EXPLORATORY DRILLING AND AQUIFER TESTING AT THE KIPAHULU DISTRICT HALEAKALA NATIONAL PARK, MAUI, HAWAII

By William R. Souza

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations

Report 83-4066

Prepared in cooperation with the

NATIONAL PARK SERVICE

U.S. DEPARTMENT OF THE INTERIOR

Honolulu, Hawaii

1983

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONVERSION TABLE

Inch-pound units have been used throughout this report. The following table converts measurements in the inch-pound system to the International System of Units (SI).

Multiply	By		To obtain units
Length			
foot (ft)	0.3048	----	meter (m)
mile (mi)	1.6093	----	kilometer (km)
Area			
square mile (mi^2)	2.590	----	square kilometer (km^2)
Volume			
acre-foot (acre-ft)	1,233	----	cubic meter (m^3)
Volume Per Unit Time			
cubic foot per second (ft^3/s)	0.02832	----	cubic meter per second (m^3/s)
gallons per minute (gal/min)	0.06309	----	liter per second (L/s)
Specific Capacity			
gallons per minute per foot [(gal/min)/ft]	0.2070	----	liter per second per meter [(L/s)/m]
Specific Conductance			
micromho per centimeter at 25° Celsius (µmho/cm at 25°C)	1.000	----	microsiemens per centimeter at 25° Celsius (µS/cm at 25°C)

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ABSTRACT

An exploratory well, located at 388 feet above sea level in Kipahulu Valley on Maui, Hawaii, was completed and tested in October 1980. The 410-foot well penetrates a series of very dense basaltic lava flows of the Hana Group of Quaternary age. At an elevation of 10 feet above mean sea level, the well penetrated a water-bearing zone of permeable basaltic rock. Water from this zone had a head of about 76 feet above sea level.

In October of 1980, the well was pump tested for nine hours at various discharge rates up to 350 gallons per minute with a maximum drawdown of about 12 feet. Based on the test data, the well should produce water at a rate of 200 gallons per minute with a drawdown of less than three feet. The water level in the well was continuously monitored from October 1980 to mid-November 1981, during which period a maximum decline of 20 feet was recorded. Water-level fluctuations in the well can be correlated to the flow in nearby Palikea Stream. The long-term water level in the well should stabilize at about 75 feet above sea level.

Water quality was excellent. The concentration of dissolved-solids was 49 milligrams per liter and the concentration of chloride was 4.2 milligrams per liter.

INTRODUCTION

Background

Kipahulu Valley, located on the Island of Maui, is one of the largest valleys on the southeast coast of Haleakala, draining an area of 12.7 mi^2 (square miles). Two major streams, Palikea and Koukouai, rise in the valley, which extends into the caldera area of Haleakala Volcano to elevations above 8,000 feet.

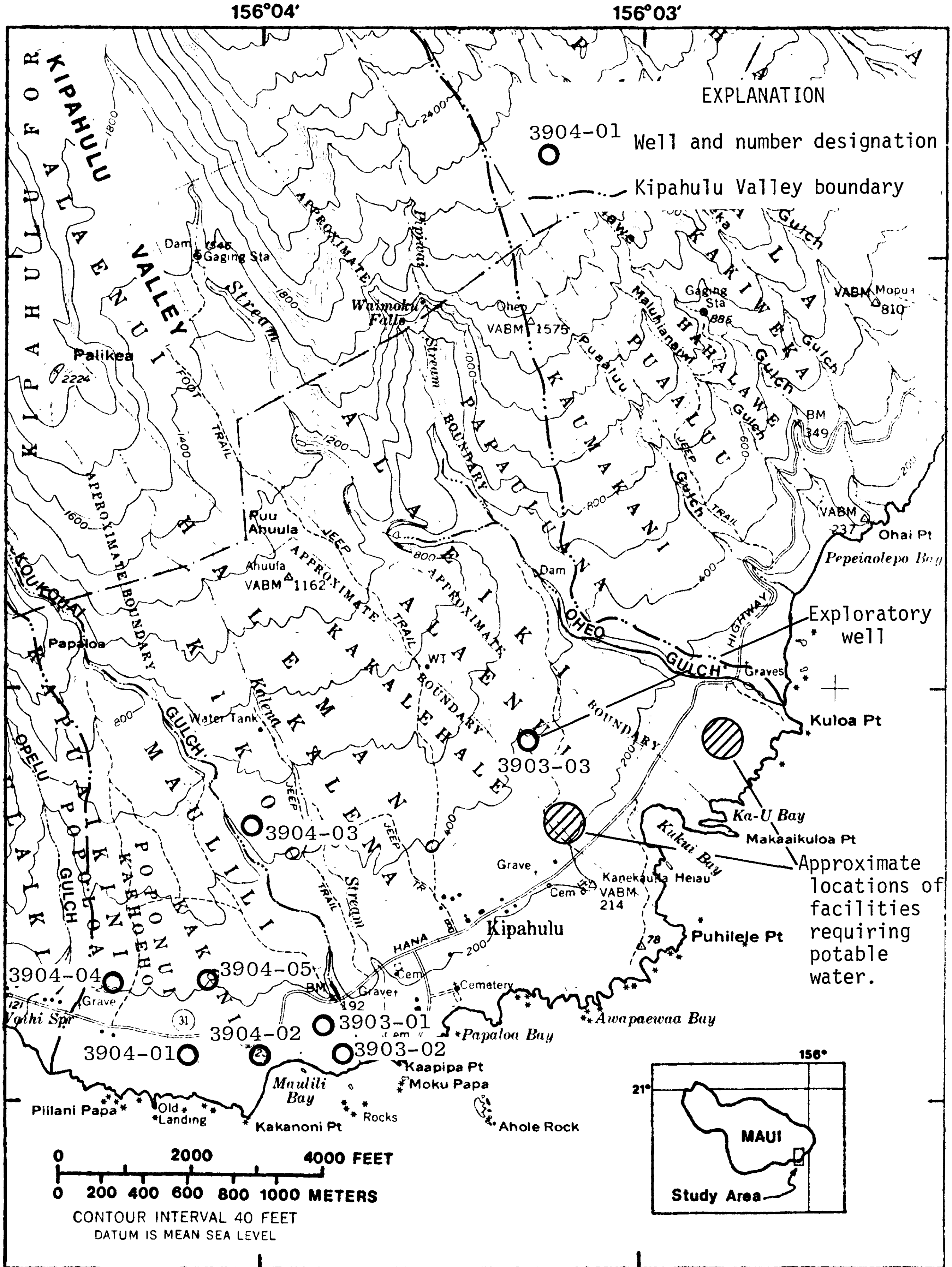
Fresh ground water occurs beneath the valley as a thin basal lens. Ground water also occurs as perched water in saturated zones above the basal water, emerging as springs and seeps along the streams and at the shoreline.

