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Measuring Surface-Water Loss in Honouliuli Stream near the ‘Ewa Shaft, O‘ahu, Hawai‘i

Scientific Investigations Report 2017–5042

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

Cover. Photograph looking upstream at the U.S. Geological Survey's Honouliuli H-1 streamflow-gaging station (16212490), from the Honolulu Board of Water Supply's ʻEwa Shaft Well compound. Photograph by Sarah N. Rosa, USGS.

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RYAN K. ZINKE, Secretary

U.S. Geological Survey
William H. Werkheiser, Acting Director

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State Well Numbers

Since 1971, Hawai‘i’s well-numbering system has contained seven digits. The first digit distinguishes the island, which is then followed by a dash separator. The next four digits represent the grid system, with the first two digits representing minutes of latitude and the second two digits representing minutes of longitude for that grid (using leading zeroes for minute values less than 10). To distinguish wells within a minute grid, two digits were added following the 4-digit minute-grid numbers with a dash separator, and are sometimes referred to as a sequence number.

In 2012, Hawai‘i’s well-numbering system was modified to accommodate more wells than the previous numbering system would allow. The sequence number was changed from two digits to three digits, allowing for a grid to have 100 or more wells. If the sequence number is less than 100, the new numbering system places a zero in front of the 2 digits. References to wells in this report will only use a two-digit sequence number when the sequence number is less than 100.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	231	cubic inch (in^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	1728	cubic inch (in^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.64631*	million gallons per day (Mgal/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Pressure	
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

*Number has been truncated in the table. The exact conversion number was used in the analysis.

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

$$°F=(1.8\times°C)+32$$

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 local mean sea level.

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

Altitude, as used in this report, refers to distance above the vertical datum.

Measuring Surface-Water Loss in Honouliuli Stream near the ‘Ewa Shaft, O‘ahu, Hawai‘i

By Sarah N. Rosa

Abstract

The Honolulu Board of Water Supply is currently concerned with the possibility of bacteria in the pumped water of the ‘Ewa Shaft (State well 3-2202-21). Groundwater from the ‘Ewa Shaft could potentially be used to meet future potable water needs in the ‘Ewa area on the island of O‘ahu. The source of the bacteria in the pumped water is unknown, although previous studies indicate that surface water may be lost to the subsurface near the site. The ‘Ewa Shaft consists of a vertical shaft, started near the south bank of Honouliuli Stream at an altitude of about 161 feet, and two horizontal infiltration tunnels near sea level. The shaft extracts groundwater from near the top of the freshwater lens in the Waipahu-Waiawa aquifer system within the greater Pearl Harbor Aquifer Sector, a designated Water Management Area.

The surface-water losses were evaluated with continuous groundwater-level data from the ‘Ewa Shaft and a nearby monitoring well, continuous stream-discharge data from U.S. Geological Survey streamflow-gaging station 16212490 (Honouliuli Stream at H-1 Freeway near Waipahu), and seepage-run measurements in Honouliuli Stream and its tributary. During storms, discharge at the Honouliuli Stream gaging station increases and groundwater levels at ‘Ewa Shaft and a nearby monitoring well also increase. The concurrent increase in water levels at ‘Ewa Shaft and the nearby monitoring well during storms indicates that regional groundwater-level changes related to increased recharge, reduced withdrawals (due to a decrease in demand during periods of rainfall), or both may be occurring; although these data do not preclude the possibility of local recharge from Honouliuli Stream. Discharge measurements from two seepage runs indicate that surface water in the immediate area adjacent to ‘Ewa Shaft infiltrates into the streambed and may later reach the groundwater system developed by the ‘Ewa Shaft. The estimated seepage loss rates in the vicinity of ‘Ewa Shaft from the two seepage runs generally ranged from 0.27 to 1.78 million gallons per day per mile of stream reach; although higher seepage rates may occur during periods of higher discharge in Honouliuli Stream. A potential source of bacteria in ‘Ewa Shaft maybe related to seepage from Honouliuli Stream; however, other sources of bacteria were not studied and cannot be excluded.

Introduction

The ‘Ewa Shaft, State well 3-2202-21, was constructed in 1936 by the ‘Ewa Plantation Company and later managed by the O‘ahu Sugar Company to supply water for sugarcane irrigation until the O‘ahu Sugar Company closed in 1995, prompting significant land-use changes in the Honouliuli study area (fig. 1). Throughout the last century, the Honouliuli area transitioned from being dominated by large-scale sugarcane cultivation and cattle grazing at higher altitudes above the cultivated areas, to the foundation of the conservation area, Honouliuli Preserve. Within the last decade, smaller diversified agricultural plots cultivated by independent farmers and seed companies, small-scale ranching operations, telecommunication sites, residential developments, and golf courses have replaced the earlier sugarcane operations (Oceanit and others, 2007). The majority of the land in the study area is classified as prime agricultural land, which is described as best suited for the production of food, feed, forage, and fiber crops due to the soil quality, growing season, and moisture supply needed to produce sustained high crop yields (State Department of Agriculture, 1977).

Owing to the land-use shift, irrigation needs have decreased and potable water demand has increased, and is projected to increase further. The Honolulu Board of Water Supply (HBWS) estimates that 27 million gallons per day (Mgal/d) of potable water will be needed for the ‘Ewa area by 2035 if the ‘Ewa Development Plan is implemented (Department of Planning and Permitting, 2013). To help meet future potable water demands the HBWS is considering using the ‘Ewa Shaft. Renovations to the ‘Ewa Shaft facility were completed in 2011 and they included lining the existing vertical shaft and an adjacent reach of Honouliuli Stream with concrete (AECOM, 2011). These modifications were intended to prevent excessive seepage losses from the stream in the vicinity of the shaft.

The ‘Ewa Shaft consists of a vertical shaft, started near the south bank of Honouliuli Stream at an altitude of about 161 feet (ft), and two horizontal infiltration tunnels excavated near sea level in flat-lying massive Ko‘olau Basalt (Stearns, 1940). The shaft extracts groundwater from near the top of the freshwater lens in the Waipahu-Waiawa aquifer system within the greater Pearl Harbor Aquifer Sector, a designated Water Management Area. Approximately 11 percent of the Waipahu-Waiawa aquifer is covered by irrigated agricultural land (Engott and others, 2015). Stearns (1940) indicated a potential for surface water to infiltrate and reach the groundwater at the ‘Ewa Shaft site based on (1) a small amount of water encountered in a lava tube at approximately 49 ft above sea level, and (2) water put back into Honouliuli Stream that apparently returned to the infiltration tunnel. An inspection documented in the final environmental assessment prepared for the HBWS in 2002 also indicates that recharge near the ‘Ewa Shaft may affect groundwater at the site (M&E Pacific Inc., 2002).

