

Prepared in cooperation with the U.S. Navy

December 23, 2021, Red Hill Synoptic Groundwater-Level Survey, Hālawā Area, O‘ahu, Hawai‘i



Open-File Report 2022–1018

Cover. View from Camp H.M. Smith, O'ahu, Hawai'i, looking east towards the Red Hill Bulk Fuel Storage Facility. Photograph by Rylen Nakama, U.S. Geological Survey, February 11, 2022.

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By Rylen K. Nakama, Jackson N. Mitchell, and Delwyn S. Oki

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

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Pressure	
pound per square inch (lb/in ²)	6.895	kilopascal (kPa)

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

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32.$$

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

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8.$$

Datum

Vertical coordinate information is referenced to local mean sea level.

Horizontal coordinate information is referenced to the North American Datum of 1983.

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

Supplemental Information

State well numbers used by the Hawai'i Commission on Water Resource Management include three digits after the second dash. For this report, the first digit after the second dash is invariably zero and was omitted.

Abbreviations

BWS	Honolulu Board of Water Supply
CWRM	Hawai'i Commission on Water Resource Management
HST	Hawai'i standard time
MP	measuring point
NAVFAC	Naval Facilities Engineering Command
USGS	U.S. Geological Survey
USN	U.S. Navy

Contents

Acknowledgments	iii
Abstract	1
Introduction.....	1
Purpose and Scope	1
Methods.....	1
Discrete Water Levels.....	7
Equipment.....	7
Tape Corrections.....	7
Gyroscopic-Survey Corrections	7
Continuous Water Levels.....	7
Equipment.....	7
Data Processing.....	7
Data	8
Limitations	8
Summary	10
References Cited.....	10

Figures

1. Wells included in the December 23, 2021, Red Hill synoptic groundwater-level survey in the Hālawā area, O‘ahu, Hawai‘i.....	2
2. Measured groundwater levels in wells during the December 23, 2021, 9:00 a.m. to 12:00 p.m. Hawai‘i standard time (HST), Red Hill synoptic groundwater-level survey in the Hālawā area, O‘ahu, Hawai‘i.....	9

Table

1. List of wells and open intervals, measuring-point altitudes, and groundwater levels measured during the December 23, 2021, Red Hill synoptic groundwater-level survey in the Hālawā area, O‘ahu, Hawai‘i.....	3
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December 23, 2021, Red Hill Synoptic Groundwater-Level Survey, Hālawā Area, O‘ahu, Hawai‘i

By Rylen K. Nakama, Jackson N. Mitchell, and Delwyn S. Oki

Abstract

On December 23, 2021, groundwater levels were measured in selected wells in the Hālawā area, O‘ahu, Hawai‘i, constituting a synoptic groundwater-level survey (shortened herein to “synoptic survey”) of the area. Groundwater levels were measured mainly from 9:00 a.m. to 12:00 p.m. (times listed in Hawai‘i standard time) and provide a snapshot of groundwater levels during the survey period. Following a reported fuel release that affected groundwater quality in the Red Hill area, several production wells were shut down in the weeks prior to the synoptic survey. These wells include the Red Hill Shaft (shut down on November 28, 2021) and the Hālawā Shaft (shut down on December 3, 2021, except for weekly, short-duration operations for water-quality sampling). Groundwater levels measured in wells during the synoptic survey ranged from 16.34 to 19.77 feet above mean sea level.

The groundwater levels collected during the multiagency synoptic survey contain uncertainty because of several potential sources of error associated with (1) the accuracy of the measuring tapes used, (2) the accuracy of the measuring-point altitude at the top of each well, (3) well plumbness and alignment, (4) human error, and (5) changing conditions during the survey period. Because of these potential sources of error, comparability of groundwater-level measurements may be affected. Some of the sources of uncertainty can be addressed and lead to improved accuracy and comparability of the groundwater levels. For example, uncertainty associated with the measuring-point altitudes can be addressed by resurveying measuring-point altitudes to a common vertical datum using consistent surveying methods.

Introduction

A synoptic groundwater-level survey (shortened herein to “synoptic survey”) provides a snapshot of groundwater levels (shortened herein to “water levels”) in wells in the surveyed area. On December 23, 2021, mainly during the three-hour period between 9:00 a.m. and 12:00 p.m. (Hawai‘i standard time), water levels were measured in selected wells in the Hālawā area, O‘ahu, Hawai‘i (fig. 1; table 1). The multiagency synoptic survey was completed following a reported fuel release at the Red Hill Bulk Fuel Storage Facility within the naval reservation at Red Hill in November 2021 (State of Hawai‘i,

2021) and the subsequent shutdown of several production wells in the area, including the Red Hill Shaft (well 3–2254–01, shut down on November 28, 2021) and the Hālawā Shaft (well 3–2354–01, shut down on December 3, 2021, except for weekly, short-duration operations for water-quality sampling).

The shutdown of production wells created a hydrologic condition different from the one that previously existed under typical withdrawal conditions. The December 23, 2021, synoptic survey provides a snapshot of water levels when Red Hill Shaft and Hālawā Shaft—the two largest production wells in the area—were shut down for about 3 weeks.

