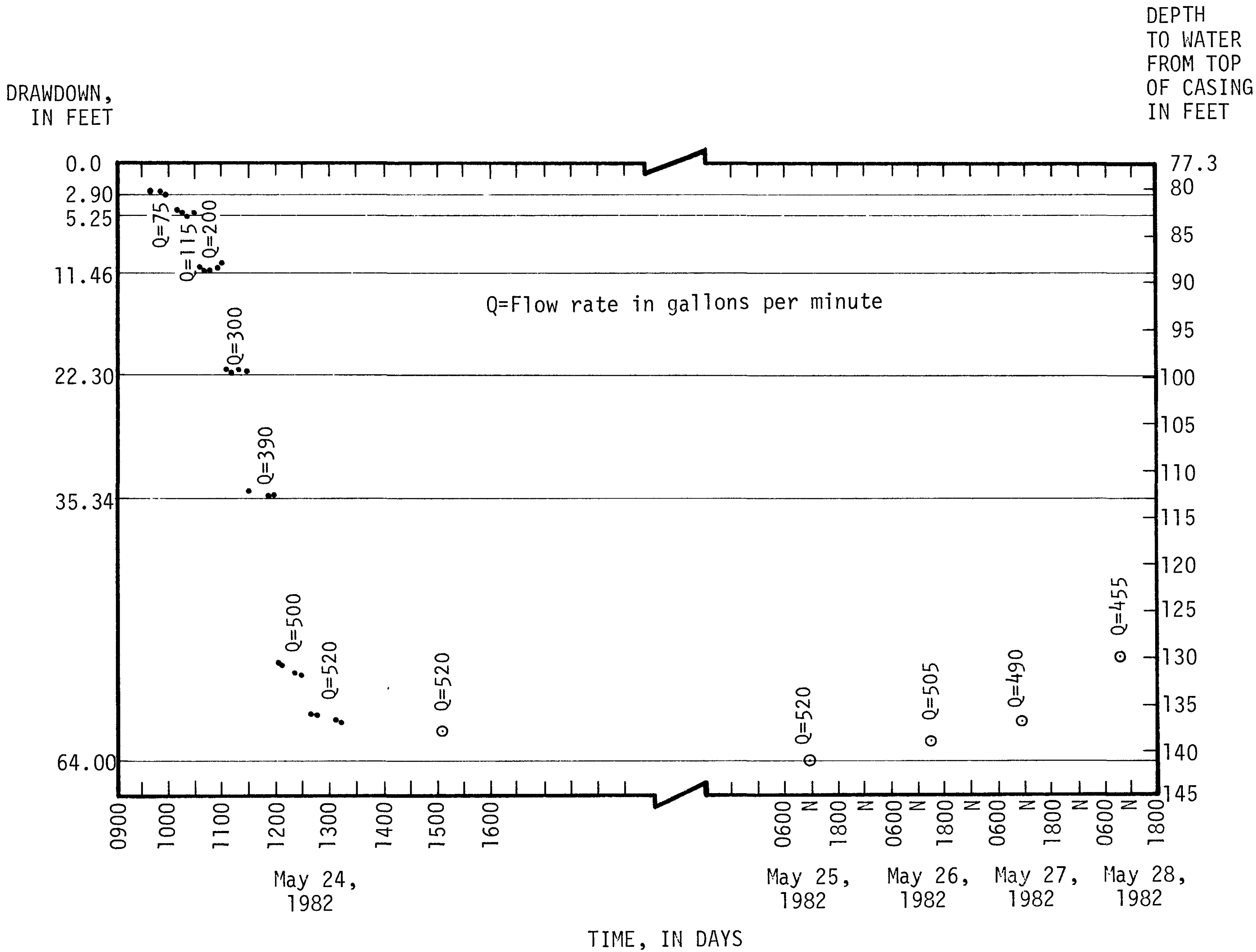


Figure 7.2-1. Drawdown versus pumping rate at the Waikele well.

The pumping rates and their observed drawdown were used with an equation developed by Jacob (1947) to predict the drawdown at any pumping rate and to determine the amount of drawdown due to laminar flow through the aquifer (aquifer loss) and the amount of drawdown due to turbulence as the water flows into the well (well loss).

Jacob's equation is:

$$s = AQ + BQ^n$$

where:

s = total drawdown,

Q = flow rate,

A = regression factor,

B = regression factor,

n = regression exponent,

AQ = aquifer loss, and

BQ^n = well loss.

A, B, and n are calculated by the method of least squares to create the curve of the form $AQ + BQ^n$ that has the best fit to the observed data. The equation for the curve is:

$$s = .0389Q + 3.3400\times10^{-6} \times Q^{2.620}$$

Table 7.2-1 and figure 7.2-2 present the drawdown equation for the Waikele well, the observed drawdown, and the calculated aquifer and well losses.