The National Park Service, in order to accommodate increased visitor demands, has formulated plans to install visitor facilities at the Kipahulu District of Haleakala National Park. In response to a request to locate a source for an anticipated need for 20,000 gal/d (gallons per day), the U.S. Geological Survey prepared a report on potential resources. The report recommended development of the basal-water lens underlying Kipahulu Valley (Soroos, 1979). At the time of the hydrologic reconnaissance of the area, there were four wells in Kipahulu Valley, all of which tapped the basal-water source in the valley (Soroos, 1979). A site for an exploratory well was chosen near the western boundary of Haleakala National Park, about 2,000 feet inland (fig. 1). This site was selected primarily to avoid the alluvium or weathered rock which might occur at shallow depths near the sides of the valley. In October 1980, an 8-inch diameter exploratory well was completed and pump tested (3903-03, fig. 1).

Purpose and Scope

The purpose of this report is to summarize the drilling, aquifer testing, and subsequent monitoring of the exploratory well. In addition, this report provides general knowledge concerning the hydrology of Kipahulu Valley.

The scope of work consisted of (1) monitoring the drilling and construction of the test well, (2) conducting and evaluating aquifer tests, (3) evaluating water quality, and (4) short-term monitoring of the water level in the well.



Base from U.S.Geological Survey, 1957, 1:24,000

Figure 1. Well locations in Kipahulu Valley.

SUMMARY OF DRILLING

The approximate land-surface elevation of the well site is 390 feet above mean sea level. A temporary reference elevation on the surface casing was established at 388 feet. All references to the well depth in this report are from this datum. The planned depth of the well was 30 to 40 feet below sea level. Drilling was done by the rotary method with a tricone bit. Drilling mud (bentonite) was used to maintain circulation in the well. An 8-inch diameter pilot hole was drilled to a depth of 410 feet (22 feet below sea level), and was later reamed to 10 inches. As expected, the drilling penetrated thin-layered basaltic flows of the valley-filling Hana Group. Cuttings from the upper 350 feet of the well contained both fine-grained basalts and basaltic andesites or possibly andesites typical of the early Hana Group as described in detail by Macdonald (Stearns and Macdonald, 1942). These flows, predominantly aa, are characterized by very dense cores surrounded by loose, clinkery, and highly permeable interflow surfaces. An exceptionally thick, dense flow was penetrated between 45-85 feet below land surface. This is the same massive flow that is exposed along the lower reaches of Palikea Stream below an elevation of 350 feet. Several of the highly permeable interflow zones caused temporary loss of drilling fluid circulation in the well. A permanent loss of circulation occurred at 350 feet and, during the drilling no cuttings were recovered below this depth. The lithology below 350 is inferred from the drillers log and bailed cuttings from the bottom of the hole. A simplified lithologic log is shown in figure 2.

Another massive 15-foot thick flow, which acts as a confining bed for an underlying artesian aquifer, was penetrated at a depth of 370 feet. Above this level, the drillers reported the well to be "dry" during drilling. Drilling through the dense flow penetrated an artesian aquifer with an initial head of 76 feet above sea level. The artesian conditions were not anticipated and similar conditions have not been reported for any other well in Kipahulu Valley. No cuttings were obtained below a depth of 350 feet during the drilling and the exact nature of the aquifer is not known. A more detailed discussion of the hydrology is contained in the section "Hydrology of Kipahulu Valley," pages 19-26.