The U.S. Geological Survey (USGS) maintains a network of groundwater monitoring sites in the greater Hālawā area. Continuous water-level data are available on the USGS National Water Information System Web Interface (NWISWeb) database (U.S. Geological Survey, 2022). Mitchell and Oki (2018) summarized continuous water-level data collected from wells in the Hālawā area during a period when withdrawals from Hālawā Shaft and Red Hill Shaft were temporally variable.

Purpose and Scope

This report presents data collected during a synoptic survey on December 23, 2021, mainly during the 3-hour period from 9:00 a.m. to 12:00 p.m. Discrete water-level measurements were made with calibrated measuring tapes in 28 wells and data from 2 additional wells with continuously recording pressure transducers were also included. To quantify water-level change during the survey period, water levels were measured twice at five selected sites: once near the beginning of the survey period and a second time near the end of the survey period.

The report also describes the data-collection methods and quality-assurance and quality-control measures for this study. The scope of the report is limited to a noninterpretive presentation of data and includes a discussion of data limitations.

Methods

Water-level measurements for the synoptic survey on December 23, 2021, were collected by the Honolulu Board of Water Supply (BWS), Hawai‘i Commission on Water Resource Management (CWRM), U.S. Navy (USN), and USGS. Water

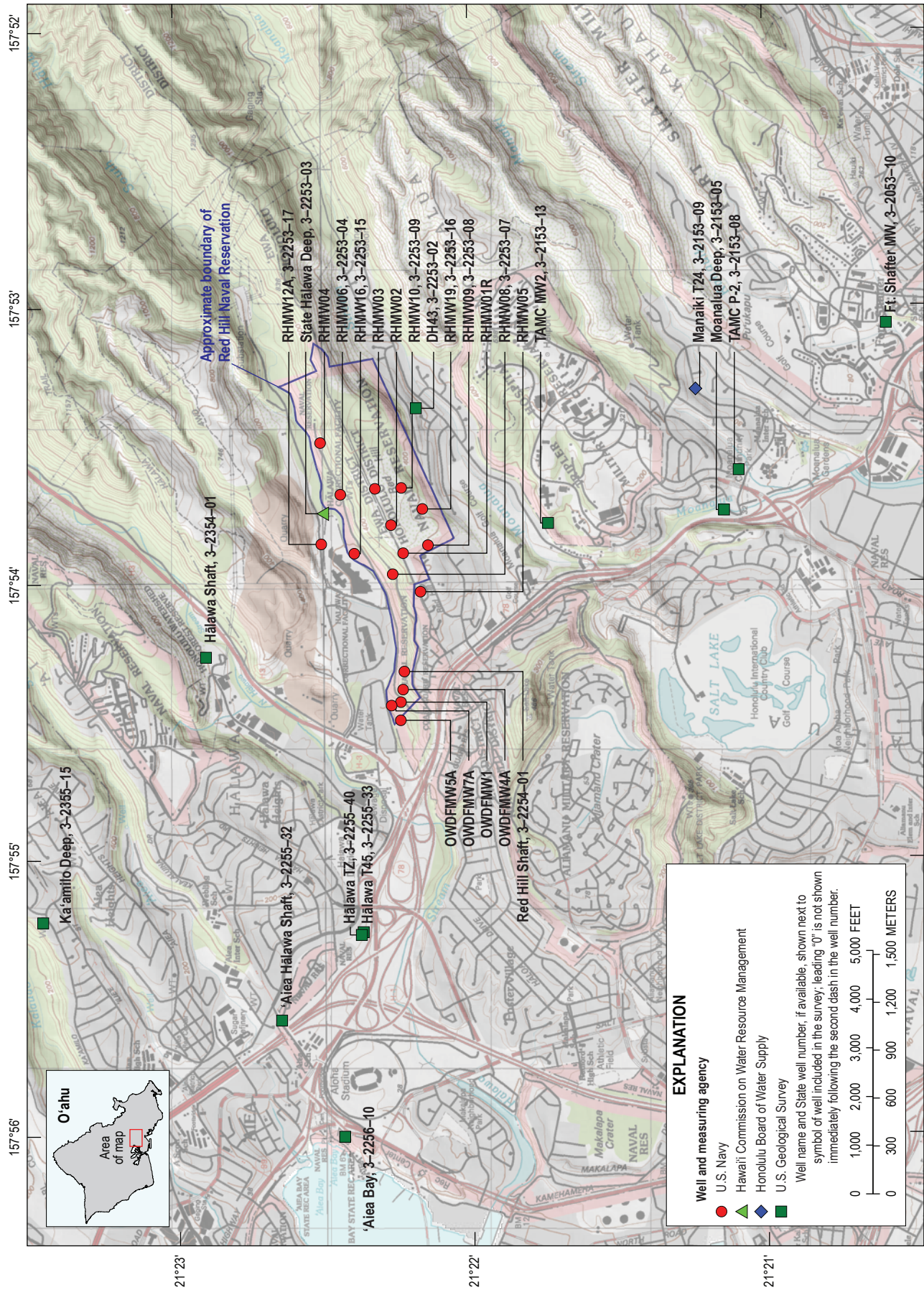


Figure 1. Wells included in the December 23, 2021, Red Hill synoptic groundwater-level survey in the Hālawā area, O‘ahu, Hawai‘i.