Table 7.2-1. Values calculated from the drawdown equation

$$s = .0389Q + 3.3400\times10^{-6} \times Q^{2.620}$$

Discharge (gal/min)	Observed drawdown (ft)	Calculated drawdown (ft)	Aquifer loss (ft)	Well loss (ft)
75	2.9	3.2	2.9	0.3
115	5.3	5.3	4.5	0.8
200	11.5	11.3	7.8	3.5
300	22.3	22.0	11.7	10.3
390	35.3	35.7	15.2	20.5
520	64.0	63.8	20.2	43.6
600		1/ 86.8	23.3	63.5
800		1/ 165.9	31.1	134.8

1/ Extrapolated from drawdown equation.

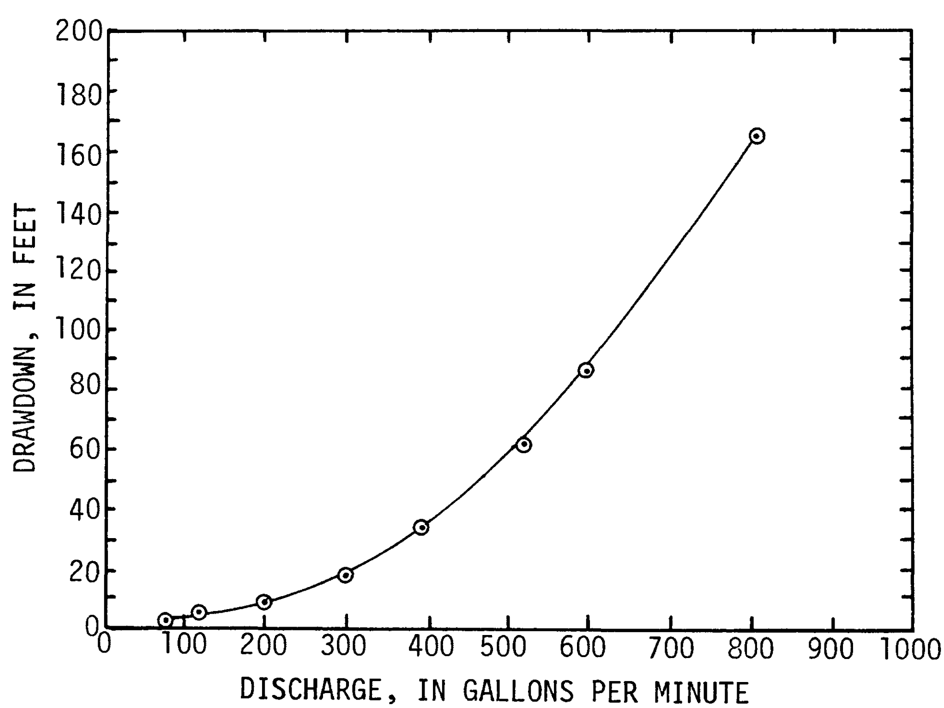


Figure 7.2-2. Graph of the Waikele well drawdown equation.

At the end of the pumping test water level recovery data was obtained. Figure 7.2-3 presents these data.