Purpose and Scope

The HBWS is currently concerned with the possibility of bacteria in the water pumped from the ‘Ewa Shaft. Although potential sources of bacteria in the pumped water are not fully understood, existing accounts indicate that surface water may be lost to the subsurface near the site. Groundwater from the ‘Ewa Shaft could potentially be used to meet future potable water needs in the ‘Ewa area as defined in the ‘Ewa Development Plan (Department of Planning and Permitting, 2013).

The objective of the report is to evaluate the location and quantity of surface-water loss in Honouliuli Stream near the ‘Ewa Shaft to improve understanding of potential sources of bacteria in the pumped water. The scope of the work included (1) the collection of new water-level and seepage-run information, and (2) an analysis of the extent of the surface-water loss in the study area.

Setting

The study area is located at the southeastern end of the Wai‘anae Range in western O‘ahu and extends into central O‘ahu (fig. 1). The study area is bounded to the west by the inferred surface contact between the Wai‘anae Volcanics and Ko‘olau Basalt, and to the east by Waikele Stream, which generally reflects the location of a possible barrier to groundwater flow associated with valley-filling alluvium and weathered volcanic rocks. The study area includes the part of the Honouliuli watershed that contributes groundwater recharge to the source aquifer for the ‘Ewa Shaft and the estimated capture zone to the north of ‘Ewa Shaft. The Honouliuli Stream and its tributary flow through the southwestern end of the study area. The confluence of the Honouliuli tributary and Honouliuli Stream is about 400 ft upstream of the U.S. Geological Survey (USGS) streamflow-gaging station 16212490 (Honouliuli Stream at H-1 Freeway near Waipahu) and the ‘Ewa Shaft (State well 3-2202-21; USGS station number 212252158025001; fig. 1). USGS streamflow-gaging station 16212480 (Honouliuli Tributary near Waipahu) is located at the northern end of the Honouliuli tributary reach included in the study area. Overflow from the Waiāhole Ditch system is periodically released in the Honouliuli tributary just downstream from the USGS Honouliuli tributary streamflow-gaging station (16212480; fig. 1). The Waiāhole Ditch system develops dike-impounded water on the windward (northeast) side of O‘ahu and transports it to leeward (southwest) agricultural developments, supplying approximately 7.5 square miles of diversified agriculture with irrigation water.

Climate

The climate of O‘ahu is characterized by persistent cool northeasterly trade winds and mild temperatures throughout the year. The steep volcanic island topography produces pronounced spatial gradients for many of the components of climate, including rainfall, solar radiation, humidity, and wind (Juvik and Juvik, 1998). In Hawai‘i, two prominent features affect climate variability: the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) (Christensen and others, 2007; Giambelluca and others, 2008). Seasonal or inter-annual climatic variability is driven by ENSO with drier periods during El Niño and wetter periods during La Niña. Typically, the dry summer season is from May to September and the rainy winter season is from October to April. Decadal variations in temperature historically have been closely coupled to the PDO, but recently temperature and the PDO have become decoupled (Giambelluca and others, 2008). Statewide analyses of rainfall and streamflow indicate that climate in Hawai‘i has been getting drier (Oki, 2004; Chu and Chen, 2005).

Prevailing northeasterly trade winds force warm moisture-laden air up the windward side of O‘ahu, causing the air to cool and condense, resulting in cloud formation and an orographic rainfall pattern, with more rain typically falling at higher altitudes. The study area is located in the leeward rain shadow, a typically drier area, on the island of O‘ahu. The average annual amount of rainfall varies spatially within the study area from about 38 inches (in.) in the northern part of the study area to 22 in. near the coast (Giambelluca and others, 2013). The area in the vicinity of ‘Ewa Shaft receives about 24 in. of average annual rainfall. Leeward sides of the Hawaiian Islands, including the ‘Ewa Shaft area, receive a high percentage of their annual rainfall from frontal storms approaching from the southwest, locally known as Kona storms. In the fall and winter months, Kona storms and some storms arriving from the north bring heavy localized rainfall to areas like Honouliuli and can produce large amounts of surface-water runoff.

