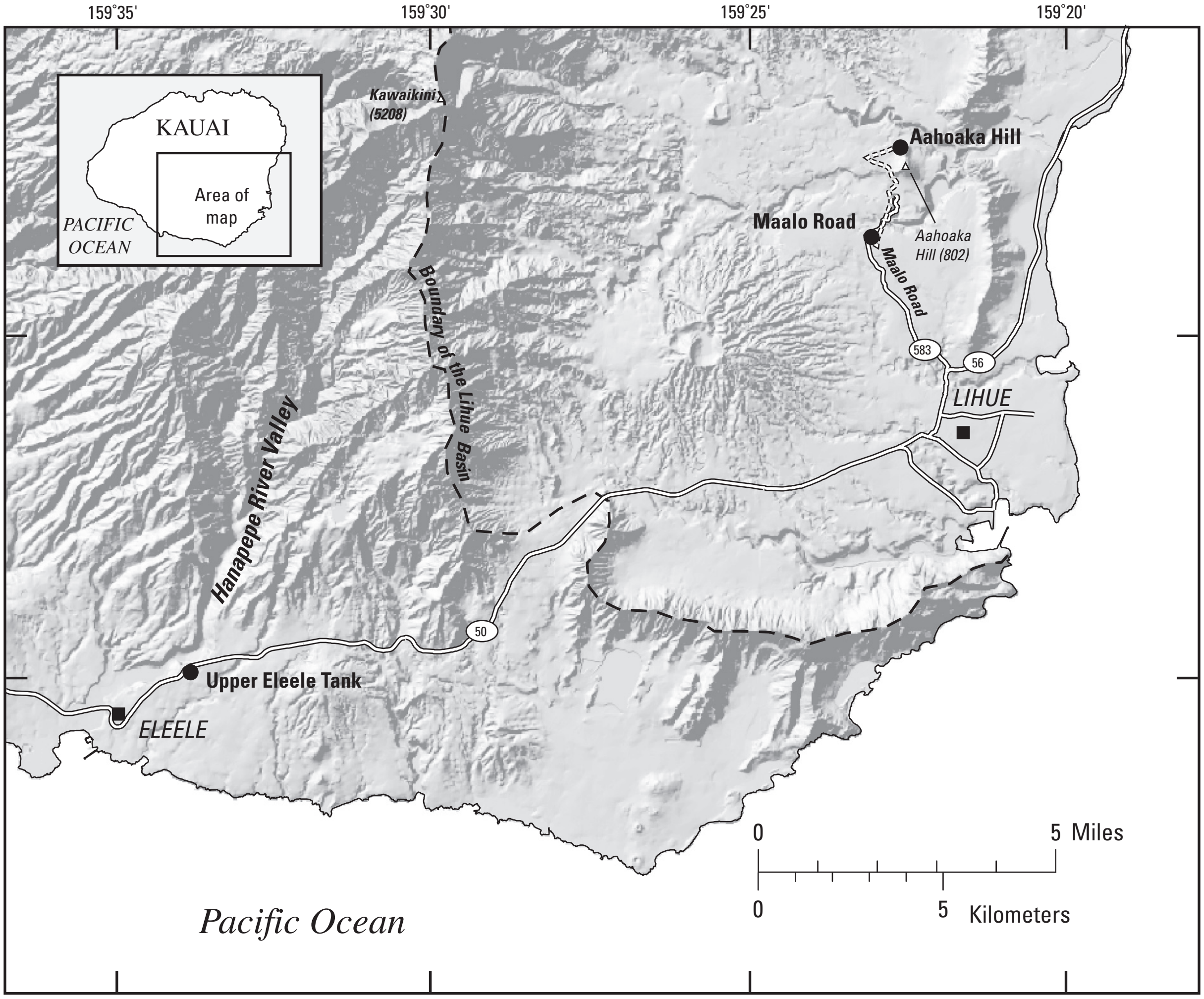
Prepared in cooperation with the Kauai County Department of Water

Construction, Geology, and Aquifer Testing of the Maalo Road, Aahoaka Hill, and Upper Eleele Tank Monitor Wells, Kauai, Hawaii



Open-File Report 2005-1159

U.S. Department of the Interior
U.S. Geological Survey

Construction, Geology, and Aquifer Testing of the Maalo Road, Aahoaka Hill, and Upper Eleele Tank Monitor Wells, Kauai, Hawaii

By Scot K. Izuka

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U.S. Geological Survey

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
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Suggested citation:
Izuka, S.K., 2005, Construction, geology, and aquifer testing of the Maalo Road, Aahoaka Hill, and Upper Eleele Tank monitor wells, Kauai, Hawaii: U.S. Geological Survey Open-File Report 2005-1159, 21 p.

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Conversion Factors and Datum

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to mean sea level. Elevation, as used in this report, refers to the distance above the vertical datum.

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C)

Clock time is expressed in the 24-hour (24-h) format in Hawaii Standard Time (HST). For example, “14:15” corresponds to 2:15 PM HST..

Construction, Geology, and Aquifer Testing of the Maalo Road, Aahoaka Hill, and Upper Eleele Tank Monitor Wells, Kauai, Hawaii

By Scot K. Izuka

Abstract

The Maalo Road, Aahoaka Hill, and Upper Eleele Tank monitor wells were constructed using rotary drilling methods between July 1998 and August 2002 as part of a program of exploratory drilling, aquifer testing, and hydrologic analysis on Kauai. Aquifer tests were conducted in the uncased boreholes of the wells.

The Maalo Road monitor well in the Lihue Basin penetrated 915 feet, mostly through mafic lava flows. Most of the rock samples from this well had chemical compositions similar to the Koloa Volcanics, but the deepest sample analyzed had a composition similar to the Waimea Canyon Basalt. Water temperature ranged from 25.6 to 27.4 degrees Celsius and specific conductance ranged from 303 to 627 microsiemens per centimeter during aquifer testing. Discharge rate ranged from 174 to 220 gallons per minute and maximum drawdown was 138.25 ft during a 7-day sustained-discharge test, but the test was affected by pump and generator problems.

The Aahoaka Hill monitor well in the Lihue Basin penetrated 804 feet, mostly through mafic lava flows and possibly dikes. The well penetrated rocks having chemical compositions similar to the Waimea Canyon Basalt. During the first three hours of a sustained-discharge aquifer test in which the discharge rate varied between 92 and 117 gallons per minute, water temperature was 24.6 to 25.6 degrees Celsius, and specific conductance was 212 to 238 microsiemens per centimeter; this test was halted after a short period because drawdown was high. In a subsequent 7-day test, discharge was 8 to 23 gallons per minute, and maximum drawdown was 37.71 feet after 1,515 minutes of testing.

The Upper Eleele Tank monitor well is near the Hanapepe River Valley. The well penetrated 740 feet through soil, sediment, mafic lava flows, volcanic ash, and scoria. Rocks above a depth of 345 feet had compositions similar to the Koloa Volcanics, but a sample from 720 to 725 feet had a composition similar to rocks of the Waimea Canyon Basalt. During a 7-day aquifer test with a sustained discharge between 278 and 290 gallons per minute, most of the drawdown of 1.10 feet occurred in the first 455 minutes of the test. Water levels measured thereafter may have been influenced by pumping from a nearby well. Water temperature ranged from 20.2 to 21.4 degrees Celsius and specific conductance from 8,380 to 18,940 microsiemens per centimeter during the aquifer tests.

Introduction

Beginning in the 1990s the U. S. Geological Survey (USGS) and the County of Kauai Department of Water (Kauai DOW) undertook a comprehensive, multi-phase study of ground water in eastern Kauai, Hawaii (fig. 1). As part of that study, six monitor wells were constructed and tested between April 1995 and April 1996 at sites in the Lihue Basin. These wells are described by Izuka and Gingerich (1997a, 1997b, 1997c, and 1997d) and Gingerich and Izuka (1997a and 1997b), and the hydrogeologic implications of the data from the wells are described in Izuka and Gingerich (1998, 2003), Reiners and others (1998), and Izuka and Oki (2002). The monitor-well construction continued in the period between July 1998 and August 2002, with the construction and testing of the Maalo Road, Aahoaka Hill, and Upper Eleele Tank monitor wells (fig. 1). This report documents the construction and testing of these wells, including (1) the drilling history, well-construction details, and summary of the driller's notes, (2) lithologic descriptions of the rock chips (cuttings) recovered during drilling, (3) geochemical composition of selected samples of the cuttings, and (4) data from step-drawdown and sustained-discharge aquifer tests.

Acknowledgements – The construction, data collection, and testing of the wells was made possible with the cooperation and assistance of the Kauai DOW. The wells were drilled on public and private land, with permission from the State of Hawaii Department of Land and Natural Resources, Amfac Sugar - Lihue Plantation (currently the Lihue Land Company), and the Kauai DOW. Drilling and well-construction information were drawn extensively from the notes of Kimo Akina of the USGS. Gregory A. Berman, Luis E. Menoyo, Jeff A. Perreault, and Todd K. Presley assisted in the preparation of this report.

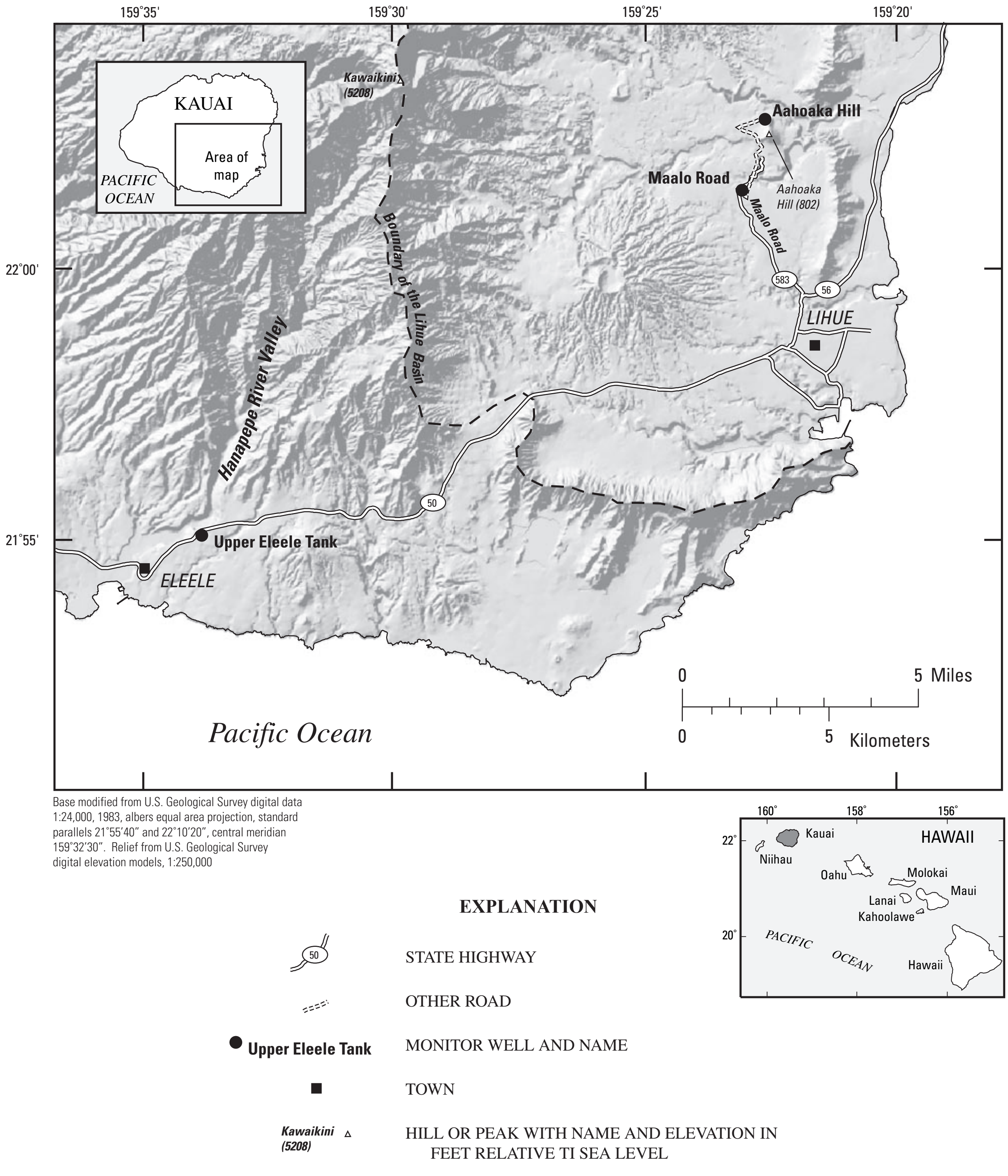

Figure 1. Location of the Maalo Road, Aahoaka Hill, and Upper Eleele Tank monitor wells, Kauai, Hawaii.