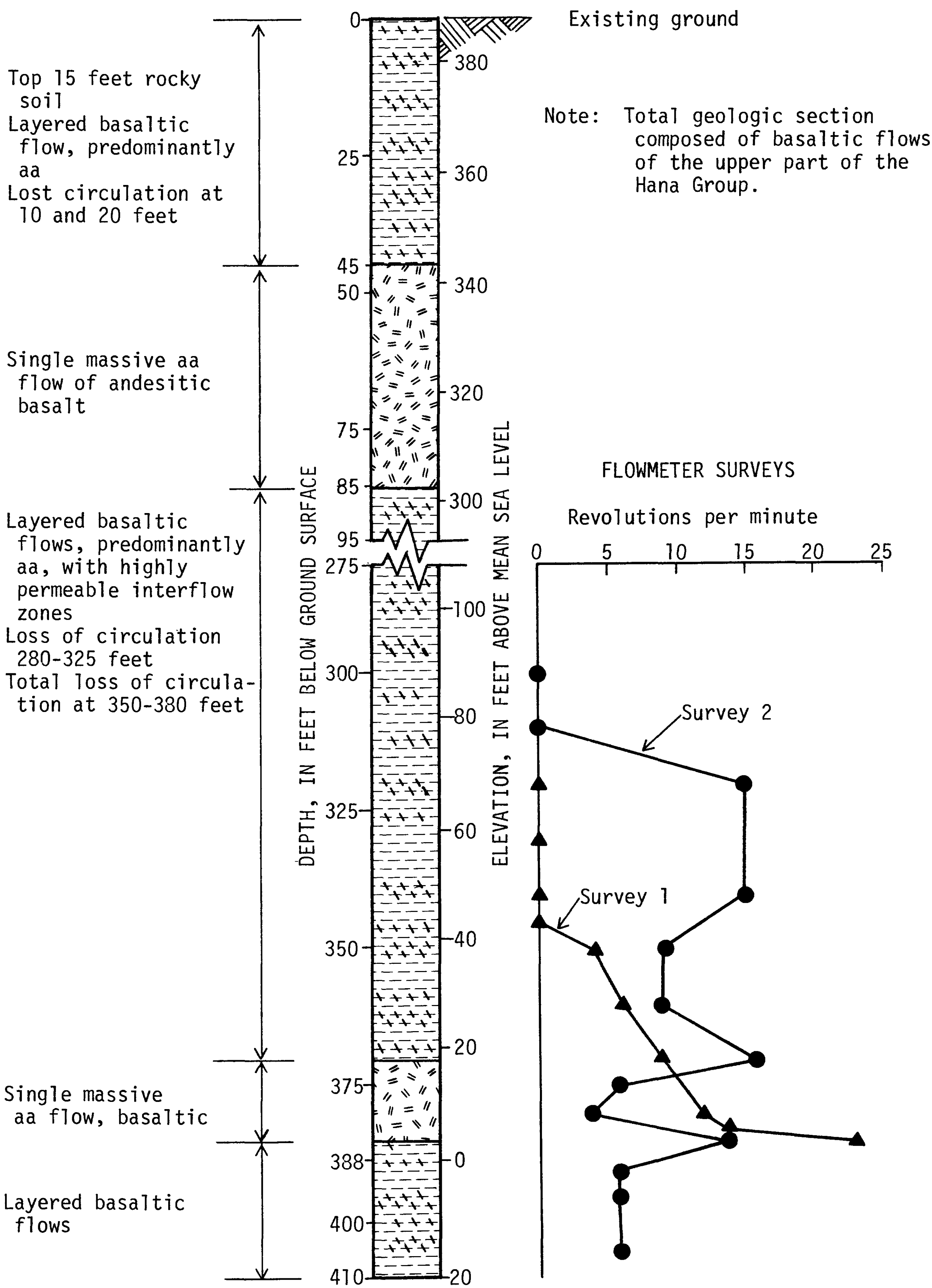


Figure 2. Lithologic log and flowmeter velocity curves.

Flowmeter Survey

After the artesian conditions were found, a flowmeter survey with an Au-type deep-well current meter was made to investigate the possibility of flow in the well. The current meter measures the velocity of flow of water at different depths in the well. No centering device was used on the meter and some variation in the measured velocities could result from the meter not being centered on the well bore. Figure 2 shows the velocity variation with depth for two separate flow-meter surveys.

The indication of survey No. 1 is that a substantial volume of water was flowing into the well at about sea level, moving up the well, and flowing into the overlying rock between 340 and 370 feet below land surface. At the time of survey No. 1, the bottom 40 feet of the well had not yet been reamed to 10 inches and the bottom 25 feet was also filled with cuttings. At the bottom of the hole the flow meter easily penetrated the cuttings, becoming clogged with a well-sorted fine sand. This, together with the erratic readings from the flowmeter, suggested that water was bubbling up from the bottom under pressure. Although 20 feet short of the planned depth, the drilling was terminated to prevent penetrating the bottom of the artesian aquifer.

Survey No. 2 was made after the bottom of the well had been reamed to 10 inches and cleaned to a total depth of 405 feet. Survey No. 2 shows an increase in the velocity and flow of water up the well, dissipating at a higher elevation in the overlying rock. The maximum velocity, beginning at 370 feet, indicates that all water enters the well below this depth, and it is probable that the water enters the well below the dense layer at 385 feet. The flow rate, based on a diameter of 10 inches at this depth, was calculated to be 55 gal/min (gallons per minute). The information from the flow-meter velocity curves and the driller's log and water levels, together confirm that the water-producing zone was at a probable depth of 385 to 410 feet and that the water was flowing up the well and into the permeable zones above 370 feet.

Well Completion

To finish the well, it was necessary to seal off the aquifer above 380 feet. The aquifer was sealed and grouted concurrently with the installation of the permanent casing. The bottom 35 feet of the well was backfilled with granular material, up to the approximate location of the confining bed at a depth of 375 feet. The permanent 8-inch casing was fitted with a temporary one-way valve at the bottom of the casing. The casing was lowered to about 5 feet above the backfill. Grout, consisting of neat cement, was forced through the one-way valve below the casing into the annular space around the bottom of the casing and the casing lowered 5 feet into place. After the grout set, the valve was drilled out and the well was cleaned to a total depth of about 410 feet. An additional flowmeter test showed no measurable flow below the casing. Figure 3 shows the construction details of the finished well.