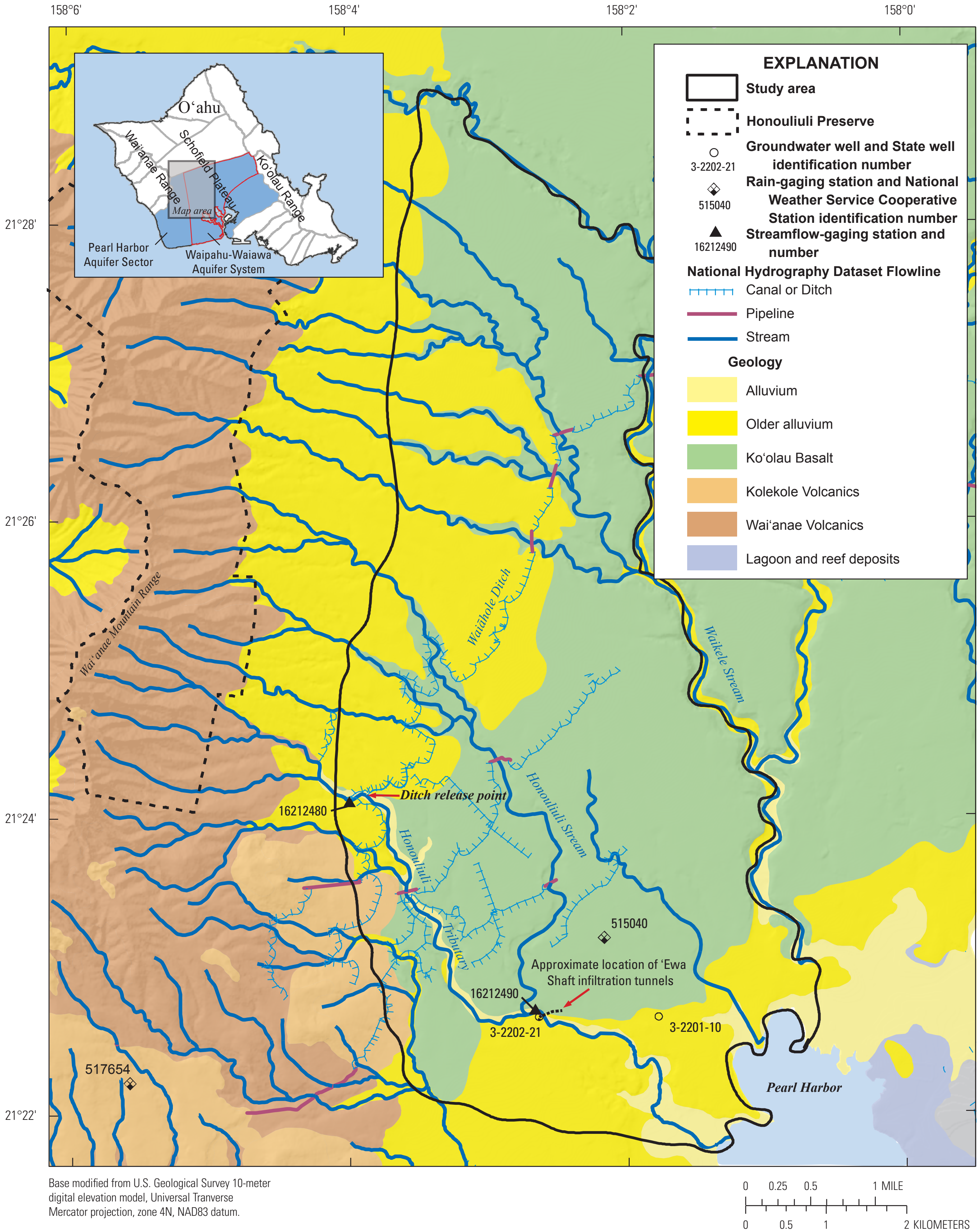

Figure 1. Location map of selected gaging stations, selected surface-water features from the National Hydrography Dataset (U.S. Geological Survey, 2010), the Honouliuli Preserve (State of Hawai'i, 2002), and the generalized geology (modified from Sherrod and others [2007]) underlying the study area. Inset map shows the location of the Waipahu-Waiawa aquifer system within the Pearl Harbor Aquifer Sector (Department of Land and Natural Resources, 2010).

Hydrogeological Setting

In the southern part of the Schofield Plateau of central O‘ahu, the older rocks of the Wai‘anae Range are overlain by the younger and highly permeable Ko‘olau Basalt. High-permeability volcanic-rock aquifers with freshwater lenses store the majority of O‘ahu's groundwater resources (Izuka and others, 2016). Within O‘ahu's freshwater lenses, groundwater generally flows from inland to coastal areas. O‘ahu's extensive coastal-plain deposits, which partly overlie the lava flows of the shield volcanoes, serve as a semiconfining caprock that resists natural groundwater discharge from the high-permeability volcanic aquifers and allows large volumes of groundwater to accumulate (Izuka and others, 2016). Low-permeability valley-fill barriers, created by alluvium and weathered rock, also create groundwater-flow barriers, forming subdivisions in the freshwater-lens system (Oki, 2005).

The surficial geology of the study area mostly consists of Ko‘olau Basalt, alluvium, and older alluvium with a small area to the west of the Honouliuli tributary containing Kolekole Volcanics (fig. 1). The ‘Ewa Shaft penetrates approximately 150 ft into the ground and at sea level the shaft opens up into two horizontal infiltration tunnels with the longer of the two tunnels (1,086 ft) extending under the Honouliuli Stream (Stearns, 1940). In sections within the tunnel, the rock is platy and yields water poorly, but in the last 500 ft the permeability of the rock increases, resulting in greater water yields (Stearns, 1940).

Surface-Water Losses

The location and quantity of surface-water loss in the Honouliuli Stream near the ‘Ewa Shaft was evaluated with continuous water-level data from the ‘Ewa Shaft (State well 3-2202-21; USGS station number 212252158025001), continuous stream-discharge data from USGS streamflow-gaging station 16212490 (Honouliuli Stream at H-1 Freeway near Waipahu), and seepage-run measurements from Honouliuli Stream and tributary (fig. 1). The water-level data, continuous stream-discharge data, and seepage-run measurements are available online in the USGS National Water Information System (U.S. Geological Survey, 2017).

Groundwater levels were recorded in the ‘Ewa Shaft from February 26, 2015, to June 1, 2016, (study period) to evaluate the relation between surface-water discharge measured at the continuous USGS gaging station (16212490) and the water level in the ‘Ewa Shaft. Groundwater was not extracted from the ‘Ewa Shaft during the study period. To better understand the surface-water loss near the ‘Ewa Shaft, two seepage runs, consisting of a series of discharge measurements along selected reaches of Honouliuli Stream and its tributary, were made under different flow conditions. The seepage-run data were used to quantify streamflow loss rates—an indicator of groundwater recharge—associated with the Honouliuli Stream and its tributary. The altitude and the latitude and longitude coordinates of the continuous-record stations and seepage-run discharge-measurement stations in the study area are listed in table 1.

Continuous Water-Level and Stream-Discharge Data

Available discharge data from USGS streamflow-gaging stations 16212490 and 16212480 indicate that both Honouliuli Stream and its tributary flowed intermittently during the study period. The maximum daily mean discharge at station 16212490 during the study period was 26.3 Mgal/d, the minimum and median daily mean discharges were 0 Mgal/d, and flow was observed at the station 37 percent of the time. The continuous stream-discharge data from USGS streamflow-gaging station 16212480 located on the Honouliuli tributary at an altitude of 629 ft just upstream of the Waiāhole Ditch water release point was not used directly in this analysis, but the data did provide an indication of when discharge measured at the downstream gaging station (16212490) contained runoff from rainfall as well as flow from the ditch release. The maximum daily mean discharge at station 16212480 during the study period was 2.7 Mgal/d, the minimum and median daily mean discharges were 0 Mgal/d, and flow was observed at the station 3 percent of the time. Daily rainfall at two rain-gage stations, the Kunia Substation 740, at an altitude of 273 ft (National Weather Service Cooperative station 515040, fig. 1) and Pālehua Corral 731.1, at an altitude of 1,140 ft (station 517654, fig. 1), were used to identify potential periods of runoff and regional groundwater recharge (fig. 2*A*). Groundwater-level data from the Kunia T41 deep monitor well (State well 3-2201-10; At the time of publication, data had not been published by the Honolulu Board of Water Supply) to the east of the ‘Ewa Shaft (fig. 1) were used to determine if groundwater levels in the shaft were changing due to Honouliuli streamflow or more widespread processes that would also affect groundwater levels recorded in Kunia T41.

Daily groundwater levels at the Kunia T41 deep monitor well, the daily rainfall records, and discharge at Honouliuli Stream gaging station (16212490) indicate that increases in groundwater levels at ‘Ewa Shaft and Kunia T41 appear to be related to rainfall (fig. 2). The concurrent increase in water levels at ‘Ewa Shaft and the nearby monitoring well during storms indicates that regional water-level changes related to increased recharge, reduced withdrawals (due to a decrease in demand during periods of rainfall), or both may

Table 1. Altitude and latitude and longitude coordinates of the continuous-record stations and the seepage-run discharge-measurement stations in the study area, O‘ahu, Hawai‘i.