Setting

Kauai is the fourth-largest island (553 mi^2) in the tropical North Pacific Hawaiian Archipelago (fig. 1). The island is formed by one or more shield volcanoes that built up from the Pacific Ocean floor by mid-plate, hot-spot volcanism. Kauai has a roughly circular outline and the broad-domed profile characteristic of shield-volcano islands, but erosion and faulting have formed large valleys, canyons, and other depressions, including the Lihue Basin. Kauai reaches an elevation of 5,243 ft near the center of the island, and the ground surface generally slopes away from this point and terminates at the coast in cliffs, rocky coasts, coastal plains, bays and beaches. The stream-drainage pattern on Kauai is primarily radial; however, geologic structure has influenced the drainage patterns in some areas such as the Lihue Basin.

Rainfall distribution on Kauai is influenced by the orographic effect. Rainfall is heaviest where the prevailing northeasterly trade winds encounter the windward flanks of Kauai’s central mountains, forcing warm, moist air into the cool, higher elevations. Average annual rainfall ranges from about 25 in/yr at leeward coastal areas to more than 400 in/yr near the crest of Kauai’s central mountains (Giambelluca and others, 1986).

Hydrogeology – The rocks of Kauai are divided into two principal geologic formations that are separated by an erosional unconformity (Macdonald and others, 1960; Langenheim and Clague, 1987). The Pliocene-age Waimea Canyon Basalt is the older of the two formations and constitutes the basement on which younger sediments and volcanic rocks lie (fig. 2). The rocks of the Waimea Canyon Basalt are primarily tholeiitic basalts, with rare hawaiites and mugearites, formed during the island's shield-building stage (Macdonald and others, 1960; Clague and Dalrymple, 1988; Reiners and others, 1998). The Koloa Volcanics is a younger formation that partially fills large valleys, canyons, and other depressions formed by erosion and faulting of the shield volcano. The Koloa Volcanics includes variably weathered, thick, massive lava flows and pyroclastic deposits of highly alkalic mafic composition, erupted from scattered rejuvenated volcanism, intercalated with terrigenous and marine sediment (Macdonald and others, 1960; Clague and Dalrymple, 1988; Holcomb and others, 1997; Reiners and others, 1998).

The Waimea Canyon Basalt is the predominant formation at the surface in western Kauai, but in eastern Kauai, the Waimea Canyon Basalt is mostly buried beneath the Koloa Volcanics (fig. 2). In some areas such as the Lihue Basin, the Waimea Canyon Basalt is buried under several hundred to more than 1,000 ft of Koloa Volcanics, and crops out only in hills and ridges. In some outcrops, the lava flows of the Waimea Canyon Basalt are intruded by numerous dense, near-vertical, sheet-like, volcanic dikes, which cut vertically across the thin lavas (Macdonald and others, 1960).

The thin lava flows of the Waimea Canyon Basalt are among the most permeable rocks on Kauai. Wells in the Waimea Canyon Basalt in southern and western Kauai have relatively high specific capacities. Ground water in this region appears to be analogous to ground water in other areas of the Hawaiian archipelago where an extensive fresh ground-water lens overlies saltwater in the aquifer. In these so-called "basal" ground-water systems (Meinzer, 1930), the water table is generally no more than a few tens of feet above sea level and slopes gently from the center of the island toward the coast. The water table is mostly far below the ground surface except at the coast where most of the freshwater flowing through the lens discharges.

In contrast, the regional permeability of the Koloa Volcanics is low (Macdonald and others, 1960; Izuka and Gingerich, 1998; Gingerich, 1999). Where this formation predominates and the climate is moist, such as in the Lihue Basin, the low-permeability aquifer becomes saturated nearly to the surface with ground water. Most ground water flowing through the basin discharges to streams rather than at the coast. Hydraulic gradients and the slope of the water table are steep near discharge points such as streams and wells (Izuka and Gingerich, 1998, 2003).

Intrusion of volcanic dikes can reduce the bulk permeability of lava-flow aquifers on shield volcanoes (Takasaki and Mink, 1985). Dikes are exposed in some outcrops of the Waimea Canyon Basalt and are likely to exist in parts of the Waimea Canyon Basalt that are buried beneath Koloa Volcanics (Macdonald and others 1960; Izuka and Gingerich, 1998).

Location of the Monitor Wells

A summary of locality information and construction history for the Maalo Road, Aahoaka Hill, and Upper Eleele Tank monitor wells is given in table 1. The Maalo Road monitor well is on the eastern side of Maalo Road (State Highway 583), about 2.7 mi north along the road from its intersection with State Highway 56 (fig. 1). The Aahoaka Hill monitor well is at the western base of Aahoaka Hill, near the eastern coast of Kauai. The land near both of these wells was used for sugarcane cultivation through most of the 20th century. Miles of irrigation ditches and reservoirs modified the natural drainage pattern to bring water to sugarcane fields. The areas near the wells were used for sugarcane agriculture until the end of 2000, when the last of the sugarcane plantations in the Lihue Basin closed. Some of the former sugarcane fields in the Lihue Basin have been converted to other agricultural uses, but much of the land is presently unused.

The Upper Eleele Tank monitor well is on the south side of State Highway 50, about 1.5 mi east along the highway from the town of Eleele (fig. 1). The well is within the fenced compound of the concrete Upper Eleele water tank, which stores drinking water for the Kauai DOW. Sugarcane was grown on land near the water tank until the 1990s when that crop was replaced by coffee. Irrigation water diverted or

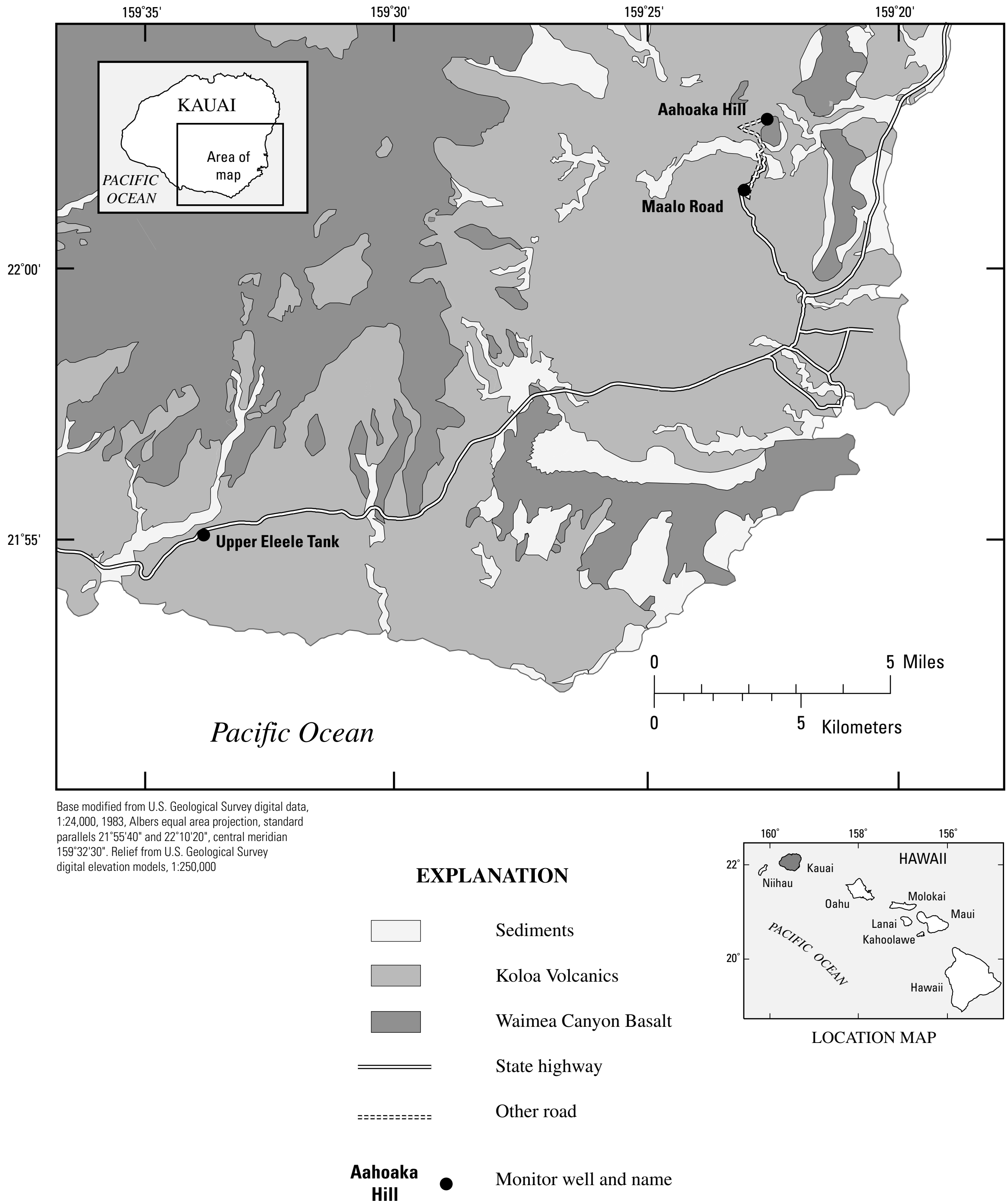

Figure 2. Geologic map showing location of the Maalo Road, Aahoaka Hill, and Upper Eleele Tank monitor wells, Kauai, Hawaii (modified from Macdonald and others, 1960).

Table 1. Summary of locality information and well-construction history for Maalo Road, Aahoaka Hill, and Upper Eleele Tank monitor wells, Kauai, Hawaii

	Maalo Road	Aahoaka Hill	Upper Eleele Tank
State well number	2-0123-01	2-0222-01	2-5534-06
Coordinates[1]	22°01'26" N, 159°23'12" W	22°02'50" N, 159°22'37" W	21°55'07" N, 159°33'56" W
Ground elevation[2]	382.57 feet	312.83 feet	385.48 feet
Start date, borehole drilling	7/21/98	9/23/98	11/3/98
End date, borehole drilling	8/27/98	10/20/98	12/16/98
Borehole depth[3]	915 feet	804 feet	740 feet
Dates of aquifer testing	9/1/1998 to 9/15/1998	11/17/98 to 11/20/98 1/1/99 to 1/28/99	1/13/99 to 2/9/99
Well-completion date	8/6/02	8/6/02	8/1/02

[1] Using North American Datum of 1983 (NAD83)

[2] Elevation, relative to mean sea level, of brass plate on concrete pad of well

[3] Below ground surface

pumped from streams and rivers in the region is carried in ditches and stored in reservoirs. A short distance to the north of the well site, the land surface drops steeply about 350 ft into the Hanapepe River Valley. On the valley floor, a mix of ground water and surface water is withdrawn from wells and galleries and pumped up the southern valley wall to ditches that irrigate the coffee fields surrounding the tank site. The nearest of these pumping facilities is at a horizontal distance of only 1,000 ft from the well site.