Base modified from U.S. Geological Survey Digital Raster Graphics topographic map, 1:24,000 scale, Universal Transverse Mercator projection, zone 4, North American Datum of 1983.

Table 1. List of wells and open intervals, measuring-point altitudes, and groundwater levels measured during the December 23, 2021, Red Hill synoptic groundwater-level survey in the Hālaḡa area, Oʻahu, Hawaiʻi.

[Site locations are provided in figure 1. The U.S. Geological Survey (USGS) site names lack Hawaiian punctuation owing to limitations within the USGS National Water Information System database. Data can be accessed at <https://doi.org/10.5066/F7P5KJN>. HI, Hawaiʻi; HST, Hawaiʻi standard time; MP, measuring point; nr, near; Res, Reservation; --, not applicable or not available; CWRM, Hawaiʻi Commission on Water Resource Management; <, less than indicated value; BWS, Honolulu Board of Water Supply]

Common name	USGS site identification	USGS site name	Measurement time, in HST	Water level ^{1,2} , in feet	Measuring equipment	Measuring agency	Approximate top altitude of open or screened well interval ¹ , in feet	Approximate bottom altitude of open or screened well interval ¹ , in feet	MP altitude ² , in feet	Source of MP altitude	Depth to water relative to MP, in feet	Gyroscopic-survey correction to be added to depth-to-water measurement ³ , in feet	Tape-specific correction to be added to depth-to-water measurement ³ , in feet
RHMW01R	212214157535402	Red Hill RHMW01R, Oahu, HI	9:35 a.m.	18.54	Electric tape	U.S. Navy	28	8	101.76	U.S. Navy	83.23	-- ⁵	-0.01
RHMW02	212216157534701	Red Hill RHMW02, Oahu, HI	9:20 a.m.	18.52	Electric tape	U.S. Navy	21	6	104.60	U.S. Navy	86.15	-0.06	-0.01
RHMW03	212219157533901	Red Hill RHMW03, Oahu, HI	9:03 a.m.	18.55	Electric tape	U.S. Navy	19	4	120.90	U.S. Navy	102.40	-0.04	-0.01
RHMW03	212219157533901	Red Hill RHMW03, Oahu, HI	12:02 p.m.	18.57	Electric tape	U.S. Navy	19	4	120.90	U.S. Navy	102.38	-0.04	-0.01
RHMW04	212231157532901	Red Hill RHMW04, Oahu, HI	9:02 a.m.	18.33	Electric tape	U.S. Navy	23	8	312.11	U.S. Navy	293.84	-0.02	-0.04
RHMW04	212231157532901	Red Hill RHMW04, Oahu, HI	12:18 p.m.	18.40	Electric tape	U.S. Navy	23	8	312.11	U.S. Navy	293.77	-0.02	-0.04
RHMW05	212210157540201	Red Hill RHMW05, Oahu, HI	9:49 a.m.	18.53	Electric tape	U.S. Navy	24	9	101.31	U.S. Navy	82.80	-0.01	-0.01
RHMW06	212226157534101	3-2253-04 Red Hill RHMW06, Oahu, HI	11:40 a.m.	18.35	Electric tape	U.S. Navy	27	-3	259.26	U.S. Navy	240.95	-0.01	-0.03
RHMW08	212216157535801	3-2253-07 Red Hill RHMW08, Oahu, HI	9:25 a.m.	18.35	Electric tape	U.S. Navy	29	-1	310.62	U.S. Navy	292.34	-0.03	-0.04
RHMW09	212209157535201	3-2253-08 Red Hill RHMW09, Oahu, HI	10:44 a.m.	18.36	Electric tape	U.S. Navy	29	-1	395.57	U.S. Navy	377.50	-0.24	-0.05
RHMW10	212213157533901	3-2253-09 Red Hill RHMW10, Oahu, HI	9:58 a.m.	18.37	Electric tape	U.S. Navy	29	-1	495.78	U.S. Navy	477.56	-0.09	-0.06

Table 1. List of wells and open intervals, measuring-point altitudes, and groundwater levels measured during the December 23, 2021, Red Hill synoptic groundwater-level survey in the Hālawā area, O‘ahu, Hawai‘i.—Continued