[abv, above; blw, below; conf, confluence; ID, identifier; nr, near; Str, Stream; Trib, tributary; US, upstream; USGS, U.S. Geological Survey; –, not applicable or sensitive information; Database limitations preclude the use of Hawaiian diacritical marks in USGS station names]

Site ID[a]	USGS station number	USGS station name[b]	Altitude[c], in feet	Latitude[d]	Longitude[d]
Continuous-record stations					
–	16212480	Honouliuli Stream Tributary near Waipahu	629	21°24’06.6”	158°04’00.9”
5	16212490	Honouliuli Str at H-1 Freeway nr Waipahu	145	21°22’41.3”	158°02’41.2”
–	212252158025001	3-2202-21 Ewa Shaft (S3)	161	–	–
–	212250158015801	3-2201-10 Kunia T41 Deep Monitor Well	84	–	–
Seepage-run discharge-measurement stations					
1	212238158030201	Honouliuli Tributary US of culvert	210	21°22’37.8”	158°03’01.9”
2	212239158025301	Honouliuli Trib nr drain outlet abv conf	190	21°22’39.2”	158°02’53.2”
3	212240158024801	Honouliuli Tributary abv confluence	162	21°22’40.2”	158°02’47.8”
4	212241158024701	Honouliuli Stream abv confluence	161	21°22’41.2”	158°02’47.2”
5	16212490	Honouliuli Str at H-1 Freeway nr Waipahu	145	21°22’41.3”	158°02’41.2”
6	212240158023801	Honouliuli Str blw channel nr H1	133	21°22’39.8”	158°02’37.6”

[a]Refer to figure 5 for locations of the sites.

[b]Station names match the names used in the National Water Information System Web database.

[c]Altitude values interpolated from U.S. Geological Survey 1:24,000-scale digital hypsography data.

[d]Latitude and longitude coordinates in North American Datum of 1983.

be occurring; although these data do not preclude the possibility of local recharge from Honouliuli Stream. Two of the larger discharge events at the end of November 2015 and May 2016 are most likely some combination of natural streamflow and water being released from the Waiāhole Ditch system into the Honouliuli tributary. A storm also occurred at the end of August 2015, but due to a gap in the groundwater-level data collected at ‘Ewa Shaft, data from the August storm were not included in the analysis. Groundwater levels in ‘Ewa Shaft and discharge at the Honouliuli streamflow-gaging station measured at 30-minute intervals at the end of November 2015 and May 2016 are plotted in figure 3. The measured groundwater levels from ‘Ewa Shaft during these events steadily increase and appear to indicate a relation between discharge and increases in water levels in the ‘Ewa Shaft.

Groundwater levels in ‘Ewa Shaft and surface-water discharge at the Honouliuli H-1 gage during the February 8 and May 4, 2016, seepage runs (described in a later section of the report) are plotted in figure 4. The measured groundwater levels from ‘Ewa Shaft during the seepage runs do not appear to unequivocally indicate a response to the discharge in Honouliuli Stream. This may be related to the small magnitude and short duration of the discharge in Honouliuli Stream.

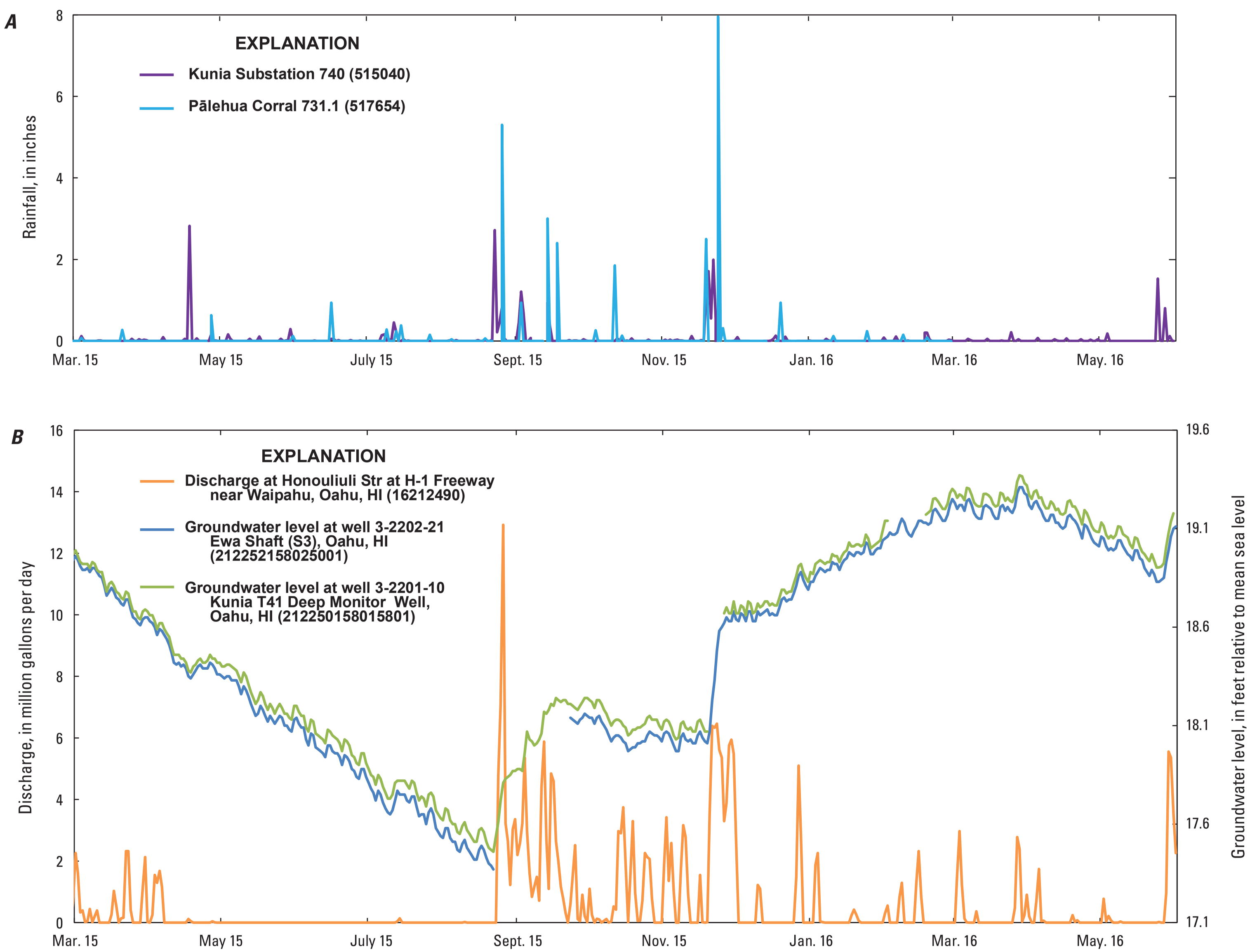

Figure 2. *A*, Daily rainfall at the Kunia Substation and the Pālehua Corral rain gages (National Oceanic and Atmospheric Administration, 2016). *B*, Daily streamflow at Honouliuli streamflow-gaging station and daily mean groundwater level at ‘Ewa Shaft (U.S. Geological Survey, 2017) and Kunia T41 deep monitor well (at the time of publication, the data had not been published by the Honolulu Board of Water Supply).