Well Construction

Borings for the Maalo Road, Aahoaka Hill, and Upper Eleele Tank monitor wells were drilled by the rotary method using a tungsten-carbide tricone bit. A mixture of air, water, and foam was injected down through the hollow drill stem and circulated back up the space between the stem and the borehole to remove cuttings as drilling progressed. Construction began with drilling through the upper unconsolidated soil and weathered rock with a 17.5-in. bit. When a firm rock stratum was reached, a 12-in.(inside diameter) steel surface casing was placed in the borehole and the space between the casing and the borehole was filled with cement grout. When the cement grout was set, a smaller bit (7.875 to 10.625 in. diameter) was inserted inside the 12-in. casing to drill the remainder of the borehole. Throughout the drilling, samples of the cuttings were collected at 5-ft intervals and stored in labeled plastic sample bags.

A submersible pump was installed in each well for the purposes of conducting aquifer tests. After completion of the aquifer tests, an inner casing consisting of alternating sections of perforated and solid 4.5-in. PVC was installed, and the upper 20 to 25 ft of the space between the inner and outer casing was grouted with cement to hold the inner casing in place. A concrete pad with a brass elevation marker was built around the well. The elevation of the brass plate and top of the steel outer casing was measured by standard surveying methods. Aspects of the completed monitor wells are illustrated in figures 3 (Maalo Road), 4 (Aahoaka Hill) and 5 (Upper Eleele Tank). A detailed account of the well construction, excerpted primarily from the notes of the well driller, is given in Appendixes 1, 2, and 3.

Borehole Geology

The rock types penetrated during construction of the Maalo Road, Aahoaka Hill, and Upper Eleele Tank monitor wells are illustrated in figure 6 and described in detail in Appendixes 4, 5, and 6. Macroscopic examination of cuttings is useful for describing the general borehole geology and distinguishing sedimentary layers from lava flows, but distinguishing between the Koloa Volcanics and the Waimea Canyon Basalt is difficult by visual examination of drill cuttings alone. Characteristics that help distinguish the two formations in outcrop and that have hydrologic significance, such as lava-flow thickness and unconformities, are lost when the rocks are pulverized by rotary drilling. However, the two

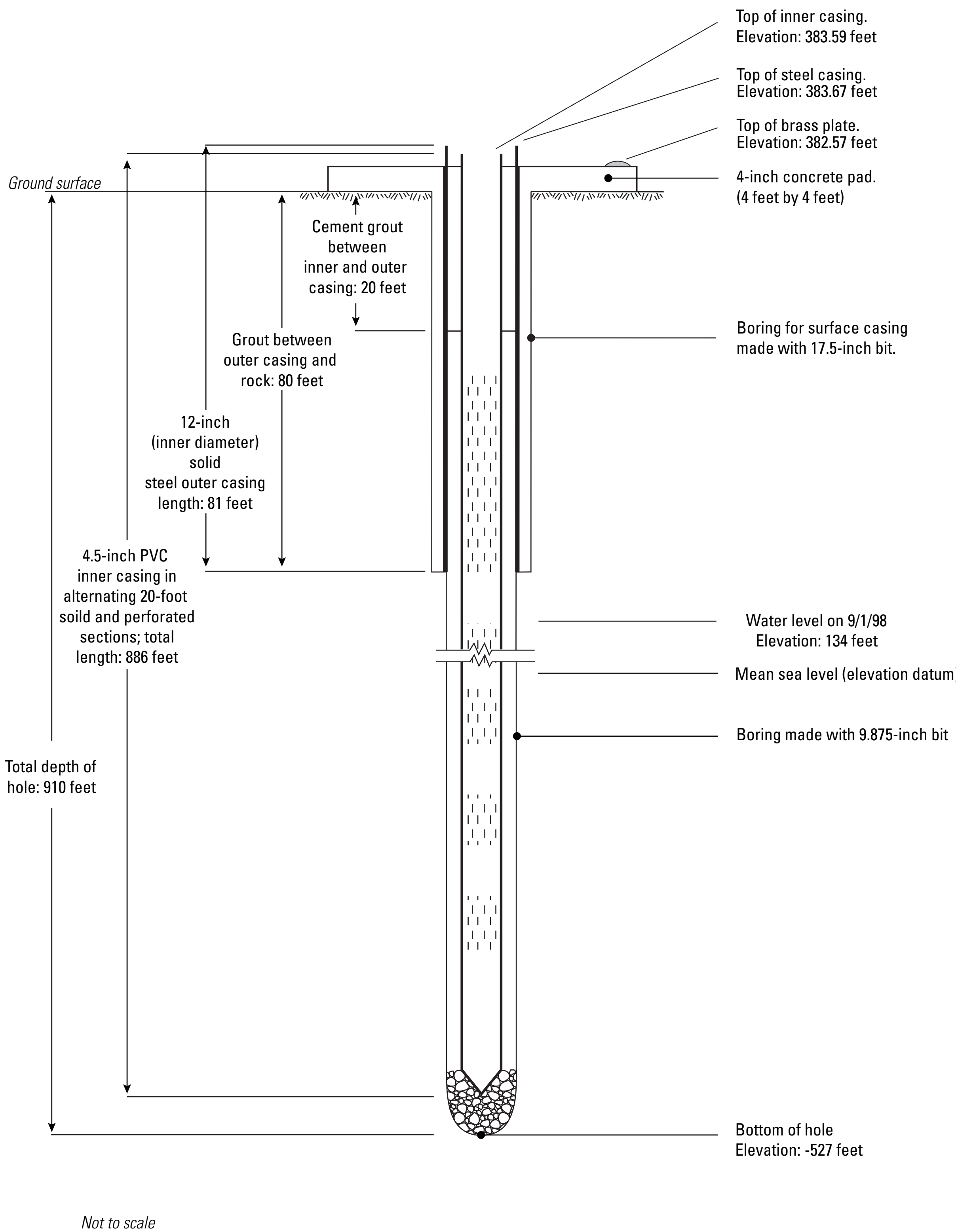

Figure 3. Construction (as-built) drawing of the Maalo Road monitor well (State well number 2-0123-01), Kauai, Hawaii.

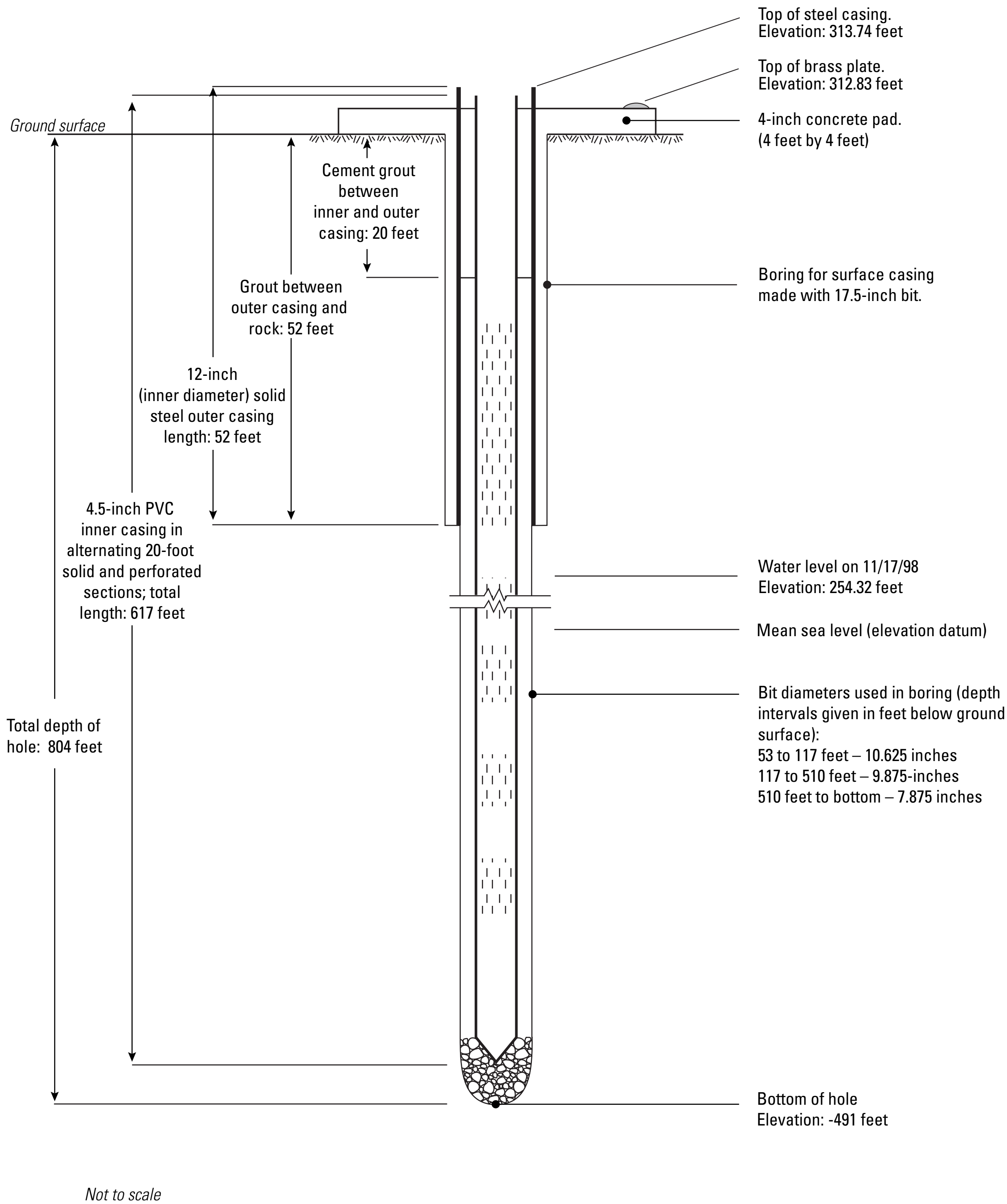

Figure 4. Construction (as-built) drawing of the Aahoaka Hill monitor well (State well number 2-0222-01), Kauai, Hawaii.