Common name	USGS site identification	USGS site name	Measurement time, in HST	Water level ^{1,2} , in feet	Measuring equipment	Measuring agency	Approximate top altitude of open or screened well interval ⁶ , in feet	Approximate bottom altitude of open or screened well interval ⁶ , in feet	MP altitude ² , in feet	Source of MP altitude	Depth to water relative to MP, in feet	Gyroscopic-survey correction to be added to depth-to-water measurement ³ , in feet	Tape-specific correction to be added to depth-to-water measurement ⁴ , in feet
RHMW12A	212230157535202	3-2253-17 Red Hill RHMW12A, Oahu, HI	12:42 p.m.	18.21	Electric tape	U.S. Navy	-175	-195	238.62	U.S. Navy	220.44	-- ⁵	-0.03
RHMW16	212224157535401	3-2253-15 Red Hill RHMW16, Oahu, HI	11:57 a.m.	17.47	Electric tape	U.S. Navy	-273	-293	219.13	U.S. Navy	201.69	-- ⁵	-0.03
RHMW19	212212157534601	3-2253-16 Red Hill RHMW19, Oahu, HI	10:24 a.m.	18.37	Electric tape	U.S. Navy	28	-2	444.82	U.S. Navy	426.51	-- ⁵	-0.06
OWDFMW1	212214157542601	Red Hill OWDFMW1, Oahu, HI	11:38 a.m.	18.39	Electric tape	U.S. Navy	6	-5	138.14	U.S. Navy	119.80	-0.03	-0.02
OWDFMW4A	212214157542301	Red Hill OWDFMW4A, Oahu, HI	11:25 a.m.	18.38	Electric tape	U.S. Navy	15	-5	166.84	U.S. Navy	148.48	-- ⁵	-0.02
OWDFMW5A	212214157543001	Red Hill OWDFMW5A, Oahu, HI	11:10 a.m.	18.48	Electric tape	U.S. Navy	-4	-24	118.78	U.S. Navy	100.31	-- ⁵	-0.01
OWDFMW7A	212216157542701	Red Hill OWDFMW7A, Oahu, HI	10:56 a.m.	18.45	Electric tape	U.S. Navy	-104	-124	119.64	U.S. Navy	101.20	-- ⁵	-0.01
Red Hill Shaft	212225157542601	3-2254-01 Red Hill Shaft (S11), Oahu, HI	10:18 a.m.	-- ⁶	Electric tape	U.S. Navy	--	--	-- ⁶	U.S. Navy	87.33	-- ⁷	-0.01
Ka‘amilo Deep	212340157552301	3-2355-15 Kaamilo Deep, Oahu, HI	10:36 a.m.	16.34	Steel tape	USGS	11	-1,126	493.29	USGS	476.94	-- ⁵	0.01
Hālawā Shaft	212305157542601	3-2354-01 Hālawā Shaft (S12), Oahu, HI	9:00 a.m.	16.96	Transducer	USGS	--	--	23.21	USGS	6.25	-- ⁷	0.00
Hālawā Shaft	212305157542601	3-2354-01 Hālawā Shaft (S12), Oahu, HI	12:00 p.m.	17.00	Transducer	USGS	--	--	23.21	USGS	6.21	-- ⁷	0.00

Table 1. List of wells and open intervals, measuring-point altitudes, and groundwater levels measured during the December 23, 2021, Red Hill synoptic groundwater-level survey in the Hālawā area, O‘ahu, Hawai‘i.—Continued

Common name	USGS site identification	USGS site name	Measurement time, in HST	Water level ^{1,2} , in feet	Measuring equipment	Measuring agency	Approximate top altitude of open or screened well interval ⁶ , in feet	Approximate bottom altitude of open or screened well interval ⁶ , in feet	MP altitude ² , in feet	Source of MP altitude	Depth to water relative to MP, in feet	Gyroscopic-survey correction to be added to depth-to-water measurement ³ , in feet	Tape-specific correction to be added to depth-to-water measurement ⁴ , in feet
‘Aiea Hālawā Shaft	212253157554301	3-2255-32 Halawa Shaft (S5), Oahu, HI	9:00 a.m.	16.59	Steel tape	USGS	--	--	28.05	U.S. Navy	11.46	-- ⁷	0.00
‘Aiea Bay	212238157561101	3-2256-10 Aiea Bay nr Naval Res (187-B), Oahu, HI	9:00 a.m.	16.58	Steel tape	USGS	-133	-163	26.07	USGS	9.49	-- ⁷	0.00
‘Aiea Bay	212238157561101	3-2256-10 Aiea Bay nr Naval Res (187-B), Oahu, HI	11:58 a.m.	16.57	Steel tape	USGS	-133	-163	26.07	USGS	9.50	-- ⁷	0.00
Hālawā TZ	212233157552302	3-2255-40 Halawa TZ Well, Oahu, HI	11:24 a.m.	16.71	Steel tape	USGS	0	-955	60.04	USGS	43.33	-- ⁷	0.00
Hālawā T45	212233157552301	3-2255-33 Halawa Observation Well (T45), Oahu, HI	11:35 a.m.	16.74	Steel tape	USGS	-2	-28	57.85	USGS	41.11	-- ⁷	0.00
State Hālawā Deep	212241157535501	3-2253-03 State Halawa Deep, Oahu, HI	9:46 a.m.	19.09	Steel tape	USGS	-25	-1,350	226.68	U.S. Navy	207.60	-0.01	0.00
State Hālawā Deep	212241157535501	3-2253-03 State Halawa Deep, Oahu, HI	2:18 p.m.	19.12	Electric tape	CWRM	-25	-1,350	226.68	U.S. Navy	207.65	-0.01	-0.08
DH 43	212225157533001	3-2253-02 Moanalua DH 43, Oahu, HI	11:17 a.m.	19.77	Steel tape	USGS	< -10	-42	234.32	USGS	214.56	-- ⁵	-0.01
TAMC MW2	212144157534701	3-2153-13 TAMC MW2, Oahu, HI	10:00 a.m.	19.23	Steel tape	USGS	26	16	179.70	USGS	160.48	-- ⁵	-0.01
Moanalua Deep	212123157535501	3-2153-05 Moanalua Fresh Water Mon. Well, Oahu, HI	10:36 a.m.	19.20	Steel tape	USGS	-31	-1,284	37.03	USGS	17.83	-- ⁷	0.00