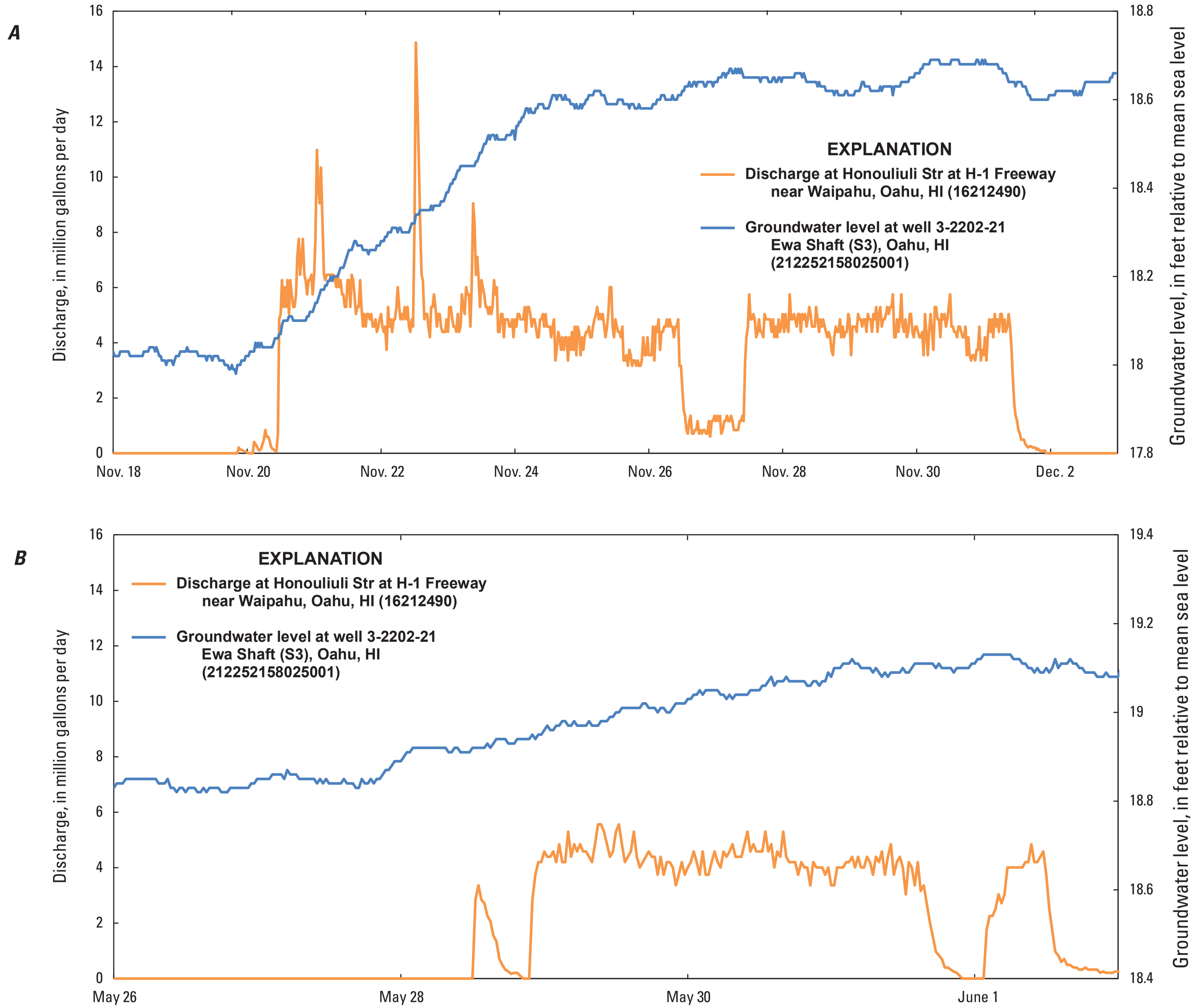

Figure 3. Groundwater level in ‘Ewa Shaft and discharge at the Honouliuli streamflow-gaging station (U.S. Geological Survey, 2017) at 30-minute intervals for a discharge event at (*A*) the end of November 2015 and (*B*) at the end of May 2016.