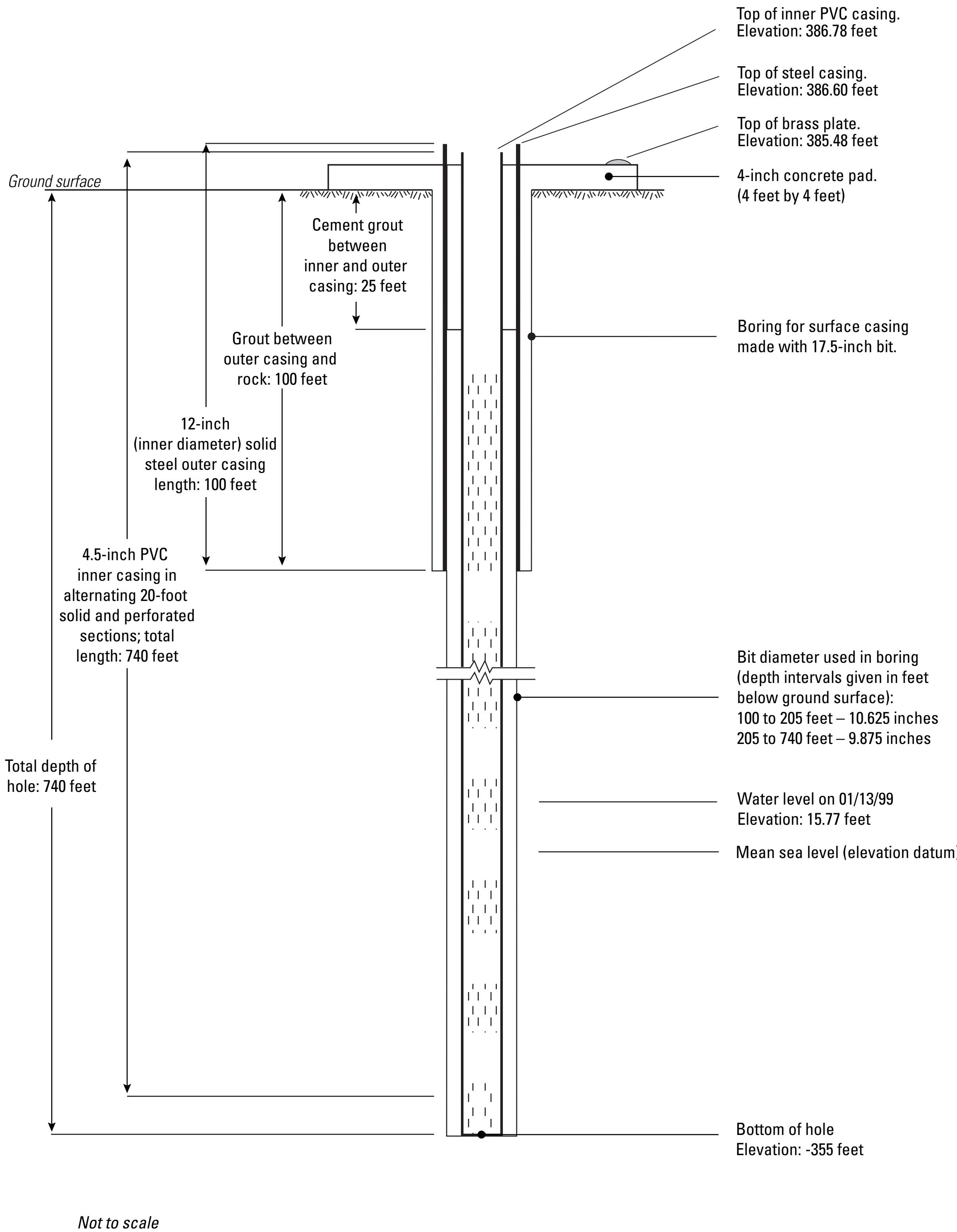

Figure 5. Construction (as-built) drawing of the Upper Eleele Tank monitor well (State well number 02-5534-06), Kauai, Hawaii.

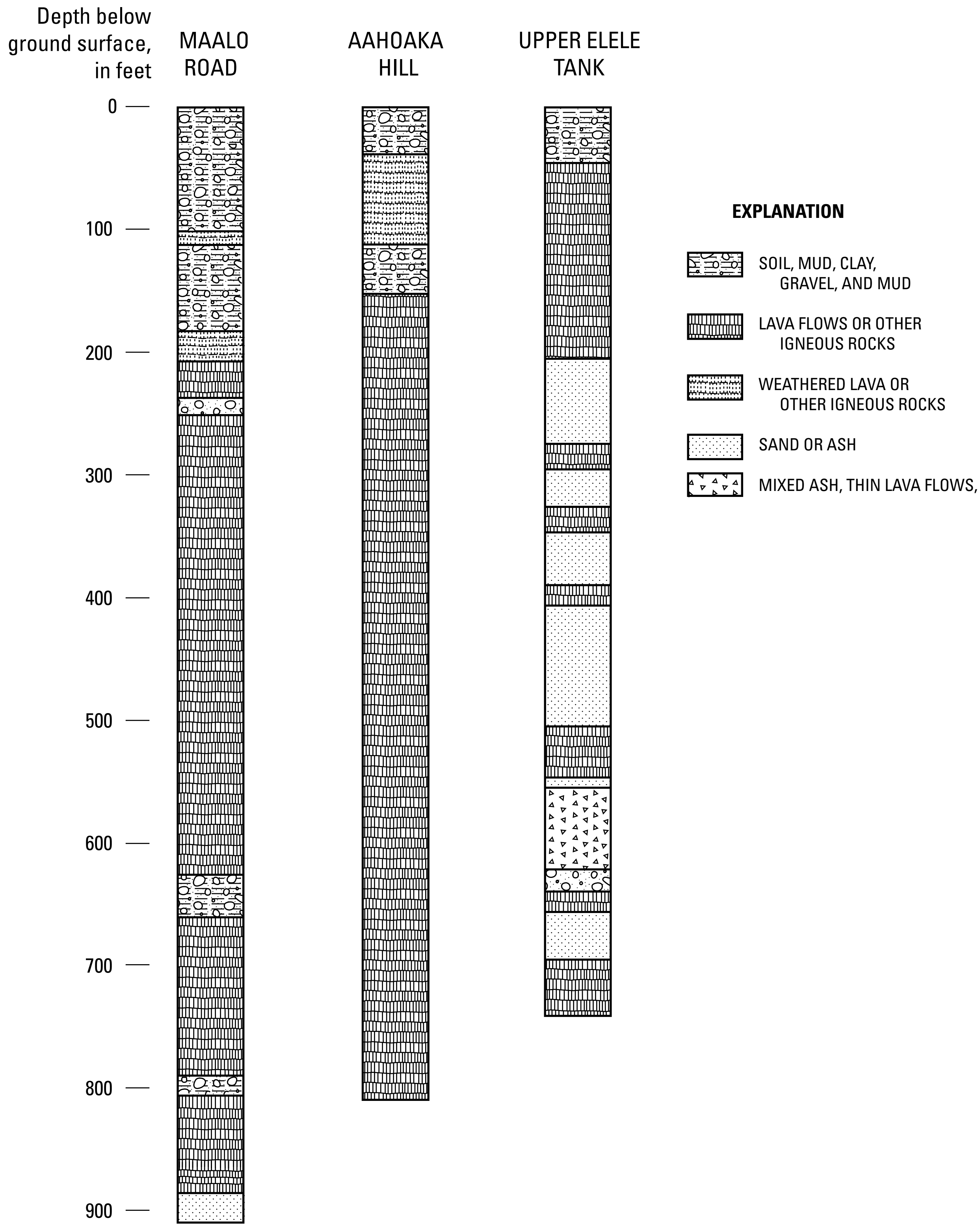

Figure 6. Generalized borehole geology of the Maalo Road, Aahoaka Hill, and Upper Eleele Tank monitor wells, Kauai, Hawaii.

formations have distinct chemistries that can be observed by geochemical analysis of the drill cuttings. The rocks of the Koloa Volcanics have lower SiO_2 than the tholeiitic basalts, hawaiites, mugearites, and alkalic basalts of the Waimea Canyon Basalt (Macdonald and others, 1960; Reiners and others, 1998; Clague and Dalrymple, 1988). Major-element compositions of selected cuttings from the Maalo Road, Aahoaka Hill, and Upper Eleele Tank monitor wells were determined by x-ray fluorescence at the University of Hawaii School of Ocean Engineering Science and Technology (table 2).

Maalo Road monitor well – The Maalo Road monitor well penetrated 915 ft, mostly through mafic lava flows, except for soil and gravel in the upper 200 ft, sedimentary layers from 625 to 660 ft and 790 to 804 ft, and a sandy layer (possibly volcanic ash) near the bottom (fig. 6). The geologic map of Macdonald and others (1960) indicates that the Koloa Volcanics is the formation at the surface at the site of the Maalo Road monitor well. Reiners and others (1998) report the presence of hawaiite, alkalic basalt, mugearite, and tholeiitic basalt in rocks samples from the nearby Pukaki Reservoir monitor well, 0.8 mi south of the Maalo Road monitor well, which indicates that the contact between the Waimea Canyon Basalt and the Koloa Volcanics is between 730 and 900 ft below the surface in that area. Most of the cuttings from the Maalo Road monitor well selected for geochemical analysis have less than 46 weight percent SiO_2 (table 2), which is similar to the composition of rocks identified as Koloa Volcanics by Macdonald and others (1960) and Reiners and others (1998). The deepest sample selected for geochemical analysis (from 855 to 860 ft) from the Maalo Road monitor well had 47.29 weight percent SiO_2, which is similar to the Waimea Canyon Basalt compositions reported in Reiners and others (1998).

Aahoaka Hill monitor well – The Aahoaka Hill monitor well penetrated 804 ft mostly through mafic igneous rocks except for two sedimentary layers near the top. Secondary minerals filled vesicles and other voids in most of the igneous rocks, and many of the samples showed indications of alteration (fig. 6). Most of the igneous rocks were probably lava flows, but it is possible that the well may have penetrated dikes of the Waimea Canyon Basalt which are known to exist in Aahoaka Hill (Macdonald and others, 1960). The well lies in an area where the surface formation is the Koloa Volcanics, but nearby Aahoaka Hill is formed by Waimea Canyon Basalt (Macdonald and others, 1960). Geochemical analysis of the drill cuttings indicate that the mafic igneous rocks penetrated by the Aahoaka Hill monitor well, at least those below a depth

Table 2. Major-element composition, in weight percent, of selected samples of drill cuttings from the Maalo Road (Maalo), Aahoaka Hill (Aahoaka), and Upper Eleele Tank (Eleele) monitor wells, Kauai, Hawaii

[analysis by x-ray fluorescence; LOI, loss on ignition]

Well	Depth Interval (feet)	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SUM	LOI	$Na_2O + K_2O$
Maalo	350-355	45.90	2.42	11.27	14.06	0.17	13.66	9.42	1.91	0.84	0.40	100.04	2.33	2.75
Maalo	455-460	41.87	2.66	11.16	14.61	0.19	14.26	13.03	1.05	0.54	0.55	99.90	6.94	1.59
Maalo	555-560	42.23	2.65	11.21	14.72	0.18	14.13	12.38	1.38	0.46	0.57	99.91	4.95	1.84
Maalo	740-745	40.74	3.07	11.54	15.33	0.20	13.58	13.09	1.28	0.45	0.66	99.92	6.01	1.73
Maalo	855-860	47.29	3.22	15.70	12.72	0.19	5.16	10.10	3.24	1.20	0.70	99.50	4.69	4.44
Aahoaka	160-165	49.57	2.32	13.11	12.68	0.15	8.95	10.23	2.09	0.39	0.26	99.75	1.93	2.48
Aahoaka	250-255	49.27	2.38	12.33	12.90	0.17	10.78	9.64	1.71	0.28	0.24	99.68	4.18	1.99
Aahoaka	425-430	48.97	1.92	10.50	12.99	0.16	15.43	7.85	1.41	0.30	0.17	99.68	9.43	1.71
Aahoaka	545-550	50.74	2.31	12.72	12.53	0.16	8.82	9.78	2.17	0.28	0.22	99.70	3.24	2.45
Aahoaka	645-650	48.26	1.90	9.35	13.57	0.17	17.95	6.80	1.02	0.33	0.17	99.52	11.15	1.35
Aahoaka	795-800	48.95	2.22	11.51	12.73	0.16	12.99	8.47	2.01	0.36	0.23	99.61	7.54	2.37
Eleele	60-65	41.28	2.84	9.93	14.63	0.18	14.04	12.03	3.04	0.74	0.87	99.54	2.45	3.78
Eleele	95-100	42.00	2.33	9.73	13.47	0.18	16.28	11.42	2.89	0.69	0.66	99.65	1.77	3.58
Eleele	165-170	43.55	2.60	10.70	14.74	0.18	13.25	10.88	3.17	0.64	0.46	100.15	2.29	3.81
Eleele	340-345	42.15	2.78	11.21	14.78	0.19	13.49	11.94	2.16	0.76	0.57	100.01	2.13	2.92
Eleele	720-725	47.83	2.40	12.52	14.05	0.18	12.74	8.31	1.72	0.27	0.23	100.21	3.67	1.99

of 160 ft, have greater than 48 weight percent SiO_2, which is similar to the tholeiitic rocks of the Waimea Canyon Basalt (Macdonald and others, 1960; Reiners and others, 1998).