Table 1. List of wells and open intervals, measuring-point altitudes, and groundwater levels measured during the December 23, 2021, Red Hill synoptic groundwater-level survey in the Hālawā area, O‘ahu, Hawai‘i.—Continued

Common name	USGS site identification	USGS site name	Measurement time, in HST	Water level ^{1,2} , in feet	Measuring equipment	Measuring agency	Approximate top altitude of open or screened well interval ³ , in feet	Approximate bottom altitude of open or screened well interval ³ , in feet	MP altitude ² , in feet	Source of MP altitude	Depth to water relative to MP, in feet	Gyroscopic-survey correction to be added to depth-to-water measurement ⁴ , in feet	Tape-specific correction to be added to depth-to-water measurement ⁴ , in feet
TAMC P-2	212117157534601	3-2153-08 TAMC P-2 (W154-1B), Oahu, HI	10:09 a.m.	19.26	Steel tape	USGS	-27	-276	33.21	USGS	13.95	-- ⁷	0.00
Manaiki T24	212127157532001	3-2153-09 Manaiki (T24), Oahu, HI	9:00 a.m.	⁸ 19.17	Transducer	BWS	-8	-57	60.90	BWS	--	--	--
Ft. Shafter MW	212046157531401	3-2053-10 Ft. Shafter MW, (W146), Oahu, HI	9:40 a.m.	19.35	Steel tape	USGS	-147	-257	24.79	USGS	5.44	-- ⁷	0.00

¹Water level is computed from the following equation: Water level = MP altitude – (Depth to water relative to MP + Gyroscopic-survey correction + Tape-specific correction).²Altitude refers to feet above local mean sea level.³Gyroscopic-survey correction (Naval Facilities Engineering Command Hawaii, 2018) is added to depth-to-water value (or subtracted from the uncorrected water-level value).⁴Tape-specific correction is added to depth-to-water value (or subtracted from the uncorrected water-level value).⁵Gyroscopic-survey correction not available.⁶Measuring-point altitude not available at the time this report was prepared.⁷Gyroscopic-survey correction not applicable because measurement made in large diameter well in which tape hangs freely or well with shallow depth to water.⁸Honolulu Board of Water Supply, 2022, written communication.

levels were measured at 30 sites: 3 Maui-type wells (‘Aiea Hālawa Shaft, Hālawa Shaft, and Red Hill Shaft; Stearns and Vaksvik, 1935), and 27 monitoring wells (fig. 1; table 1). Water-level measurements were collected using methods consistent with those described by Cunningham and Schalk (2011) to ensure comparability. Water levels at five sites (RHMW03, RHMW04, ‘Aiea Bay, State Hālawa Deep, and Hālawa Shaft) were measured near the beginning and end of the synoptic survey to characterize the water-level change during the survey. Data collected for the synoptic survey include discrete water levels and instantaneous water levels derived from continuously recording equipment.

Discrete Water Levels

Water levels were measured between 9:00 a.m. and 2:18 p.m., with most of the measurements made during the target period of 9:00 a.m. to 12:00 p.m. Depth to water was measured from an established measuring point (MP) at each site (table 1). To reduce the potential for human error, each depth-to-water measurement was replicated with a check measurement about a minute after the initial measurement, although only the initial measurement is published. Depth-to-water measurements were converted to water-level altitudes by subtracting the measured depth-to-water values from the MP altitudes and then applying relevant tape corrections and (or) gyroscopic-survey corrections.

Equipment

Discrete water-level measurements were collected using graduated steel tapes and electric tapes accurate to 0.01 foot (ft) (Cunningham and Schalk, 2011). The tape type (steel or electric; table 1) and identification number were recorded for each measurement.

Tape Corrections

The accuracy of water-level tapes may be affected by general wear and the development of bends and kinks. Water-level tapes can be calibrated with a reference tape of known accuracy to evaluate the accuracy of the water-level tape and determine tape-correction values. Tape corrections used during the synoptic survey were derived from a down-hole calibration of water-level tapes in September 2019. The depth to water was measured with each water-level tape at wells of various depths and compared to measurements made by a reference tape certified by the National Institute of Standards and Technology. Correction tables were developed for each water-level tape and appropriate tape corrections were applied to all depth-to-water measurements made during this survey.