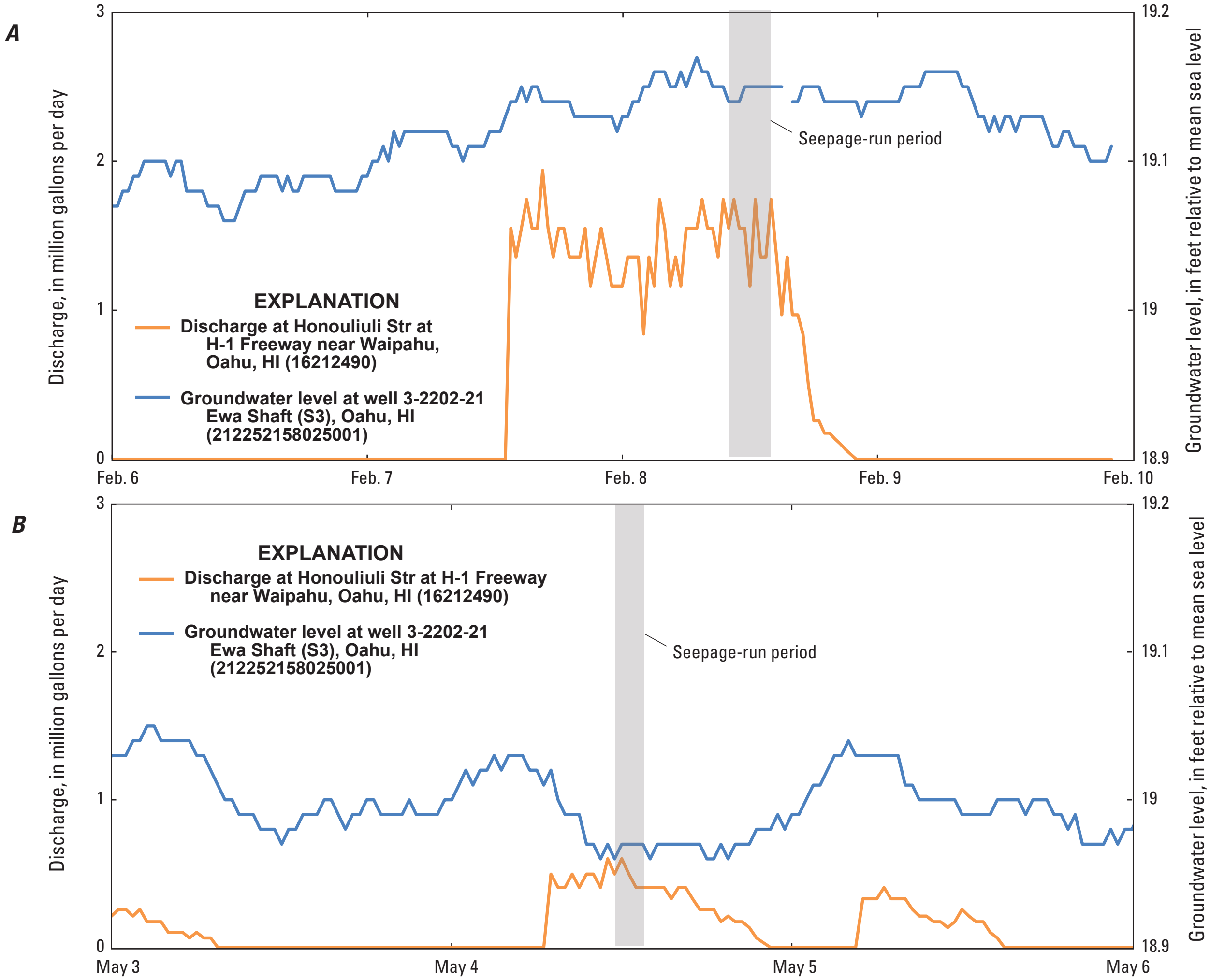

Figure 4. Groundwater level in ‘Ewa Shaft and discharge at the Honouliuli streamflow-gaging station (U.S. Geological Survey, 2017) at 30-minute intervals during the (*A*) February 8, 2016 seepage run, and (*B*) the May 4, 2016 seepage run.

Seepage Run

Seepage runs typically are conducted to determine the magnitude of streamflow gains and losses in selected stream reaches. A seepage run consists of making multiple same-day discharge measurements at selected sites along a stream. The discharge measurements should be made when streamflow is generally stable and direct runoff is considered negligible. Stability of flow conditions during a seepage run can be evaluated by recording the stage during the time when each discharge measurement is being made, and at the start and end of the seepage run. Measurements should be made at a common location with a stable reference point from which the stage can be accurately measured. Flow conditions during both of the seepage runs were documented by recording the stage during each discharge measurement, and by recording the stage relative to a pin installed at the continuous streamflow-gaging station (16212490) located immediately upstream from the concrete-lined reach of the Honouliuli Stream at the start and near the end of the seepage runs. Station 16212490 also provided a continuous record of stream stage for the duration of the seepage run.

Two seepage runs were conducted in this study, one in the wet season (February 8, 2016) with slightly higher flows and one in the dry season (May 4, 2016) with lower flows, to characterize the magnitude of the gains and losses along the Honouliuli Stream and its tributary in the ‘Ewa Shaft area. The seepage-run stations established for this study are listed in table 1. An abbreviated site identifier (site ID) was assigned to the stations for ease of reference in the report. Discharge measurements were also made at one of the continuous-record stations during the seepage runs. Among the six sites where discharges were measured during the seepage runs, three were in the Honouliuli tributary, one was in Honouliuli Stream upstream of the confluence with the Honouliuli tributary, and two were in Honouliuli Stream downstream of the confluence (fig. 5). The station at the highest altitude (210 ft, site 1) was about 1.9 miles (mi) downstream of the Waiāhole Ditch water release into the Honouliuli tributary and the station at the lowest altitude (133 ft, site 6) was about 50 ft downstream from the concrete-lined reach of Honouliuli Stream next to the ‘Ewa Shaft pumping facility.

In the study area, the Honouliuli Stream and its tributary and are ephemeral, flowing naturally only during storms, which is not conducive to seepage runs as a result of the flashy and unstable nature of streamflow during these periods. Streamflow at station 16212490 is augmented periodically by water releases from the Waiāhole Ditch. Therefore, to complete the seepage runs under stable-flow conditions, all discharge measurements for the seepage runs were made during periods of releases of water from the Waiāhole Ditch into the Honouliuli tributary downstream of station 16212480 (fig. 1). The duration of the water releases from the Waiāhole Ditch system varied. The release for the February 8, 2016 seepage run began around mid-day February 7, 2016, and ended just before midnight on February 8, 2016 (fig. 4). The February seepage run took about five hours to complete (discharge measurements began at 9:37 a.m. and finished at 2:28 p.m.). The release for the May 4, 2016, seepage run began around 6:00 a.m. on May 4, 2016, and ended just before midnight the same day (fig. 4). The May seepage run took about two hours to complete (discharge measurements began at 11:51 a.m. and finished at 1:29 p.m.). Although the extent of wetting of the streambed sediments during the seepage runs was not characterized, water was flowing for at least a few hours in the measured reaches before starting the seepage run measurements. No other return flows or diversions along the Honouliuli Stream and its tributary were documented during the reconnaissance survey in the reaches selected for the seepage runs. For both seepage runs, the estimated seepage gains and losses in the measured reaches of the Honouliuli Stream and its tributary were calculated as the difference between the discharges measured at the upstream and downstream stations. During the seepage runs, streamflow gains and losses were estimated along a 0.53-mi reach of Honouliuli Stream and its tributary.

During the wet-season seepage run of February 8, 2016, discharge measurements were made at six sites located between stream-channel altitudes of about 133 and 210 ft above mean sea level (table 1; fig. 5). Because the stream stage changed during the seepage-run measurement period,