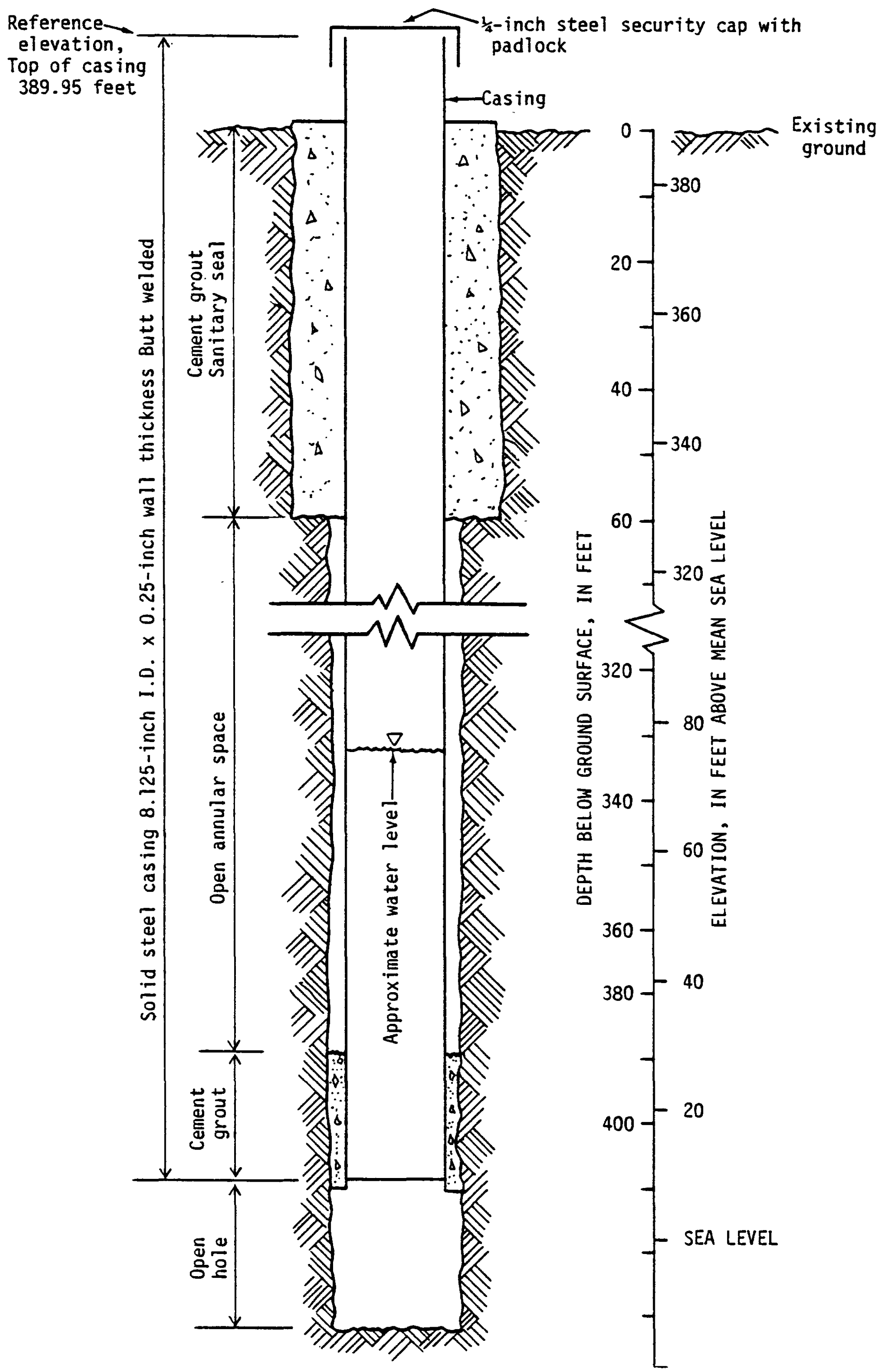


Figure 3. Construction details of the finished well.

AQUIFER TESTING

Aquifer tests were conducted in October 1980 by pumping the well at various rates for about nine hours. The well had been cased and sealed, and allowed to stabilize for two weeks before the test. The initial water level on the day of the testing was 78 feet above mean sea level. Water levels during the tests were measured by an airline and mercury manometer.

The analysis of step-drawdown tests allows the drawdown in a pumping well to be separated into components of (1) drawdown from turbulent losses in the well bore and (2) drawdown in the aquifer. The total drawdown in the well may be extrapolated to estimate actual drawdowns in the well at various pumping rates. The drawdown in the aquifer can then be used to estimate the aquifer properties.

Step-drawdown Test

A step-drawdown test was conducted by pumping the well at rates of 80, 180, 250, and 340 gal/min. Each rate was held for approximately an hour. Table 1 lists the step-drawdown data. The specific capacity of the well, listed on table 2, decreased with each increase in flow rate, indicating substantial head losses within the well bore. The data were analyzed using a least-squares approximation to fit the data to the following equation:

$$S = AQ + BQ^n$$

where:

S is the total drawdown,

Q is the discharge rate,

A, B, and n are regression constants,

AQ is the aquifer loss term, and

BQ is the well term.

Table 1. Aquifer test data, October 1980

Time	Pump rate (gal/min)	Draw-down (ft)	Tem-pera-ture (°C)	Spe-cific conduc-tance (µmho/cm)	Chlo-ride concen-tration (mg/L)	Remarks
9:05 a.m.	0	0	19.5	62	5.0	Pump 1 hour for well cleaning.
10:05	280	--	19.5	62	5.0	
10:30	24	--	--	--	--	Start step-drawdown test.
10:55	30	--	20.5	62	5.0	Drawdown too small to measure.
11:00	80	--	--	--	--	Increase rate.
11:29	80	--	20.0	61	5.0	Drawdown too small to measure.
11:30	180	--	--	--	--	Increase rate.
11:54	180	2.24	--	--	--	
11:57	260	--	20.0	60	5.0	Increase rate.
12:21 p.m.	250	5.01	20.0	60	5.0	
12:36	350	--	--	--	--	Increase rate--maximum for pump.
12:56	340	11.82	--	--	--	
1:45	340	11.82	--	--	--	Pump stopped. Water in fuel line.
2:30	0	0	--	--	--	Recovery instantaneous.
2:55	305	--	--	--	--	Additional rate for step-drawdown test.
3:25	305	8.73	--	--	--	
3:50	285	6.30	19.0	59	5.0	
4:10	275	5.75	19.0	59	5.0	
4:40	275	5.81	19.0	59	5.0	
5:10	335	--	--	--	--	Increase to maximum rate.
6:00	335	11.81	19.0	59	5.0	
6:10	335	11.75	--	--	--	
6:11	0	0	--	--	--	Recovery instantaneous.