Gyroscopic-Survey Corrections

Naval Facilities Engineering Command (NAVFAC) Hawaii used gyroscopic surveys at 10 of the 27 monitoring wells to evaluate the plumbness and alignment of each well

(Naval Facilities Engineering Command Hawaii, 2018). The gyroscopic-survey data consisted of sets of horizontal and vertical coordinates measured at 10-ft intervals along the length of each well, representing deviations from an origin at the center of the top of the well. NAVFAC Hawaii used the coordinate values and three-dimensional-modeling software to estimate the difference between the measured depth and true vertical depth of each well. The resulting gyroscopic-survey corrections were applied to each depth-to-water measurement collected at wells included in the gyroscopic survey (table 1) (Naval Facilities Engineering Command Hawaii, 2018).

Continuous Water Levels

At two wells (Hālawa Shaft and Manaiki T24), water levels for the synoptic survey were measured using equipment that had been installed prior to the survey and that recorded continuous water levels at fixed time intervals. Continuous water levels from these two wells were processed and reviewed by the measuring agency before use in the synoptic survey (table 1).

Equipment

At Hālawa Shaft, continuous water levels were recorded using a vented submersible pressure transducer (shortened herein to “transducer”). The transducer recorded water pressure at 10-minute intervals (for example, 08:50, 09:00, 09:10). The transducer has a manufacturer-stated water-level accuracy of 0.01 ft. The transducer was attached to a 25-ft vented cable, to which a desiccant pack was connected at the top to prevent moisture from entering the venting system and adversely affecting the equipment. An on-site pressure-depth calibration of the transducer could not be conducted at Hālawa Shaft. Instead, the transducer was calibrated in a laboratory setting by placing it in a transparent cylinder with a graduated tape and incrementally filling the cylinder with water while recording the submergence depth (Freeman and others, 2004).

At Manaiki T24, continuous water levels were recorded using a nonvented transducer (Nancy Matsumoto, Honolulu Board of Water Supply, written commun., 2022). The transducer recorded water pressure at 6-hour intervals (for example, 03:00, 09:00, 15:00).

Data Processing

The transducer at Hālawa Shaft was programmed to record submergence-pressure values in units of pounds per square inch. The transducer internally compensated for barometric-pressure changes, resulting in an output of submergence pressure. The submergence pressures were converted to submergence depths by multiplying the submergence pressures by the pressure-depth relation developed for the transducer. The submergence depths were converted to water levels by applying offset corrections to match the discrete water-level measurements collected during site visits at the beginning and end of the record period. The offset-correction values were prorated linearly between consecutive site visits.

BWS provided continuous water-level data from the nonvented pressure transducer at Manaiki T24 (Nancy Matsumoto, Honolulu Board of Water Supply, written commun., 2022). BWS applied barometric-pressure corrections to the data and provided the processed data to USGS.

Data

Water-level data collected during the synoptic survey are stored in the publicly accessible NWISWeb database (U.S. Geological Survey, 2022), including the furnished data collected by CWRM and USN. The data can be accessed on the NWISWeb database using the USGS site identifiers provided in table 1. The single water level provided by BWS was not included in the NWISWeb database because the quality-assurance and quality-control measures were not available at the time this report was prepared. The water level provided by BWS is, however, included in the report for completeness.

Water levels were recorded at 30 sites between 9:00 a.m. and 2:18 p.m. Discrete water-level measurements were collected at 28 of these sites. For Hālawā Shaft, water levels were extracted from the continuous record at 9:00 a.m. and 12:00 p.m., bracketing the 3-hour period of the synoptic survey. For Manaiki T24, where water levels are recorded at 6-hour intervals, the water level recorded at 9:00 a.m. was extracted from the record (a water level at 12:00 p.m. was not available). Measured water levels during the synoptic survey ranged from 16.34 to 19.77 ft above mean sea level (table 1; fig. 2).

Two sets of discrete water-level measurements were collected at the following sites to characterize water-level changes during the synoptic survey: RHMW03, RHMW04, ‘Aiea Bay (3–2256–10), and State Hālawā Deep (3–2253–03). Observed water-level changes between 9:00 a.m. and 2:18 p.m. ranged from –0.01 to 0.07 ft and indicate a generally increasing water-level trend during the synoptic survey (table 1; fig. 2). Continuous water-level data from Hālawā Shaft corroborate the observed trend.

Limitations

Water-level data collected during the synoptic survey have several limitations that may affect their accuracy. The accuracy of the discrete water-level measurements may be affected by (1) the accuracy of the measuring tapes used, (2) the accuracy of the MP altitude at the top of each well, (3) well plumbness and alignment, (4) human error, and (5) changing conditions during the survey period. In addition, comparability among the water levels may be affected by vertical hydraulic gradients in the aquifer.

The tape-correction values, applied to each depth-to-water measurement during the synoptic survey, reflect tape errors at specific depths and may not perfectly reflect errors at depths of each site in the study. The tapes used during the current synoptic survey were last calibrated in September 2019. Results of the tape calibration in September 2019 indicated that tape

corrections ranged in magnitude from 0 to 0.08 ft for depths measured at the 30 sites included in the synoptic survey. Changes in tape length (from either stretching, bending, or kinking)—and thus, the value of the appropriate tape correction—may have occurred in the 2 years since the last tape calibration and may not be reflected in the tape-correction values used for the synoptic survey. A planned biennial 2021 tape calibration prior to the synoptic survey was postponed owing to health and safety concerns related to the coronavirus pandemic.