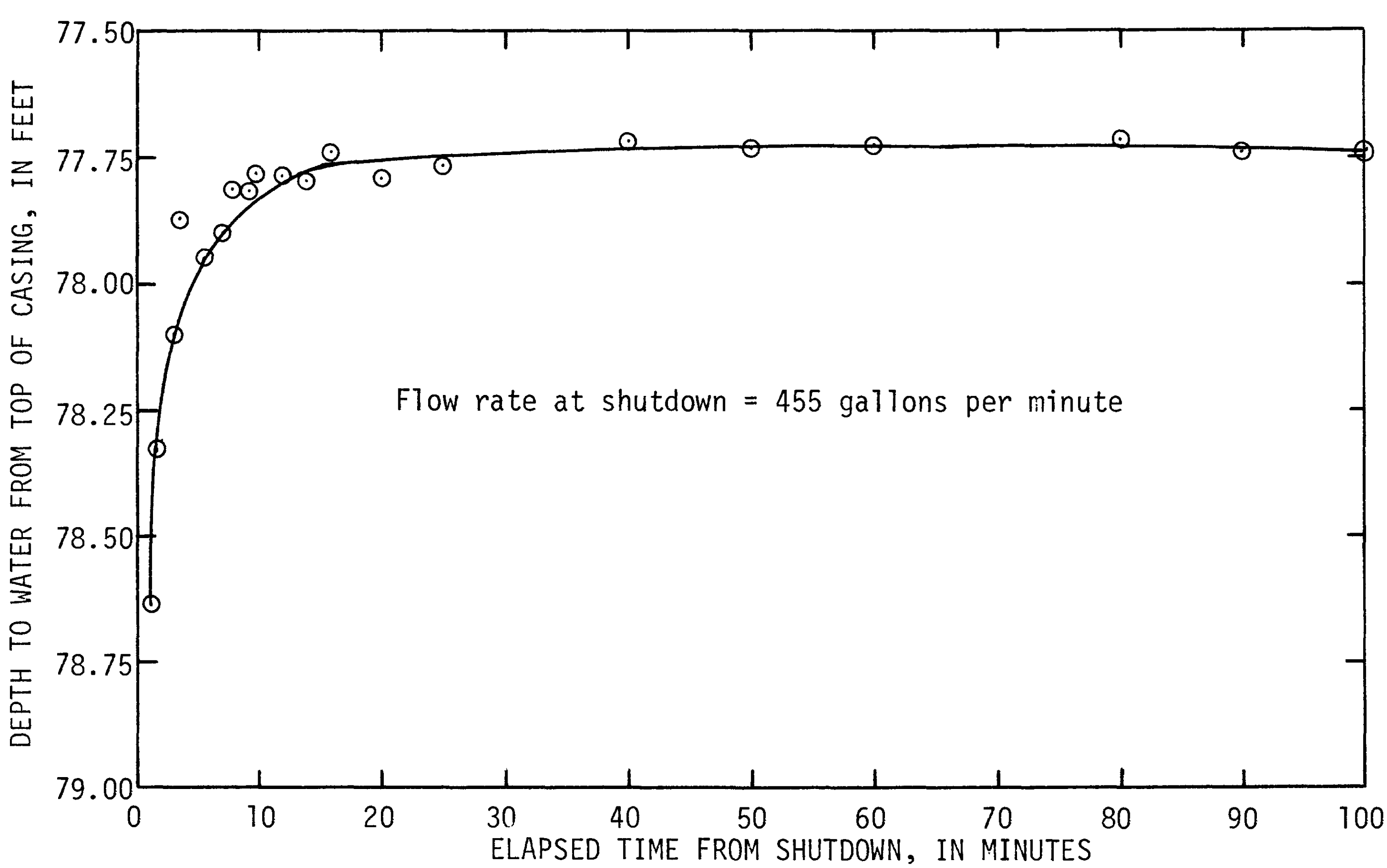


Figure 7.2-3. Recovery data at the Waikele well, May 28, 1982.

7.0 PUMPING TEST

7.3 CALCULATION OF AQUIFER HYDRAULIC CONDUCTIVITY (K)

The two methods used to calculate K produced values of about 50 ft/d.

Calculations of aquifer hydraulic conductivity are based on equations which describe specific and idealized geologic and hydrologic conditions. Generally, conditions in Hawaii do not closely resemble the conditions described by available equations and it is difficult to know whether calculated K values are significantly in error. The two methods used to obtain K values for the aquifer tapped by the Waikele well produced values of 40 and 50 ft/d.

7.3.1 CALCULATION OF K BASED ON FLOW INTO A CYLINDER. K = 50 FT/D.

The hydraulic conductivity of the aquifer can be estimated by use of the Theim equation. This equation applies Darcy's Law to flow into a cylinder (the open part of the well). The equation is derived for the situation of horizontal, radial flow to a cylindrical well that fully penetrates a homogeneous, isotropic and confined aquifer. The Waikele well only partly penetrates the Pearl Harbor aquifer, which is unconfined, heterogeneous, and anisotropic; therefore, the estimate of permeability obtained from the equation is at best, an approximation. The estimated K could be in error for at least two reasons. First, the equation will attribute the relatively large observed drawdown (head loss) to a low K value whereas actually the head loss results, to some extent, from the force required to make deep flow lines curve so that they converge on the partially penetrating well. This error would cause K to be underestimated. Second, the thickness of the flow field moving to the well, assumed to be the active (open-hole) length of the well, may be underestimated because the well only partially penetrates the aquifer and flow can occur below the active length. This error would cause K to be overestimated. Errors resulting from anisotropy and heterogeneity are more difficult to assess.

Having expressed these reservations, the Theim equation will be explained and applied to the Waikele data.

Darcy's Law states that $Q = -KAdh/dl$,

where:

Q = flow rate from the well,

K = hydraulic conductivity of the aquifer,

A = the surface area through which flow occurs,

dl = a small distance along the flow path of ground water moving to the well,

dh = the change in head of the ground water along the distance dl, and

dh/dl = the hydraulic gradient.

For flow into a cylinder, $A = 2\pi rb$,

where:

A = surface area of the cylinder,

r = the radius of the cylinder,

b = theoretically, the thickness of the flow field; approximately, the active (intake) length of the well.