Table 2. Results of step-drawdown analysis

Discharge rates (gal/min)	Well drawdown (ft)	Specific capacity [(gal/min/ft)]	Calculated well loss (ft)	Calculated aquifer loss (ft)
180	2.24	80.4	1.35	0.88
250	5.01	50.0	3.82	1.23
305	8.73	34.9	7.19	1.50
340	11.82	28.8	10.15	1.67
450	1/ 27.03	16.5	24.82	2.21
600	1/ 65.00	9.2	62.05	2.95

1/ Extrapolated value.

Aquifer Properties

In general, aquifer properties of hydraulic conductivity and storage coefficient are difficult to determine from single-well pumping tests. No observation well was available for this test. The data from the sustained test was insufficient to calculate the aquifer storage coefficient.

Soroos (1973) has shown that the estimated aquifer drawdown from the step-drawdown analysis can be used to calculate the hydraulic conductivity using the Theim equation. The limitation of the Theim equation is that it is derived for steady-state conditions in a fully penetrated homogeneous, isotropic, confined aquifer. However, this limitation is violated in this analysis, and the calculated values serve as indicators of aquifer performance.

From the Theim equation, the calculated hydraulic conductivity is 1,440 ft/d (feet per day), a typically high value for the permeable basalts in Hawaii. The aquifer will yield water readily to the well, and aquifer losses are very small. The well yields water at 250 gal/min [15,000 gal/hr (gallons per hour)] with a drawdown of less than four feet. Recovery from pumping during all phases of the test was nearly instantaneous, and no residual drawdown could be measured after nine hours of intermittent pumping. The aquifer is contained within the eastern half of Kipahulu Valley and, thus, is limited in areal extent and total available storage is small. Based on the test results, the capacity of the well exceeds the 20,000 gal/d requirement of the Kipahulu District.

WATER QUALITY

The chemical composition of a sample of water taken from the well during the pump testing is listed in table 3. The sample was collected after 100,000 gallons of water had been pumped from the well. The quality of the water is excellent. The concentration of dissolved-solids was 49 mg/L (milligrams per liter) and the concentration of chloride was 4.2 mg/L. The temperature of the water at the time of collection was 18.5°C. This ground-water sample had one of the lowest dissolved solids concentration collected from any Hawaiian ground-water source.

Periodic sampling during the aquifer testing showed no change in the low-chloride content of the water. The chemical data do not support any hydraulic connection of the aquifer with the ocean and based on current chemical data no potential problem with saltwater contamination is expected. The low temperature and pristine nature of the water suggests that the aquifer is recharged by rainfall at high elevations near the head of Kipahulu Valley.

HYDROLOGY OF KIPAHULU VALLEY

The quantitative hydrology of Kipahulu Valley, even on a regional scale, is not well understood. Ground water underlying the valley is probably recharged in the wetter, upper reaches of the valley, and commonly occurs as basal water; that is, as a freshwater lens floating on seawater. Presently, there are eight wells in Kipahulu Valley including the exploratory well as shown in figure 1. All wells, except the exploratory well, penetrate the low-head, basal, freshwater lens. In well 3904-03 located 3,500 feet from the shore, the measured water level was 2.4 feet above sea level. By contrast, the exploratory well (National Park Service well 3903-03), the only well located in the eastern half of the valley, has an artesian head of about 75 feet. This well was the first indication of artesian conditions occurring in Kipahulu Valley.

An indication of differing hydrologic conditions was noted by Soroos (1979) from observations of Palikea Stream and Koukouai Gulch. Streamflow measurements during the reconnaissance study showed that Palikea Stream, on the east side of the valley, had an increase in flow of about 50 percent below an elevation of 480 feet. However, Koukouai Gulch, on the west side of the valley, showed a negligible increase in flow through a similar reach.

Table 3. Water quality data

Constituent	Unit	Concentration
Specific conductance ----------	µmho/cm at 25°C	59
pH --------------------------------	--	8.3
Temperature -----------------------	°C	18.5
Hardness, as $CaCO_3$ ------------------	mg/L	11
Hardness, noncarbonate as $CaCO_3$------	mg/L	0
Calcium, dissolved (Ca) ------------	mg/L	2.7
Magnesium, dissolved (Mg) -----------	mg/L	1.1
Sodium, dissolved (Na) --------------	mg/L	6.7
Sodium, percent -------------------	percent	51
Sodium adsorption ratio (SAR) -------	--	0.9
Potassium, dissolved (K) ------------	mg/L	2.0
Alkalinity, total as $CaCO_3$ ----------	mg/L	25
Sulfate, dissolved (SO_4) ------------	mg/L	0.5
Chloride, dissolved (Cl) ------------	mg/L	4.2
Fluoride, dissolved (F) -------------	mg/L	0.1
Silica, dissolved (SiO_2) ------------	mg/L	16
Dissolved solids, sum of constituents	mg/L	49
Nitrogen (NO_2 + NO_3), dissolved as N	mg/L	0.13
Arsenic, total (As) ----------------	µg/L	0
Barium, total (Ba) -----------------	µg/L	0
Cadmium, total (Cd) ----------------	µg/L	0
Chromium, total (Cr) ---------------	µg/L	20
Copper, total (Cu) -----------------	µg/L	48
Iron, total (Fe) -------------------	µg/L	260
Iron, dissolved (Fe) ---------------	µg/L	< 10
Lead, total (Pb) -------------------	µg/L	23
Manganese, total (Mn) --------------	µg/L	10
Manganese, dissolved (Mn) -----------	µg/L	< 1
Mercury, total (Hg) ----------------	µg/L	0.2
Selenium, total (Se) ---------------	µg/L	0
Silver, total (Ag) -----------------	µg/L	0
Zinc, total (Zn) -------------------	µg/L	30
Cyanide, total (CN) ----------------	mg/L	0.00