Water-level data were collected with respect to the altitude of a MP at the well; consequently, any inaccuracies in the MP altitude are reflected in the water-level data. The personnel, equipment, and procedures used to determine the MP altitudes were not identical at each site, which may influence the comparability and accuracy of each reported MP altitude. In addition, the altitudes of the National Geodetic Survey benchmarks on O‘ahu—which are used as the vertical controls for surveying the MP altitudes of wells—were adjusted in 2019 (Roman, 2020). The benchmark altitudes were not uniformly affected by the adjustment. Differences in the magnitude of the benchmark-altitude adjustment would affect the MP altitudes of wells that were surveyed using the respective benchmark as a vertical control. If appropriate, the water levels measured for the synoptic survey can be revised if the MP altitudes are resurveyed using consistent methods that incorporate the adjusted benchmark altitudes.

The gyroscopic-survey data, available for 10 of the 30 monitoring wells in the study, resulted in well corrections ranging from –0.01 to –0.24 ft (as much as –0.07 ft correction per 100 ft of depth) (table 1). The gyroscopic-survey corrections are added to the measured depth-to-water values. Gyroscopic-survey corrections are not necessary at sites with direct access to the water table (for example, Red Hill Shaft, Hālawā Shaft, ‘Aiea Hālawā Shaft). All other factors being equal, sites with large boreholes and (or) small depths to water are expected to be less affected by borehole deviation than sites with small boreholes and (or) large depths to water. The gyroscopic-survey corrections likely improved the accuracy of the water-level data collected at the 10 sites; however, the corrections also may introduce a potential bias in the data. Gyroscopic-survey corrections can only result in an increase in measured water levels because the true vertical depth to water cannot exceed the measured depth to water. Consequently, wells where a gyroscopic survey was completed may have an elevated water level compared to wells that were not surveyed, all other factors being equal.

The continuous water-level data from Hālawā Shaft and Manaiki T24—used to determine water levels during the synoptic survey instead of collecting discrete measurements—are only as accurate as the discrete water-level measurements collected during the site visits bracketing the continuous record. Other potential sources of error unique to continuous water-level data include (1) the accuracy of the transducers, (2) vertical movement of the transducers in the water column during the period of record, and (3) internal drift of the transducers’ pressure sensors. Errors associated with the continuous water-level data from Hālawā Shaft used for the synoptic survey are likely minimal because (1) a backup transducer at the site was used to corroborate the data, and (2) a