Darcy's Law becomes $Q = -2\pi rKbdh/dr$

or $Q = 2\pi rKbds/dr$

where ds is the change in drawdown along a small distance of the radial flow path, dr. By integrating and rearranging terms, the Theim equation is obtained:

$$K = \frac{Q}{2\pi b} \frac{\ln(r_2/r_1)}{s_1 - s_2}$$

where s_1 = the drawdown at distance r_1 from the well; similarly for s_2 and r_2.

Although two pairs of r and s values are required to solve this equation, for Hawaiian basalts the drawdown is negligible approximately 1,000 feet away from a well pumping at the moderate rates used in this test. Therefore, r_2 and s_2 can be set at 1,000 and 0 feet, respectively. The value of r_1 can be chosen as the well radius and s_1, the aquifer loss, is calculated from Jacob's equation presented earlier in table 7.2-2.

Then,

$$K \text{ ft/d} = \frac{75 \text{ gal/min}}{2\pi \times 130 \text{ ft}} \times \frac{\ln(1{,}000 \text{ ft}/.33 \text{ ft})}{2.9 \text{ ft} - 0 \text{ ft}} \times \frac{192.5 \text{ ft}^3/\text{d}}{\text{gal/min}}$$

$K = 50$ ft/d.

Using flow rates of 200 and 390 gal/min and their respective aquifer losses also produce K values of 50 ft/d. If 2,000 feet, rather than 1,000 feet, is used as the radius of influence, $K = 56$ ft/d.

7.3.2 CALCULATION OF K BASED ON FLOW INTO A HEMISPHERE.

K = 40 FT/D.

Because the well only partially penetrates the aquifer, it can also be viewed as similar to a dug well in which water flows through a hemispherical surface area to reach the well.

Darcy's Law, $Q = -KAdh/dl$, still applies, but in this case, $A = 2\pi r^2$. Then, $Q = K2\pi r^2 ds/dr$.

Upon integrating

$$s_2 - s_1 = \frac{Q}{2\pi K}\left(\frac{1}{r_2} - \frac{1}{r_1}\right) \text{ (Bear, 1979);}$$

and $K = \frac{1}{2\pi}\left(\frac{Q}{s_2 - s_1}\right)\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$.

Letting $s_2 = 0$ at $r_2 = \infty$ or equivalently;

Letting s_2 be negligibly small at relatively large r_2;

$$K = \frac{Q}{2\pi r_1 s_1} .$$

The r value in this equation is the radius of an equivalent hemispherical well that would produce the same aquifer loss as the real cylindrical well. This r value, r_h, must be calculated from the real well dimensions. Zangar (1953) shows that $r_h = L/\ln(L/rw)$,

where:

r_h = radius of the equivalent hemispherical well;

r_w = radius of the real well;

L = active length of the real well;

ln = natural logarithm.

Then,

$$r_h = \frac{130 \text{ ft}}{\ln(130 \text{ ft}/.33 \text{ ft})} ;$$

$$r_h = 21.75 \text{ ft};$$

and $K = \frac{75 \text{ gal/min} \times 192.5}{2\pi \times 21.75 \text{ ft} \times 2.9 \text{ ft}}$;

K = 40 ft/d.

8.0 CONCLUSIONS

Well 2401-01 in Waikele Gulch can supply the Naval Magazine with 400 to 500 gal/min of potable water.

Well logging confirmed the dimensions of the well presented in the 1946 well log. A step-drawdown pumping test indicated that as much as 400 to 500 gal/min can be pumped from the well without drawing the water level near the bottom of the casing which is 170 feet below the ground surface, (approximately 90 feet below the water table). Extrapolation of the data indicates that rates of 600 gal/min will draw the water down to near the bottom of the casing.

Chemical analyses show the well water meets EPA primary drinking-water standards. The water was analyzed for chloride concentration in 1946, 1954, and 1982, and each time the chloride concentration was less than the previous time. Although a long-term trend of declining chloride concentration may exist, three observations in 36 years are insufficient to prove it. In any case, the well will deliver water probably with a chloride concentration of 220 mg/L or less.

Calculations using step-drawdown data produced values of aquifer hydraulic conductivity (K) of about 50 ft/d. This value is much lower than the values obtained from unweathered Hawaiian lavas (K = 1,000-2,000 ft/d) indicating that the permeability of this lava has been reduced by chemical weathering as a result of its location in a stream valley.

The results of this study indicate that Waikele well 2401-01 can serve as a reliable standby source for the Naval Magazine Lualualei, Waikele Branch water system.

9.0 POTENTIAL FOR OBTAINING ADDITIONAL HYDROLOGIC INFORMATION

To obtain the flow rate that this well is capable of yielding, the pump intake should be set near the bottom of the casing (170 feet below the ground surface). The pump intake should be located within the casing where it will be protected from the sides of the open hole. If the well is used infrequently, the initial water pumped from the well should be wasted in order to assure that any local contaminants are flushed from the system.

After the well is put into production, water-level and water-quality data should be obtained periodically.

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