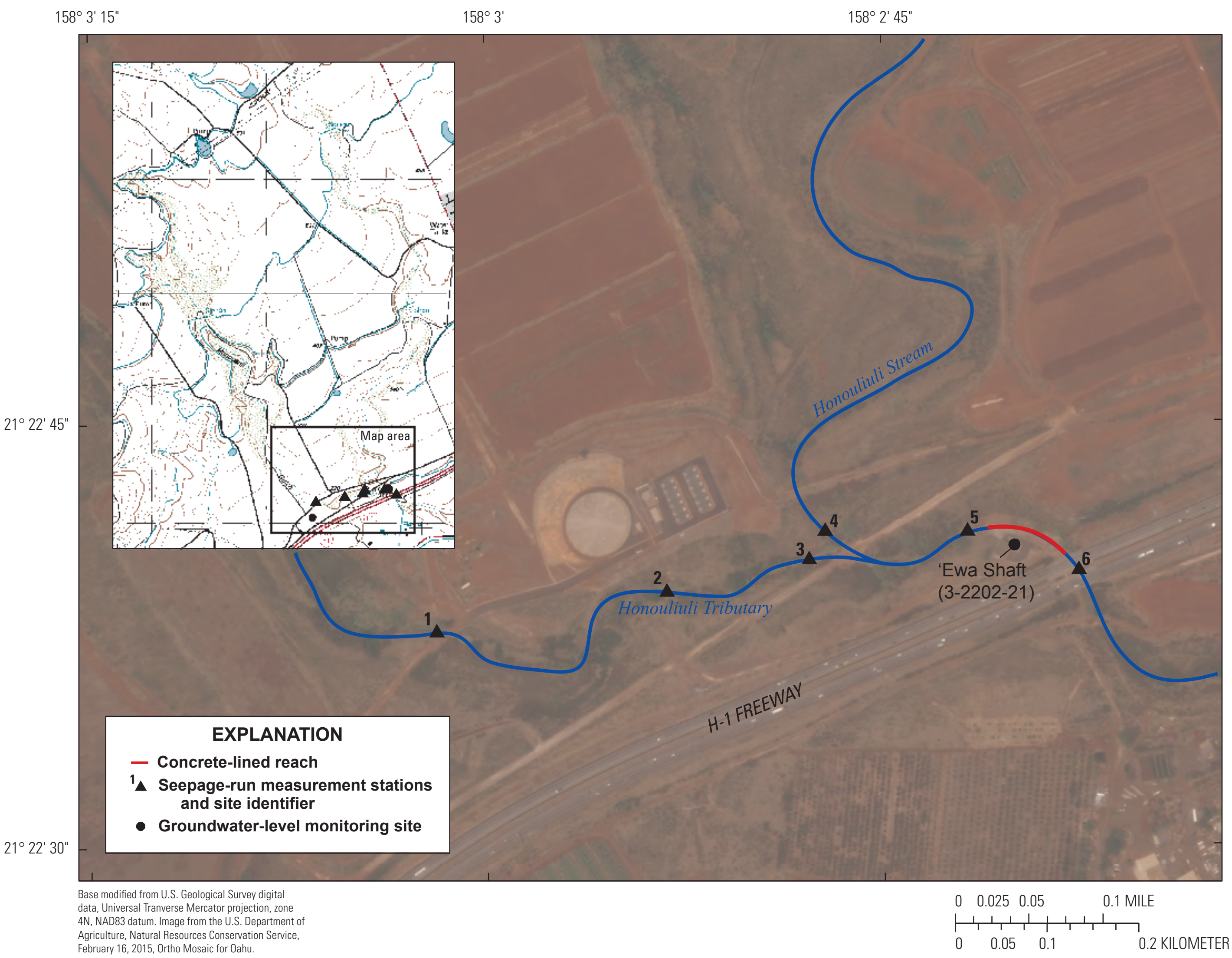

Figure 5. Map showing seepage-run measurement stations for the February 8 and May 4, 2016, seepage runs on the Honouliuli Stream and its tributary and the location of the ‘Ewa Shaft. Inset in map shows where the seepage-run measurement stations are located within the part of the Honouliuli watershed included in the study area.

seepage-loss calculations were made using the difference between each measured discharge and the average discharge at the streamflow-gaging station (site 5) during each discharge measurement period to account for the temporal variability of discharge within the seepage-run reaches (table 2). The flow at the Honouliuli Stream H-1 gaging station 16212490 was decreasing slightly during the approximately 5-hour seepage run. Flow ranged from 1.91 to 1.16 Mgal/d and averaged about 1.58 Mgal/d (fig. 4). In addition the discharge at the gage was fairly erratic, with sudden rises and falls, due to a sensitive control at the gage (small changes in stage equate to large changes in discharge). Manual stage readings from one of the gaging station’s established reference points ranged from 5.19 ft at 8:47 a.m. to 5.16 ft at 1:40 p.m. Readings from the reference point confirm that the stage in the Honouliuli Stream and tributary was decreasing slightly with a 0.03-ft drop in stage during the approximate 5-hour duration of the seepage run.

Between site 1 and site 5 (USGS gaging station 16212490 about 0.42 mi downstream from site 1), flow in Honouliuli Stream and its tributary decreased from 2.15 to 1.62 Mgal/d (table 2; fig. 5). Between sites 2 and 5 (about 0.22 mi downstream of site 2), flow in Honouliuli Stream and its tributary decreased from 2.02 to 1.71 Mgal/d (table 2). At site 4 there was no flow in Honouliuli Stream above its confluence with the Honouliuli tributary. All flow for the seepage run in the Honouliuli tributary resulted from the Waiāhole Ditch flow release. Between sites 3 and 5, flow decreased slightly from 1.69 to 1.53 Mgal/d in Honouliuli Stream downstream of the confluence (table 2). Between sites 5 and 6 (0.11 mi downstream of site 5), flow in Honouliuli Stream decreased from 1.62 to 1.47 Mgal/d during the first measurement (table 2). During the second check measurement at site 6, which was made during more stable flow conditions, flow in Honouliuli Stream decreased from 1.53 Mgal/d at site 5 to 1.33 Mgal/d (table 2). The seepage rate in million gallons per day per mile (Mgal/d/mi) for the 4 reaches analyzed (reaches between sites 1 and 5; sites 2 and 5; sites 3 and 5; and sites 5 and 6) ranged from 1.26 Mgal/d/mi to 1.78 Mgal/d/mi of flow lost. The largest loss occurred in the reach between sites 5 and 6, which includes the concrete lined reach of the Honouliuli Stream channel (table 2). The more stable estimate of loss between sites 5 and 6 during the check measurement resulted in a seepage rate of 1.78 Mgal/d/mi.

Results from the wet-season seepage run indicate that the lower reach between sites 5 and 6, from about 40 ft upstream of the USGS gaging station to about 50 ft downstream of the concrete channel, likely loses water to the subsurface. Photographs of the Honouliuli streamflow-gaging station pool located just above the concrete-lined channel, a view of the concrete-lined channel looking downstream, and the measurement section at site 6 on May 4, 2016, are included in figure 6. These results focused the dry-season seepage run on the pair of sites (sites 5 and 6 on fig. 5) defining the lower reach, and shifted the seepage-run measurement approach. Multiple simultaneous measurements were made by two hydrographers (one stationed at site 5 and the other at site 6) to best account for possible variability of streamflow.

During the dry-season seepage run of May 4, 2016, discharge measurements were made at sites 5 and 6 (table 3; fig. 5), both of which were located on Honouliuli Stream downstream from the tributary. The two sites were located between stream-channel altitudes of about 133 and 145 ft above mean sea level. Three successive measurements were made at each site. During the seepage run, flow at the Honouliuli Stream H-1 gaging station 16212490 (site 5) was declining slightly and averaged about 0.49 Mgal/d (fig 4*B*). Manual stage readings from one of the gaging station’s established reference points ranged from 5.11 ft at 11:45 a.m. to 5.08 ft at 1:30 p.m., confirming that the stage in the Honouliuli Stream was decreasing slightly with a 0.03-ft drop in stage for the approximate 2-hour duration of the seepage run. Another independent temporary reference mark was monitored at site 6, showing a stable stage during the first paired measurements and a slightly declining stage for the last two paired measurements.