Upper Eleele Tank monitor well – The Upper Eleele Tank monitor well penetrated 50 ft of surface soil and sediment, mafic lava flows from about 50 to 205 ft, then alternating layers of volcanic ash, lava flows, and scoria for the remainder of the well's 740-ft depth (fig. 6). The geologic map of Macdonald and others (1960) indicates that the Koloa Volcanics lies at the surface at the well site, but the underlying Waimea Canyon Basalt crops out in the precipice that drops into the Hanapepe River Valley just 200 ft north of the drill site. Samples of cuttings selected for geochemical analysis from depth intervals above 345 ft in this well had less than 44 weight percent SiO_2, which is similar to the low-SiO_2 contents of rocks of the Koloa Volcanics. In contrast, the sample from 720 to 725 ft had a SiO_2 content of nearly 48 weight percent, which is similar to rocks of the Waimea Canyon Basalt.

Aquifer Tests

Each of the three monitor wells was tested to gather data that can be used to assess aquifer hydraulic properties. The tests were conducted after the borehole had been drilled to its final depth but before installation of the 4.5-in. PVC inner casing (fig. 7). The aquifer tests consisted of monitoring the change in water level (drawdown) induced by pumping the wells at measured discharge rates. The tests included (1) step-drawdown tests, in which water was pumped from the well at different rates of discharge (steps), and (2) sustained-discharge tests, in which water was pumped from the borehole at a relatively steady discharge rate for several days. Temperature and specific conductance of the discharge water was measured on selected occasions.

In all of the aquifer tests, water was pumped from the wells using a submersible electric pump (fig. 7). Water levels were measured with an electric water-level measuring tape; in the test of the Upper Eleele Tank monitor well, a pressure transducer (vented to the surface to eliminate barometric variations) also was used. In most tests, the electric water-level measuring tape was inserted into a 0.75- to 1-in. PVC pipe (measuring tube) that was strapped to, and extended the length of, the pump's discharge pipe. The measuring tube shielded the electric water-level measuring tape from cascading water and turbulence in the borehole, thus increasing the precision of the water-level measurements. In the case where both a pressure transducer and electric water-level measuring tape were used, the pressure transducer was inserted into the measuring tube, and the electric water-level measuring tape was inserted into the annular space between the pump riser pipe and the open borehole. A water meter was installed at the top of the well to measure discharge rate, and in some tests, a parshall flume, a second meter, or a volumetric measurement was used as a backup in case the totalizing water meter failed. Discharge rate was controlled by a valve connected down-flow from the meter.

Maalo Road Monitor Well

The Maalo Road monitor well was tested for aquifer properties on September 1 to September 15, 1998. A 50-horsepower submersible pump was set with its intake at an elevation of -47 ft in the borehole of the well. On September 1, a step-drawdown test was conducted with five steps having discharge rates of 95 to 280 gal/min. Maximum drawdown during this test was 134.93 ft (fig. 8, Appendix 7). In the fifth step, however, the discharge rate decreased from an initial rate of 280 gal/min to 220 gal/min and the test was stopped because of a malfunctioning electrical generator. Water temperature ranged from 25.6 to 26.3 °C and specific conductance from 303 to 363 µS/cm during this test.

A sustained-discharge test was started on September 8, 1998 at an initial discharge rate of 220 gal/min. The discharge rate slowly decreased over the duration of the test, probably as a result of rock debris clogging the pump intake (fig. 9, Appendix 8), and at 4,620 min of elapsed time, discharge had decreased to 174 gal/min. At 5,340 min of elapsed time (06:00 on September 12, 1998), the generator was found stopped due to mechanical problems. It is not known at what time between 4,620 and 5,340 min the generator failed. The generator was repaired and the test resumed at 14:00 on September 12 and continued at an average discharge rate of 176 gal/min until September 15, 1998. The maximum drawdown measured during the test was 138.25 ft. Water temperature ranged from 25.8 to 27.4 °C and specific conductance gradually increased from 348 to 627 µS/cm during this test.

Aahoaka Hill Monitor Well

The Aahoaka Hill monitor well was tested over two periods: (1) in November 1998 and (2) in January 1999. In the November 1998 tests, the rate of water-level decline was so rapid even at discharge rates of less than 100 gal/min the tests were halted prematurely to prevent the water level in the well from reaching the pump intake. Additionally, rock debris shed from the uncased borehole sometimes clogged the meter used to monitor discharge rate. Because of these difficulties, the Aahoaka Hill monitor well was tested again in January 1999 with a smaller pump and backup methods for monitoring discharge rate in case the water meter failed.

Tests of November 1998 – The Aahoaka Hill monitor well was tested in November 1998 with a 6-in., 50-horsepower submersible pump with its intake at an elevation of -117 ft in the uncased borehole. On November 17, a step-drawdown test was conducted in which a discharge rate of 41 to 44 gal/min was maintained for 60 min for the first step of the test (fig. 10, Appendix 11). The discharge rate was increased to between 86 and 88 gal/min for the second step, but after 7 min at this rate, the water meter became clogged with rock particles. Despite the meter malfunction, the test was continued at the

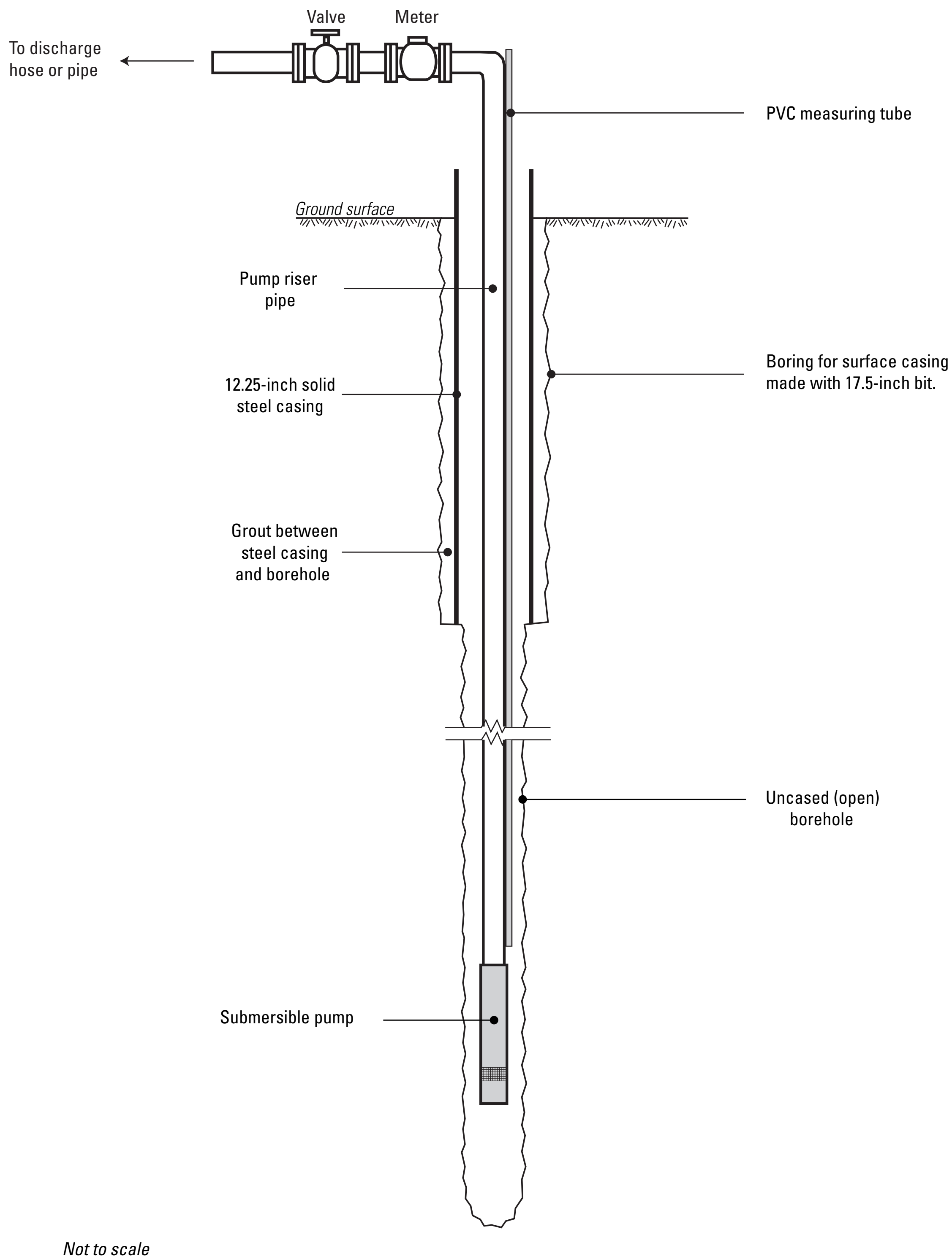

Figure 7. Schematic drawing of the typical setup used for the aquifer tests at the Maalo Road, Aahoaka Hill, and Upper Eleele Tank monitor wells, Kauai, Hawaii (actual setup may have differed slightly for each well).

higher rate for a full hour, but then was halted so the meter could be fixed.

On November 18, a second step-drawdown test was conducted with the first step having a discharge rate of 46 to 67 gal/min maintained for 60 min, followed by a second step of 118 to 129 gal/min (fig. 11, Appendix 10). However, after pumping at the second step for 20 min, the meter became clogged again. The meter was cleared by momentarily opening the valve to increase the pumping rate, but it was thereafter difficult to return the discharge rate to 118 gal/min. The pump was shut down after pumping 60 min of the second step. Water temperature ranged from 24.6 to 24.9 °C and specific conductance from 231 to 233 µS/cm during this test.

A sustained-discharge test was conducted on November 19-20, 1998. Because the water meter showed a tendency to become clogged during the step-drawdown tests, a parshall flume was installed as a backup means of measuring discharge. During the first 60 min of the test, the discharge rates indicated by the parshall flume agreed within 3 percent of the flow indicated by the meter (Appendix 11). After 60 min, the water meter became clogged, so for the remainder of the test, the pumping rate was monitored using the parshall flume. After 3 hours of pumping at a rate of 92 to 117 gal/min, the drawdown had exceeded 300 ft (fig. 12, Appendix 11). The pumping rate was reduced twice (once from 117 to 71 gal/min, then from 71 to 56 gal/min) to prevent the water level from reaching the pump. Even so, the trend in the drawdown curve indicated that the water level would reach the pump intake by about 2,000 min, so the pump was shut off at 1,924 min. Water temperature ranged from 24.6 to 25.6 °C and specific conductance from 212 to 238 µS/cm during this test.

Tests of January 1999 – The Aahoaka Hill monitor well was tested again with a smaller pump in January 1999. A 10-horsepower submersible pump was set with its intake at an elevation of about 4 ft above sea level. As a backup method for discharge measurement in case the meter became clogged, a volumetric method (measuring the time required for the well discharge to fill a 5-gal container) was used. On January 12, 1999, a step-drawdown test was conducted consisting of four 60-min steps with pumping rates ranging from 5 to 28 gal/min. Maximum drawdown during this test was 31.80 ft (fig. 13 and Appendix 12). The entire step-drawdown test was completed without the meter clogging. Throughout the test, discharge measured by the volumetric method differed from that measured by the water meter by less than 9 percent.

A sustained-discharge test was conducted on January 21-28, 1999 (fig. 14 and Appendix 13). The test began with a discharge rate of 20 to 23 gal/min, but after 1,035 min the discharge rate began to decline, probably as a result of clogging of the pump-intake screen with rock debris from the uncased borehole. By 1,515 min, the discharge rate had declined to 17 gal/min. At 2,029 min the meter was found stopped due to clogging, and the discharge rate was 13 gal/min (as determined by the volumetric method). At 2,033 min and 2,853 min the pump was shut off for 1 to 3 seconds and restarted in attempt to unclog the pump screen. This momentarily increased the pumping rate, but within a few minutes the pumping rate declined again. Prior to shutting down the pump at 10,151 min, the pumping rate had declined to only 9 gal/min. The maximum drawdown measured during this test was 37.71 ft at 1,515 min, when the discharge was 17 gal/min.