Water-level Fluctuations

Water entering the aquifer is confined beneath a dense impermeable layer of basalt penetrated by the test well. The water level in the well rises to balance the pressure in the aquifer. Water-level fluctuations in the well reflect pressure changes in the aquifer, which can be shown to correlate with rainfall-runoff patterns as reflected in the streamflow in Kipahulu Valley. Figure 4, a comparison of water levels in the test well and concurrent discharge from Palikea Stream, shows this correlation and indicates the area above the stream-gage location as a recharge area. The hydrograph and water-level measurements from the well are for the period from October 1980 to June 1982. Approximately one year of continuous water-level record was obtained. The well was not being pumped and no other well is known to tap the same aquifer. In general, the well hydrograph represents a cyclic decline and recovery through a very dry period. For the period, October 1980 to July 1981, the streamflow in Palikea Stream was 73 percent below the long-term mean, and the December 1980 flow, normally the wettest month, was the driest December on record. By July 1981, the water level declined 21 feet. However, by June 1982, the well had completely recovered to the October 1980 level. This low rainfall period is clearly reflected in the well hydrograph. Each peak in the well hydrograph is preceded by a corresponding peak in the stream hydrograph, with a lag time between the stream and well peaks of about 4 days. These short-term fluctuations of 5 to 10 feet in the water level may be normal for this well.

The steep decline, from late October 1980 to late January 1981 followed by a series of recession-type curves, suggests that a lower limit exists for extreme seasonal fluctuations. An extrapolation of the hydrograph beyond July 20 indicates that the water level would have declined and stabilized at about 55 feet above sea level.

Based on the recovery of the water level during the early part of 1982, the long-term level in the well should average about 75-80 feet above sea level. Seasonal fluctuations of 10 to 20 feet may be normal.

The prominent short-term fluctuations in the well and close correlation with Palikea Stream indicate that the water level in the well is controlled by rapid recharge from the watershed above Palikea Stream. Additionally, an upper threshold to the water level may exist above which excess recharge is lost to discharge into streams and springs in the valley.