Between site 5 (USGS gaging station 16212490) and site 6 (about 0.11 mi downstream from site 5), flow in Honouliuli Stream decreased from 0.57 to 0.54 Mgal/d during the first set of measurements (table 3). The stage in Honouliuli Stream during the first set of paired measurements was stable. During the second set of measurements, flow between sites 5 and 6 in Honouliuli Stream decreased from 0.52 to 0.51 Mgal/d (table 3), respectively, but the stage at both the gage and the lower temporary reference mark showed a 0.01 ft decrease, adding uncertainty to both measurements. During the third set of measurements, flow between sites 5 and 6 in Honouliuli Stream decreased from 0.47 to 0.46 Mgal/d (table 3), respectively, but the stage at both reference marks again dropped by 0.01 ft adding uncertainty to the discharge measurements. Even with the added uncertainty as a result of the slight decrease in stream stage, each pair of measurements taken at sites 5 and 6 shows that flow is being lost to the subsurface in the 0.11 mi reach. The seepage rate for the reach analyzed, which includes the concrete-lined reach of the Honouliuli Stream channel, ranged from 0.09 to 0.27 Mgal/d/mi. The largest loss (0.27 Mgal/d/mi) of surface water to the subsurface occurred at the beginning of the seepage run when the stage of the stream was the highest and most stable (table 3).

Table 2. Honouliuli Stream and tributary seepage investigation of February 8, 2016.

[ID, identifier; Mgal/d, million gallons per day; mi, miles; --, not applicable; A series of discharge measurements were made on February 8, 2016, on Honouliuli Stream and tributary, Oʻahu, Hawaiʻi, to determine streamflow gains and losses. The discharge measurements were made during a water release from the Waiāhole Ditch to the tributary. Due to variability in stage during the seepage run, seepage loss calculations were made using the difference between each measured discharge and the average discharge at the streamflow-gaging station (site 5) during the period of each measurement to attempt to account for the temporal variability of discharge within the seepage-run reaches]

Site ID[a]	Measurement time	Discharge, in Mgal/d	Distance to site 5, in mi	Average discharge at site 5 during indicated measurement time[c], in Mgal/d	Seepage loss, in Mgal/d	Seepage rate, in Mgal/d/mi
1	09:37-10:00	2.15	0.42	1.62	0.53 (2.15–1.62)	1.26
2	10:26-10:51	2.02	0.22	1.71	0.31 (2.02–1.71)	1.40
3	11:17-11:44	1.69	0.1	1.53	0.16 (1.69–1.53)	1.58
4	11:52-11:54	0	–	–	–	–
5	12:21-12:52	1.94	0	1.71	–	–
6	13:15-13:40	1.47	0.11	1.62	0.15 (1.62–1.47)	1.38
6[b]	13:51-14:28	1.33	0.11	1.53	0.20 (1.53–1.33)	1.78

[a]Refer to figure 5 for locations of the sites.

[b]Check measurement made under more stable-flow conditions.

[c]Average values were computed using all data values recorded within and inclusive of the indicated starting and ending measurement times.

Table 3. Honouliuli Stream and tributary seepage investigation of May 4, 2016.

[ID, identifier; Mgal/d, million gallons per day; mi, miles; --, not applicable; A series of paired discharge measurements were made on May 4, 2016, on Honouliuli Stream and tributary, Oʻahu, Hawaiʻi, to determine seepage gains and losses in the 0.11-mi stream reach between the sites. The discharge measurements were made during a fairly stable water release from the Waiāhole Ditch to the tributary]

Site ID[a]	Measurement time	Discharge, in Mgal/d	Seepage loss, in Mgal/d	Seepage rate, in Mgal/d/mi
5	11:51-12:09	0.57	–	–
6	11:45-12:15	0.54	0.03 (0.57–0.54)	0.27
5	12:21-12:40	0.52	–	–
6	12:17-12:54	0.51	0.01 (0.52–0.51)	0.09
5	13:00-13:18	0.47	–	–
6	13:00-13:29	0.46	0.01 (0.47–0.46)	0.09

[a]Refer to figure 5 for locations of the sites.

A

B

C

Figure 6. Selected photographs of the Honouliuli Stream measurement sites and the concrete-lined channel near the ‘Ewa Shaft on May 4, 2016. *A*, Looking upstream at the streamflow-gaging station (16212490) pool for site 5. *B*, Looking downstream in concrete-lined reach of the Honouliuli Stream. *C*, Looking upstream at the seepage-run measurement cross section for site 6, located downstream of the concrete-lined reach of the Honouliuli Stream channel.

Study Limitations and Additional Data Needs

Seepage rates were calculated as the difference between the upstream and downstream discharges over the length of stream reach. Considering the potential error in the seepage-run measurements, the estimated seepage rates may reflect some uncertainty relative to the true gains and losses within a reach. Contributing factors to discharge-measurement errors include the condition of the measuring instrument and instrument error, characteristics of the measurement cross section, spacing and number of observation verticals in a cross section, changing stage during the measurement, flow depth and velocity, and environment (Rantz and others, 1982). Additional discharge measurements at the established seepage-run sites during periods of higher stable discharge in Honouliuli Stream would increase the level of confidence in the estimated seepage rates and help to bracket the possible range of losses in the area.

A comparison of the water-quality characteristics of ‘Ewa Shaft’s water, the shallow water-table aquifer, and the Honouliuli Stream could also help discriminate the source of bacteria by (1) using water temperature, stable isotopes, or dye tracer studies, or (2) fingerprinting the bacteria populations in the water using a polymerase chain reaction on the microbial deoxyribonucleic acid (DNA).

Summary

Records of groundwater levels from ‘Ewa Shaft and surface-water discharge at the Honouliuli Stream H-1 streamflow-gaging station appear to indicate a correlation between discharge and increases in water levels in the ‘Ewa Shaft. However, concurrent increases in groundwater levels at ‘Ewa Shaft and Kunia T41 deep monitor well that occurred during periods of heavy rainfall indicate that regional water-level changes related to increased regional recharge, reduced withdrawals, or both may be occurring. Local recharge from the Honouliuli Stream channel also may occur during periods when Honouliuli Stream is flowing, although this phenomenon may not be identifiable from the groundwater-level records alone. The measured groundwater levels from ‘Ewa Shaft during the seepage runs do not appear to unequivocally indicate a response to the discharge in Honouliuli Stream. This may be related to the small magnitude and short duration of the measured discharges in Honouliuli Stream.

Two seepage runs were made during periods when Honouliuli Stream was flowing. The streamflow was mainly related to the release of water from the Waiāhole Ditch system into the stream channel. Both seepage runs indicated that surface water in the 0.11-mi reach in the immediate area adjacent to ‘Ewa Shaft was being lost to the subsurface. The estimated seepage-loss rates in the vicinity of ‘Ewa Shaft from the two seepage runs generally ranged from 0.27 to 1.78 Mgal/d/mi of stream reach, although higher seepage rates may occur during periods of higher discharge in Honouliuli Stream.

Seepage from the Honouliuli Stream channel in the vicinity of ‘Ewa Shaft was documented as part of this study and represents a potential source of bacteria to the ‘Ewa Shaft. However, the scope of this study was limited to evaluating location and quantity of surface-water loss in Honouliuli Stream near the ‘Ewa Shaft and, therefore, other potential sources of bacteria were not identified, but likely exist.

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