Upper Eleele Tank Monitor Well

The Upper Eleele Tank monitor well was tested for aquifer properties on January 13 to February 9, 1999. On January 13, 1999, two attempts at step-drawdown tests were made. In the first attempt, started at 12:10, the well discharge was maintained at 283 to 285 gal/min for 60 min (fig. 15, Appendix 14), then was halted because the pump could not provide a higher discharge rate. Water temperature ranged from 20.4 to 20.7 °C and specific conductance from 17,930 to 18,170 µS/cm during this test. The water level in the well was allowed to recover for 110 min before the second step test was started.

In the second step test, the well discharge was maintained at 94 to 97 gal/min for 60 min, then increased to 175 to 176 gal/min for another 60 min (fig. 16; Appendix 15). Water temperature ranged from 20.8 to 21.4 °C and specific conductance from 18,370 to 18,940 µS/cm during this test.

On January 28, 1999, a vented pressure transducer was installed in the measuring tube to monitor water levels in the well. The pressure-transducer collected 5 days of data prior to the start of the sustained-discharge test of February 2, 1999, and continued monitoring through the first 24 hours of the test (fig. 17). Water levels prior to the test show tidal oscillations as well as a general increase in water level of about 1 ft over 5 days.

A sustained-discharge test was conducted from February 2 to 9, 1999 (fig. 18, Appendix 16). The discharge rate was monitored with two meters installed in the discharge line in case one meter failed. The average discharge readings of the two meters ranged between 278 and 290 gal/min during the test. Water level in the well declined 1.10 ft in the first 455 min of the test, but during the remainder of pumping, water levels both rose and fell, possibly reflecting pumping effects from a nearby well in Hanapepe Valley. Water temperature ranged from 20.2 to 21.4 °C and specific conductance from 8,380 to 14,860 µS/cm during this test. Pressure-transducer readings showed substantially higher noise during the aquifer test than in the antecedent monitoring period, however, the concurrent pressure transducer and electric water-level measuring tape measurements generally agree (fig. 19).

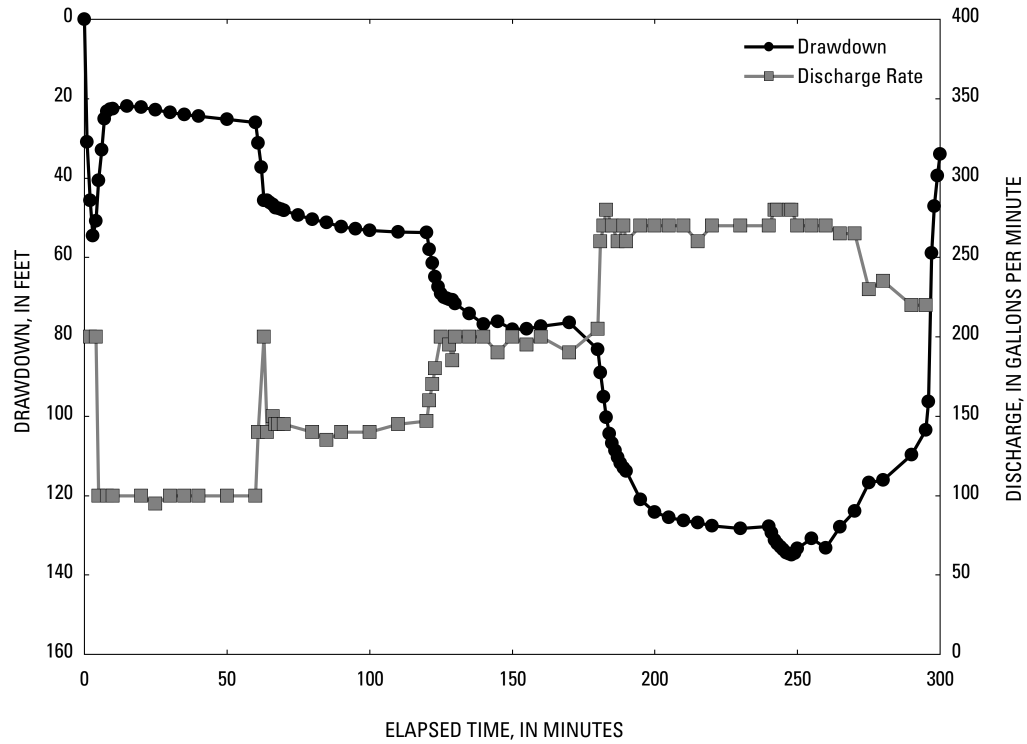

Figure 8. Drawdown and discharge during the September 1, 1998 step-drawdown aquifer test at the Maalo Road monitor well, Kauai, Hawaii.

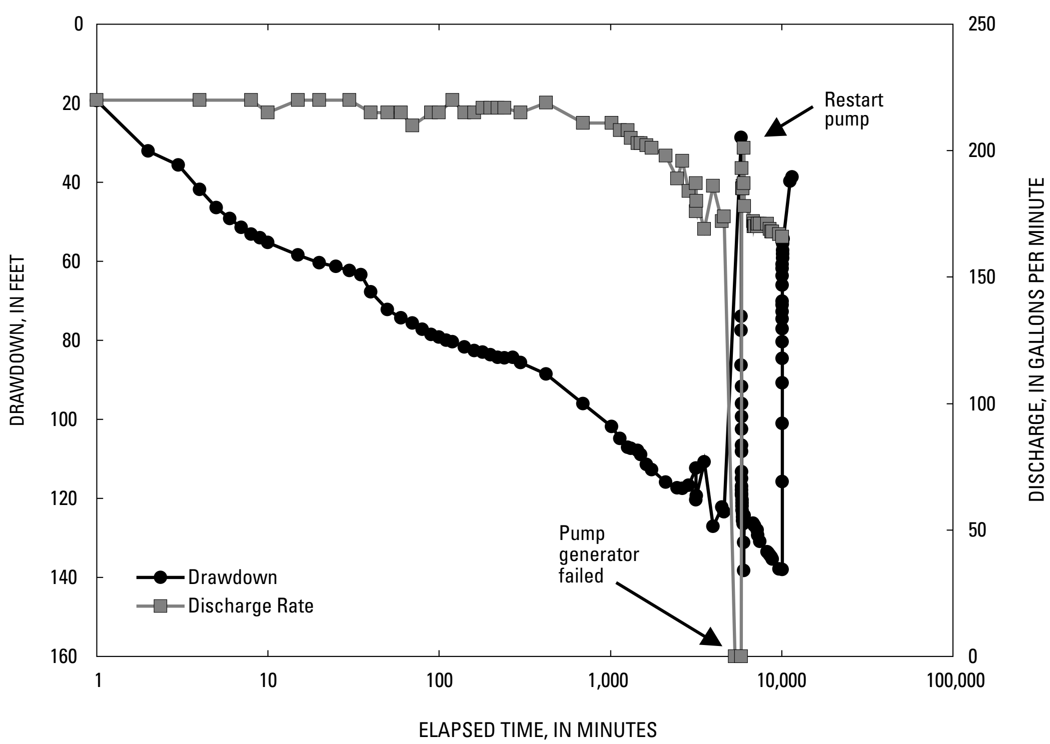

Figure 9. Drawdown and discharge during the September 8 - 15, 1998 sustained-discharge aquifer test at the Maalo Road monitor well, Kauai, Hawaii.

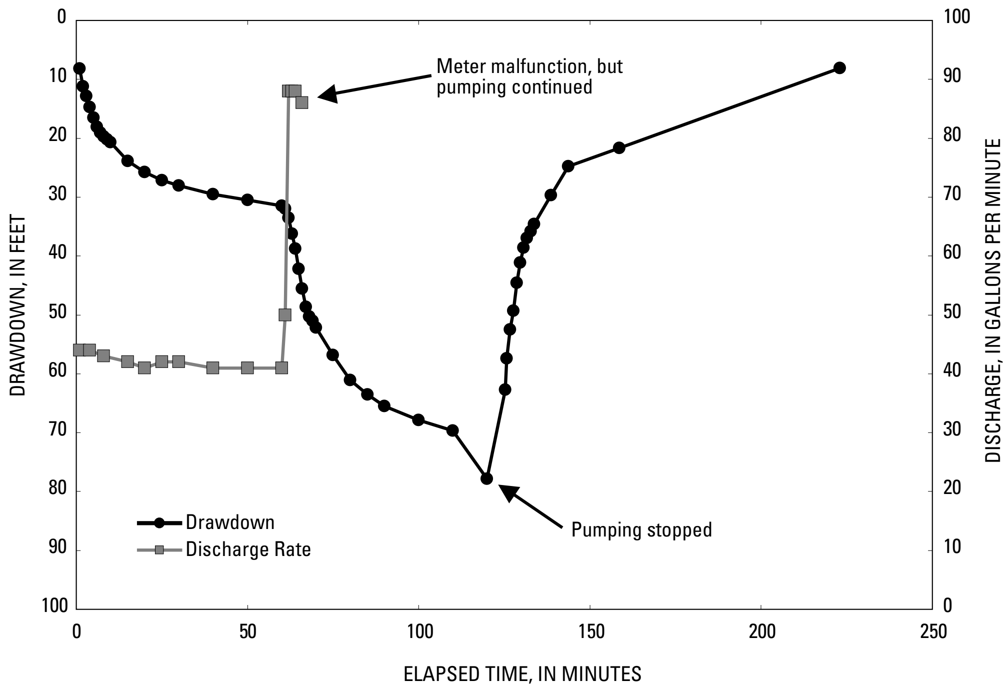

Figure 10. Drawdown and discharge during the November 17, 1998 step-drawdown aquifer test at the Aahoaka Hill monitor well, Kauai, Hawaii.

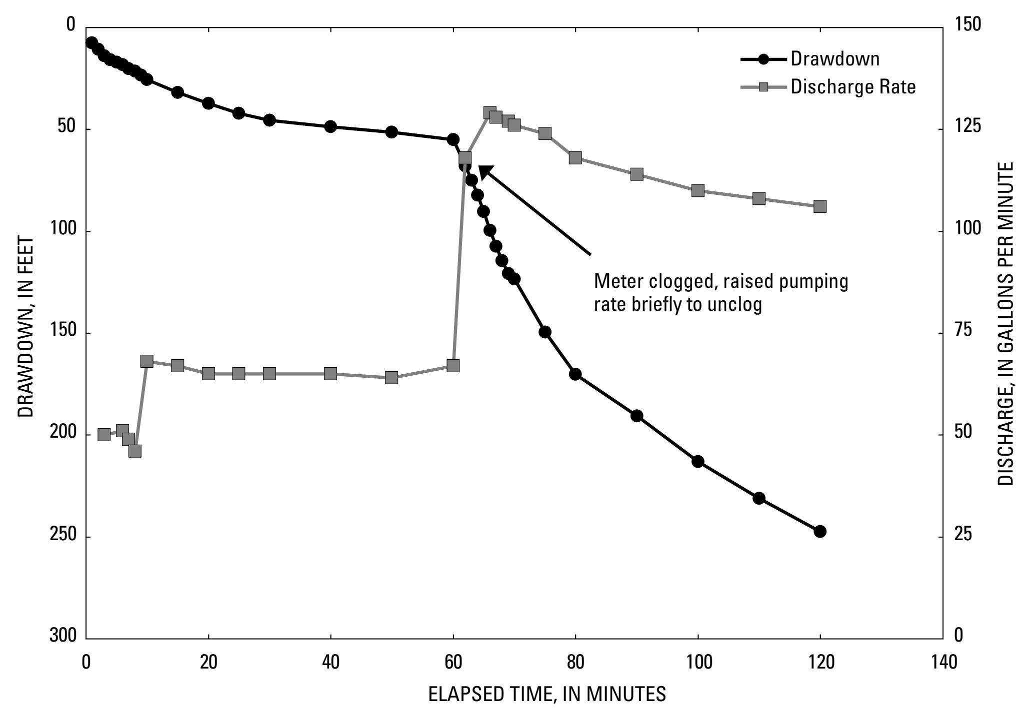

Figure 11. Drawdown and discharge during the November 18, 1998 step-drawdown aquifer test at the Aahoaka Hill monitor well, Kauai, Hawaii.