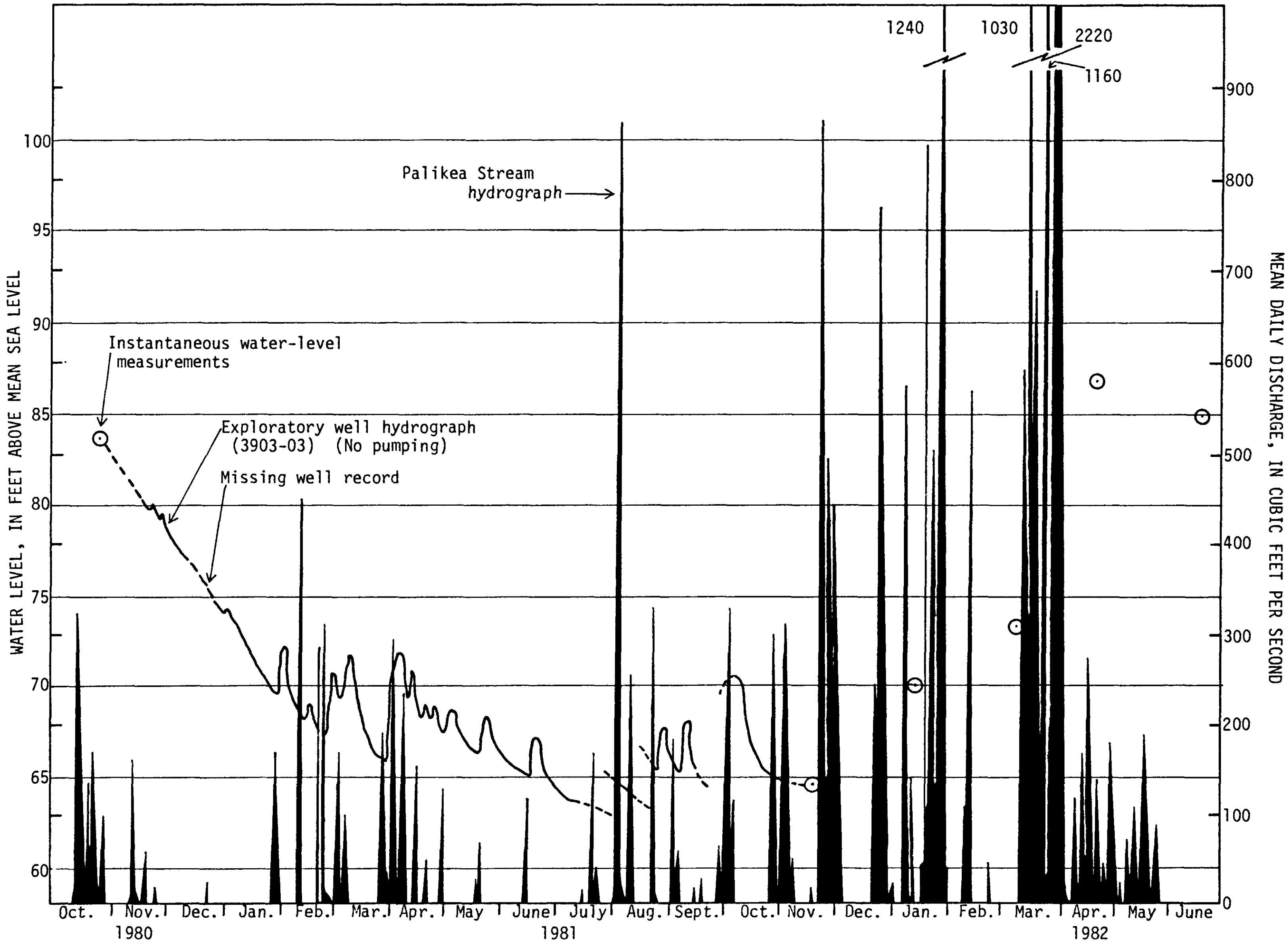


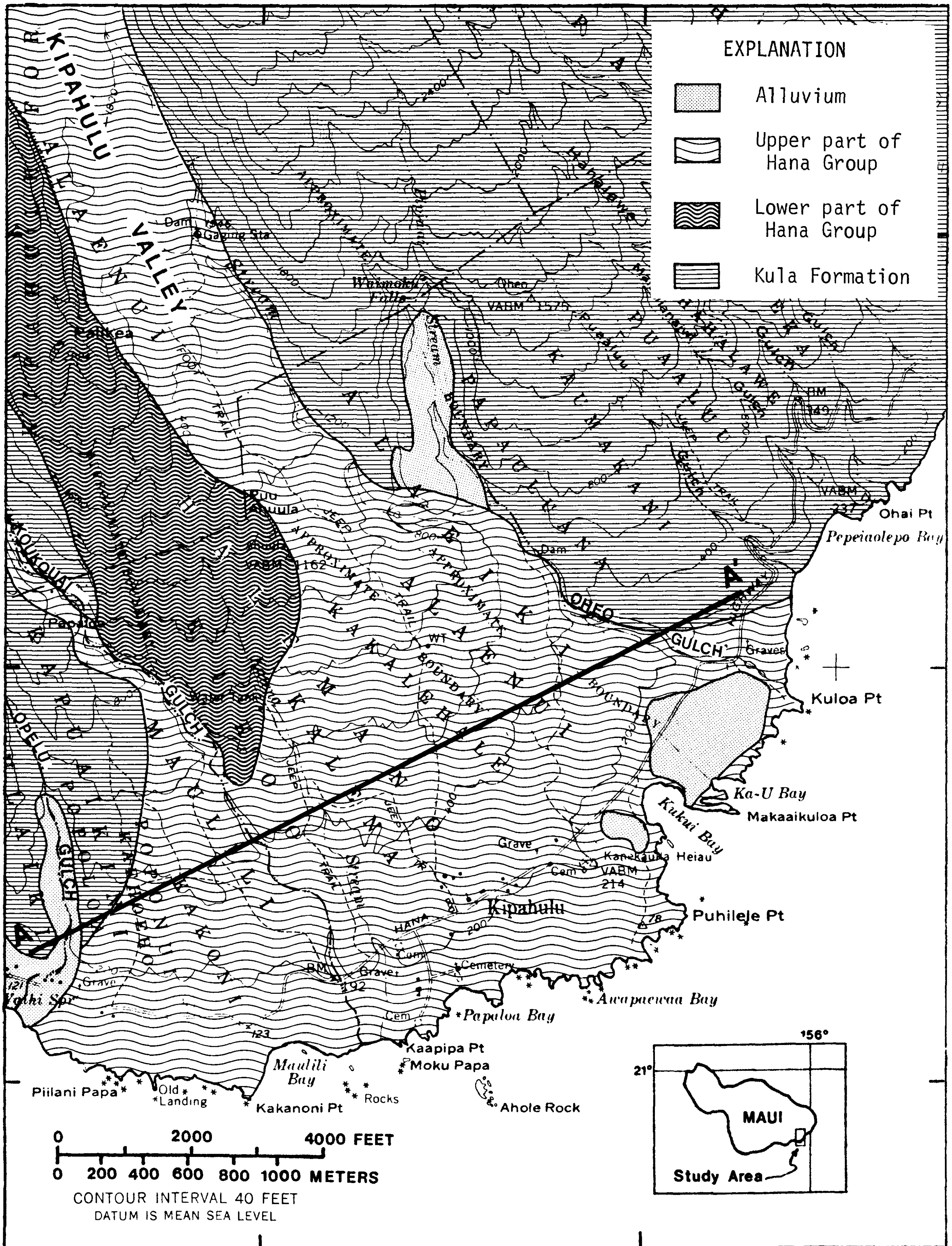
Figure 4. Hydrographs of Palikea Stream and exploratory wells.

Hydrogeology

The surficial geology of Kipahulu Valley is shown in figure 5. The valley, now flat-bottomed and filled with recent lava flows, was originally a deep wide canyon cut into the southeast flank of Haleakala. Recent lava flows of the Hana Group flooded the original canyon during at least two separate eruptive episodes, forming the existing flat-bottomed floor and delta-shaped apron at the shore. The Hana Group, much of it below sea level, forms the aquifers in Kipahulu Valley. The Hana flows were separated by intervals sufficiently long to allow erosion and weathering of the flow surfaces before they were buried by subsequent flows.

It is estimated by Stearns (1942) that the Hana lavas filling the ancestral Kipahulu Valley are more than 1,500 feet thick. Subsequent downcutting of the early Hana lavas formed a large canyon on the east side of the valley. Several episodes of renewed volcanic activity refilled the canyon and spread out covering the mouth of the valley. Many individual flows have been identified by Stearns (1942); however, they generally are grouped into the upper part of the Hana Group. Figure 6 is a generalized and interpretive geologic cross-section of lower Kipahulu Valley. The early Hana lavas shown are exposed in the upper valley (fig. 5); however, the buried features in figure 6 are, for the most part, conjectural.