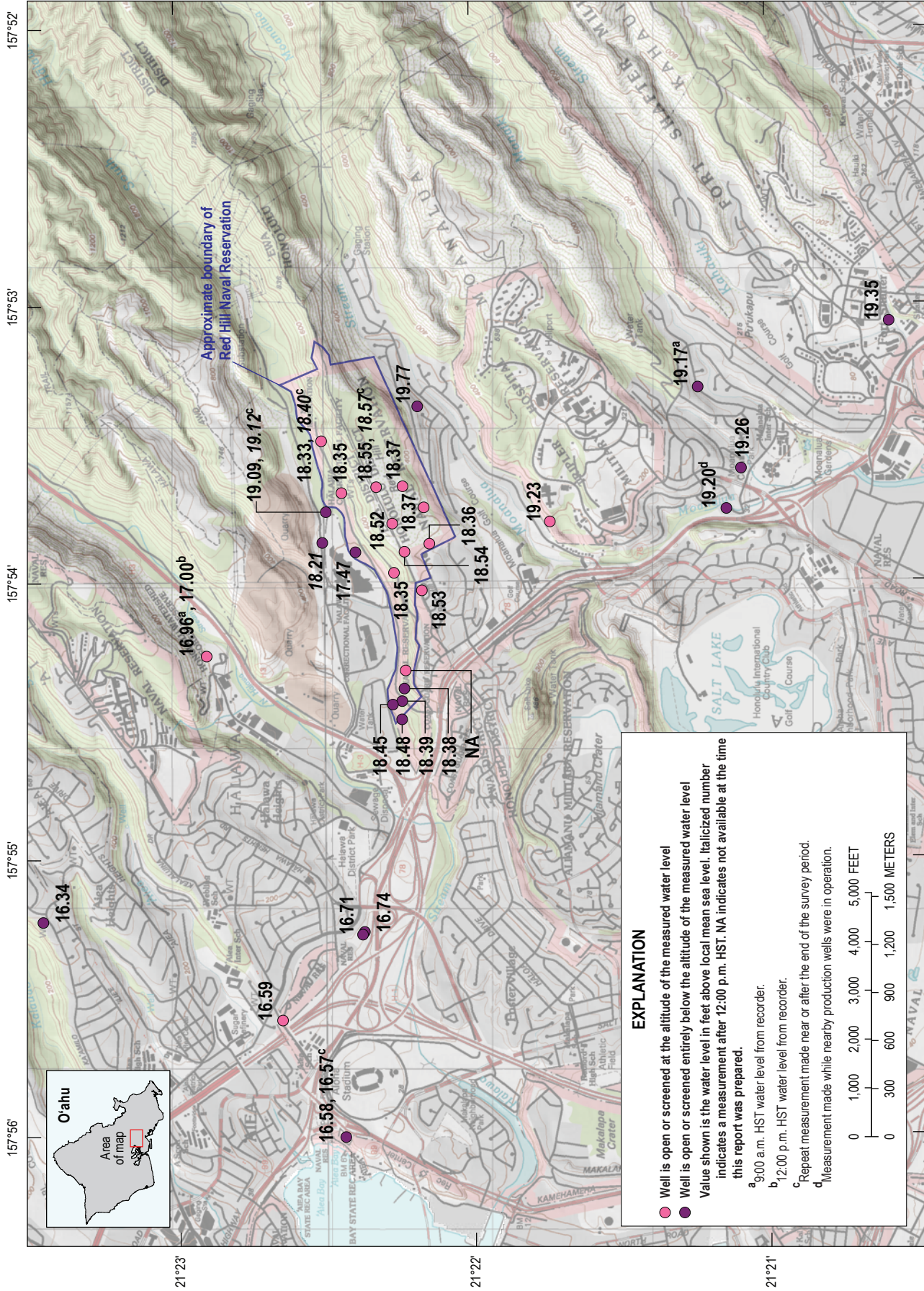


Figure 2. Measured groundwater levels in wells during the December 23, 2021, 9:00 a.m. to 12:00 p.m. survey. The map shows the Halawa area, Oahu, Hawaii, with various landmarks and topographic features. The approximate boundary of the Red Hill Naval Reservation is indicated. The map includes an inset of Oahu, a scale bar, and an explanation of the symbols and values.

Base modified from U.S. Geological Survey Digital Raster Graphics topographic map, 1:24,000 scale, Universal Transverse Mercator projection, zone 4, North American Datum of 1983.

discrete water-level measurement was collected during a site visit to download the continuous data on December 29, 2021—only 6 days after the synoptic survey—which limits the potential for the transducer to physically shift in the water column and for the transducer’s pressure sensor to drift. Because a nonvented transducer was used to collect water-level data at Manaiki T24, the accuracy of the data is also affected by the accuracy of the barometer used to adjust the data from the nonvented transducer.

Water levels during the synoptic survey can change in response to human (for example, groundwater withdrawals from wells) and natural (for example, barometric pressure) factors. Comparisons of water levels measured during the synoptic survey may be affected by temporally variable conditions. Measurements were collected from 9:00 a.m. to 2:18 p.m., with the majority of the measurements collected from 9:00 a.m. to 12:00 p.m. For the same pair of wells, comparisons between water levels measured at the extremes of the timeframe (for example, 9:00 a.m. and 2:18 p.m.) likely differ from comparisons between water levels measured concurrently. The magnitude of water-level changes at the five well sites with measurements at both the start and end of the synoptic survey (RHMW03, RHMW04, ‘Aiea Bay, State Hālawā Deep, and Hālawā Shaft) ranged from a decrease of 0.01 ft to an increase of 0.07 ft, although four of the wells had changes of 0.04 ft or less (table 1; fig. 2).

Comparability among the water levels measured during the synoptic survey may be affected by vertical hydraulic gradients in the aquifer. Four of the wells included in the synoptic survey were deep monitor wells with long (hundreds of feet) open boreholes below casing (Ka‘amilo Deep, Hālawā TZ, State Hālawā Deep, and Moanalua Deep). Water levels measured in these wells represent vertically averaged water levels that could be affected by vertical hydraulic gradients in the aquifer. Several other wells are not open or screened at the water table and, thus, the water levels measured in these wells are representative of conditions below the water table.

Summary

In November 2021, a fuel release at the Red Hill Bulk Fuel Storage Facility was reported by the U.S. Navy and was followed by the shutdown of several nearby production wells, including Red Hill Shaft and Hālawā Shaft. The Honolulu Board of Water Supply, Hawai‘i Commission on Water Resource Management, U.S. Navy, and U.S. Geological Survey (USGS) conducted a synoptic groundwater-level survey in the Hālawā area, O‘ahu, Hawai‘i, to provide a snapshot of water levels during the survey period. The survey entailed making near-concurrent water-level measurements at 30 sites near the Red Hill Bulk Fuel Storage Facility and within the greater Hālawā area on December 23, 2021, mostly within the targeted time period between 9:00 a.m. and 12:00 p.m. (Hawai‘i standard time).

The water-level data collected during the synoptic survey are available on the USGS National Water Information System Web Interface (NWISWeb) database (U.S. Geological Survey,

2022); the data can be found using the USGS site identifiers listed in table 1. The water-level data have several limitations that may affect interpretation, including, but not limited to, inaccuracies in measuring-point altitudes, tape corrections, gyroscopic-survey corrections (if applicable), and continuous water-level recorders.

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