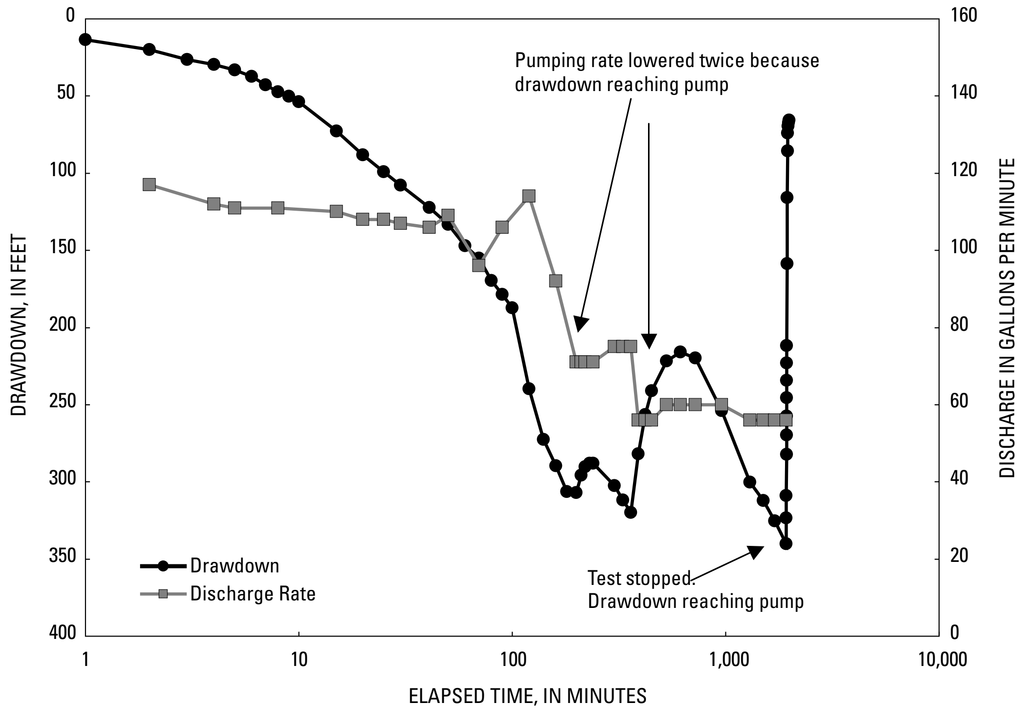

Figure 12. Drawdown and discharge during the November 19-20, 1998 sustained-discharge aquifer test at the Aahoaka Hill monitor well, Kauai, Hawaii.

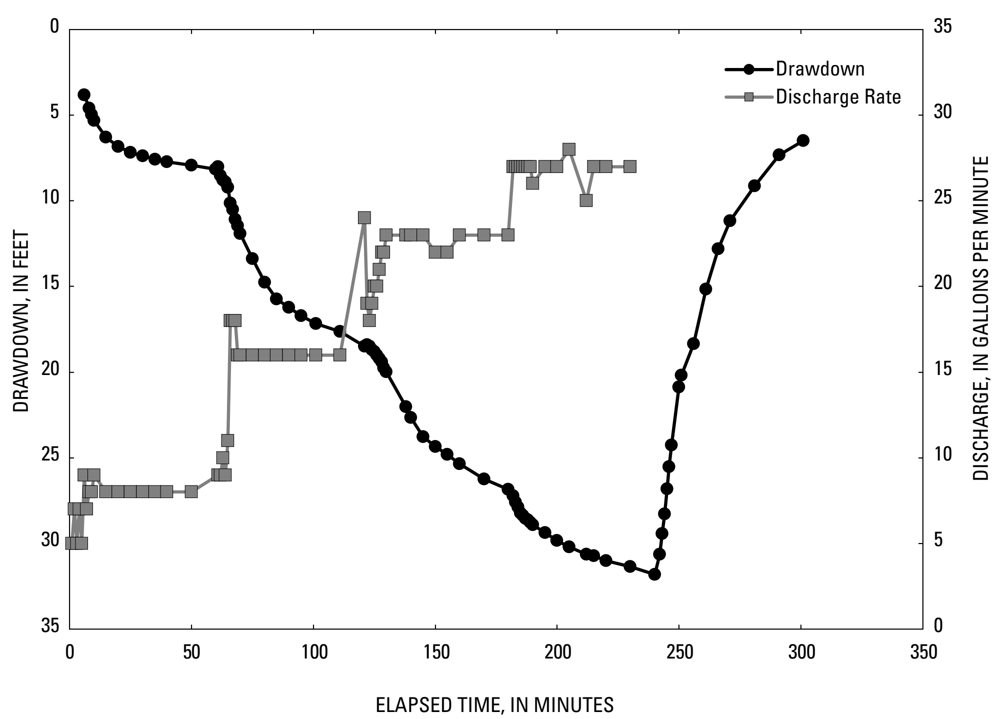

Figure 13. Drawdown and discharge during the January 12, 1999 step-drawdown aquifer test at the Aahoaka Hill monitor well, Kauai, Hawaii.

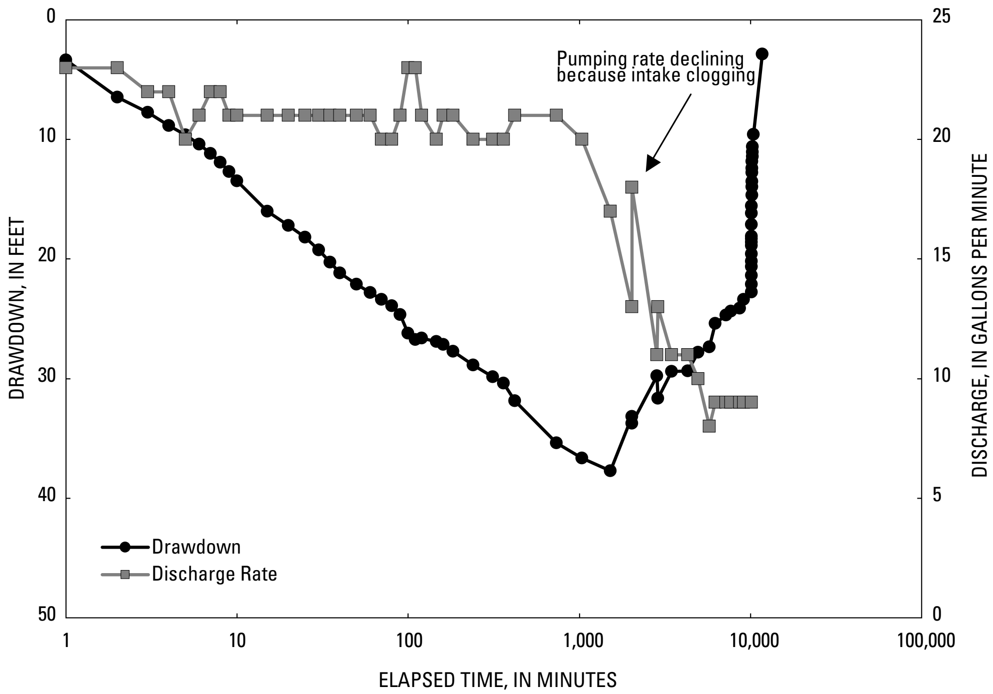

Figure 14. Drawdown and discharge during the January 21-28, 1999 sustained-discharge aquifer test at the Aahoaka Hill monitor well, Kauai, Hawaii.

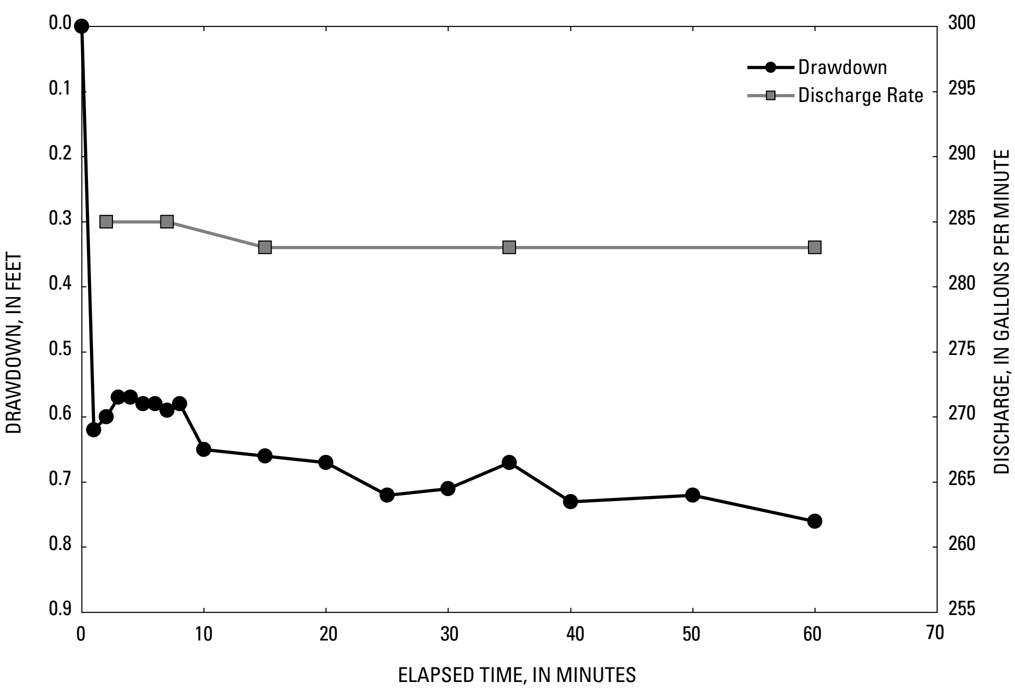

Figure 15. Drawdown and discharge during the first step-drawdown aquifer test of January 13, 1999 at the Upper Eleele Tank monitor well, Kauai, Hawaii.

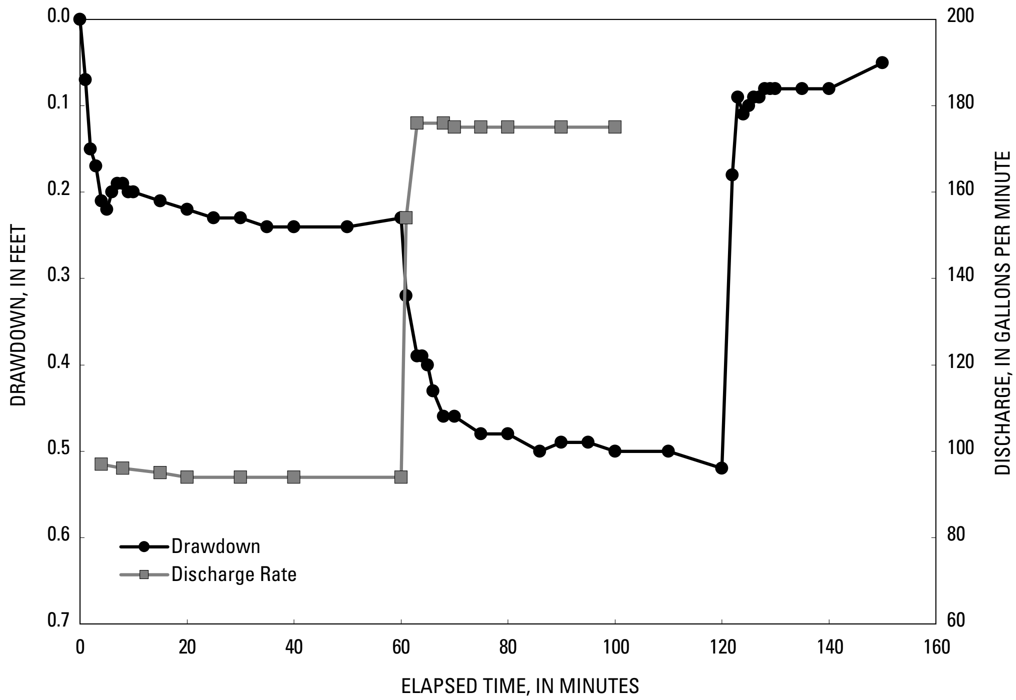

Figure 16. Drawdown and discharge during the second step-drawdown aquifer test of January 13, 1999 at the Upper Eleele Tank monitor well, Kauai, Hawaii.