Additional buried valleys and other structures certainly exist. Stream-rounded gravels found in bailed cuttings after the completion of drilling indicate that at least one buried valley was encountered below 350 feet in the well. In figure 6, the confining structure, shown to be a thick, dense, extensive aa flow, is the most probable explanation based on the drilling log. The bottom of the aquifer may be another dense flow or possibly the surface of a smaller buried valley. The well did not completely penetrate the aquifer; therefore, the thickness, as well as the lateral extent of the aquifer, is unknown. The geology depicted in figure 6 suggests an explanation for the different conditions in two apparently similar wells.



Base from U.S.Geological Survey, 1957, 1:24,000

Figure 5. Generalized geologic map of Kipahulu Valley (modified from Stearns and Macdonald, 1942).

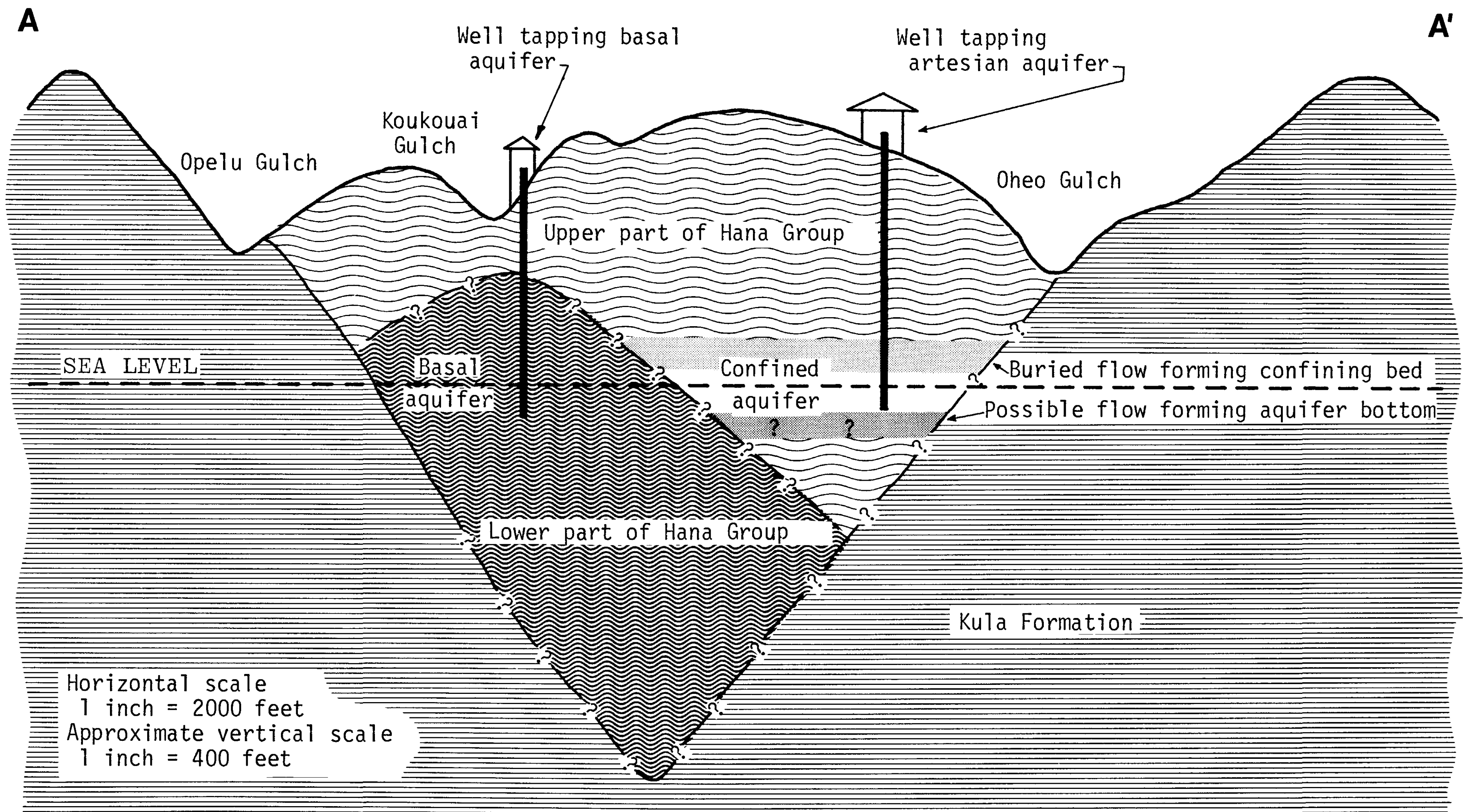


Figure 6. Generalized and interpretive geologic cross section of lower Kipahulu Valley.

SUMMARY

The exploratory drilling in Kipahulu Valley resulted in the discovery of a previously unknown, high-yield, artesian aquifer. Artesian aquifers, such as the one described in this report, are rare in Hawaii. The aquifer, a result of unique hydrologic conditions, is not areally extensive but should produce sufficient quantities of potable water to meet any future needs of Kipahulu Park.

The aquifer may not be subject to saltwater contamination. Recharge to the aquifer occurs at high elevations within Haleakala National Park where sources of contamination are not anticipated, and as a result the water has a very low concentration of dissolved solids.

The well yields water at 250 gal/min with a drawdown of less than four feet. The static water level in the well has a normal seasonal fluctuation of 10-15 feet, depending on the rainfall in Haleakala Crater. The long-term water level should stabilize at about 75 feet above sea level. During heavy pumping or future droughts, the water level should remain at least 50 feet above sea level.

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