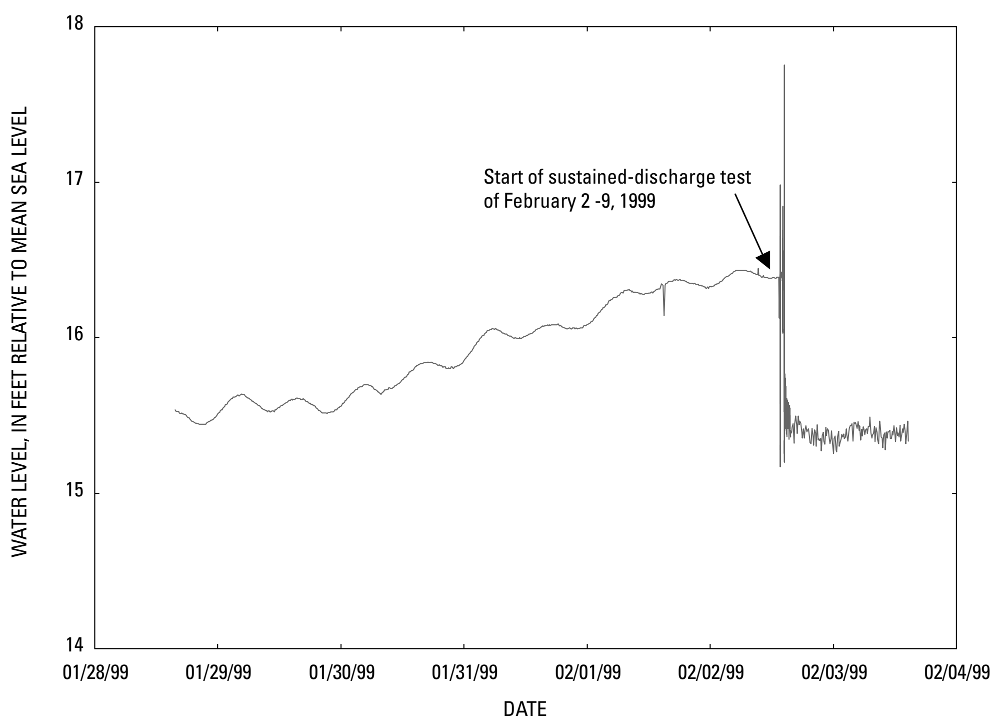

Figure 17. Water levels during the January 28 – February 3, 1999 pressure-transducer monitoring at the Upper Eleele Tank monitor well, Kauai, Hawaii.

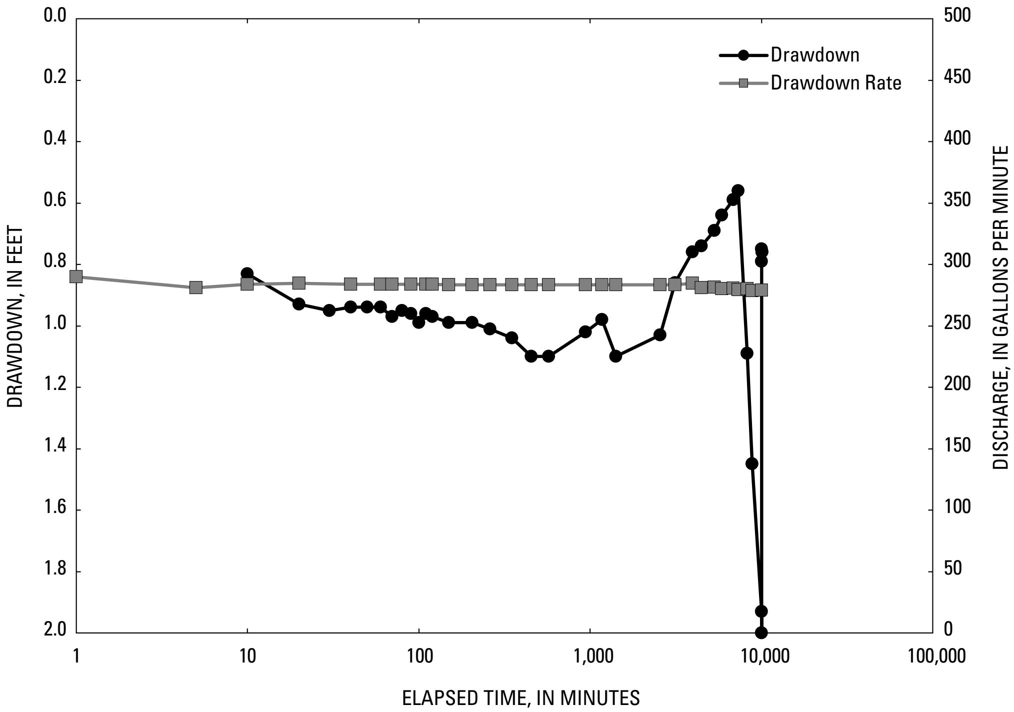

Figure 18. Drawdown and discharge during the February 2–9, 1999 sustained-discharge aquifer test of the Upper Eleele Tank monitor well, Kauai, Hawaii.

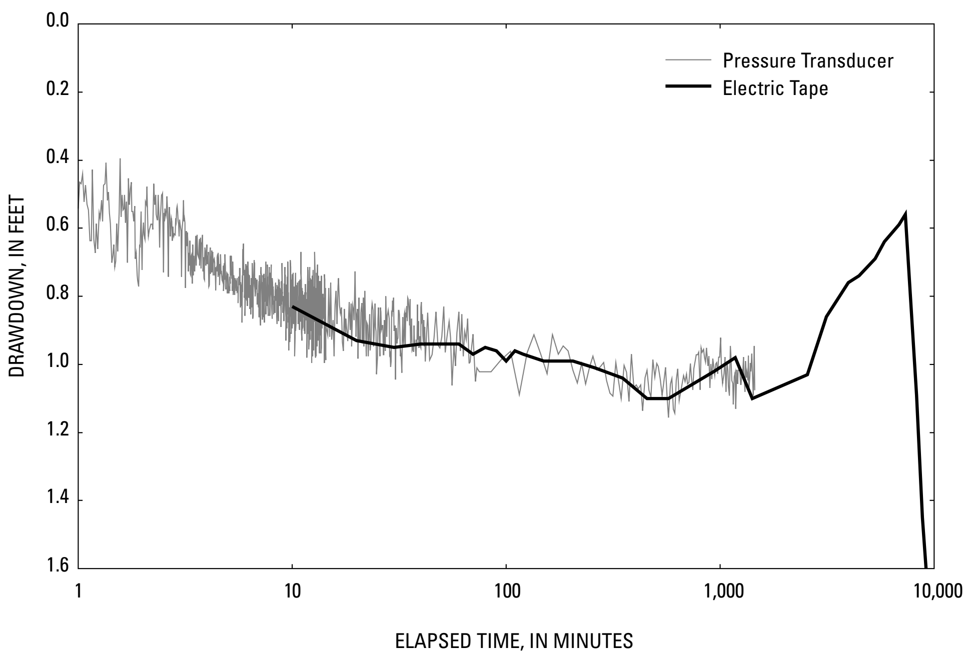

Figure 19. Drawdown measured by electric tape and by pressure transducer during the February 2-9, 1999 sustained-discharge aquifer test, at the Upper Eleele Tank monitor well, Kauai, Hawaii.

Summary

The Maalo Road, Aahoaka Hill, and Upper Eleele Tank monitor wells were constructed between July 1988 and August 2002 as part of a program of exploratory drilling, aquifer testing, and hydrologic analysis on Kauai. The borings for these wells were made by rotary drilling, and samples of drill cuttings were examined and tested to determine the geology. After drilling the first 100 to 200 ft of each borehole with a 17.5-in. diameter bit, a solid steel casing was installed and grouted in place, and the remainder of the borehole was drilled with a smaller diameter bit inserted into the steel casing. When the borehole was drilled to its final depth, a submersible pump was installed for aquifer tests. Aquifer tests included step-drawdown tests and sustained-discharge tests. After the aquifer tests, an inner casing of alternating sections of slotted and solid 4.5-in. PVC was installed.

The 915-ft-deep Maalo Road monitor well is in the Lihue Basin. The well penetrated mafic lava flows for most of its depth. Most of the cuttings selected for chemical analysis have compositions similar to the rocks of the Koloa Volcanics, but the deepest sample analyzed had a composition similar to the Waimea Canyon Basalt. Aquifer tests at this well included a step-drawdown and a 7-day sustained-discharge test. Water temperature ranged from 25.6 to 27.4 °C and specific conductance ranged from 303 to 627 µS/cm during these tests. The sustained-discharge aquifer test had problems with clogging of the pump and generator failure. Discharge rate ranged from 174 to 220 gal/min and maximum drawdown was 138.25 ft during the sustained discharge test.

The 804-ft-deep Aahoaka Hill monitor well is at the western base of Aahoaka Hill, in the Lihue Basin. The well penetrated mostly mafic lava flows and possibly dikes. Sample cuttings selected for chemical analysis had a composition similar to the Waimea Canyon Basalt. The well was initially tested with a 50-horespower pump but the drawdown rate was so high (more than 300 ft after only 3 hours at a rate of 92 to 117 gal/min) that the discharge rate was reduced twice, and the test eventually halted prematurely. Water temperature ranged from 24.6 to 25.6 °C and specific conductance from 212 to 238 µS/cm during the tests using the 50-horsepower pump. The well was retested in with a 10-horsepower pump. The retesting included a 7-day sustained-discharge test which started with a discharge rate of 20 to 23 gal/min but declined to as low as 8 gal/min as the pump intake became clogged. The maximum drawdown measured during this test was 37.71 ft at 1,515 min, when the discharge was 17 gal/min.

The 740-ft deep Upper Eleele Tank monitor well is a short distance from a precipice that drops 350 ft into the Hanapepe River Valley in southern Kauai. The well penetrated soil, sediment, lava flows, volcanic ash, and scoria. Selected cuttings from depth intervals above 345 ft in this well had compositions similar to the Koloa Volcanics, but a sample from 720 to 725 ft had a composition similar to rocks of the Waimea Canyon Basalt. During a 7-day aquifer test with a sustained discharge of between 278.5 and 290 gal/min, most of the drawdown of 1.10 ft occurred in the first 455 min of the test; thereafter, water levels fluctuated probably as a result of pumping influence from a nearby well in Hanapepe Valley. Water temperature ranged from 20.2 to 21.4 °C and specific conductance from 8,380 to 18,940 µS/cm during the step-drawdown and sustained-discharge tests. Water levels monitored in the well 5 days prior to the aquifer test show tidal oscillations as well as a gradual increase in water level of about 1 ft.

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