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# January 18, 2022, Red Hill Synoptic Groundwater-Level Survey, Hālawa Area, Oʻahu, Hawaiʻi

Open-File Report 2022–1048

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

**Cover.** Photograph of the Red Hill Bulk Fuel Storage Facility viewed from the Tripler Army Medical Center, O‘ahu, Hawai‘i. U.S. Geological Survey photograph by Rylen Nakama, April 29, 2022.

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U.S. Geological Survey, Reston, Virginia: 2022

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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 °F = (1.8 × °C) + 32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as °C = (°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 |

# January 18, 2022, Red Hill Synoptic Groundwater-Level Survey, Hālawa Area, Oʻahu, Hawaiʻi

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

## Abstract

On January 18, 2022, groundwater levels were measured in selected wells in the Hālawa area, Oʻahu, Hawaiʻi, 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 Hawaiʻi 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 Hālawa 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 16.81 to 20.19 feet above mean sea level. The groundwater levels measured on January 18, 2022, were about 0.3 to 0.6 feet higher than those measured at common sites during a synoptic groundwater-level survey on December 23, 2021.

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

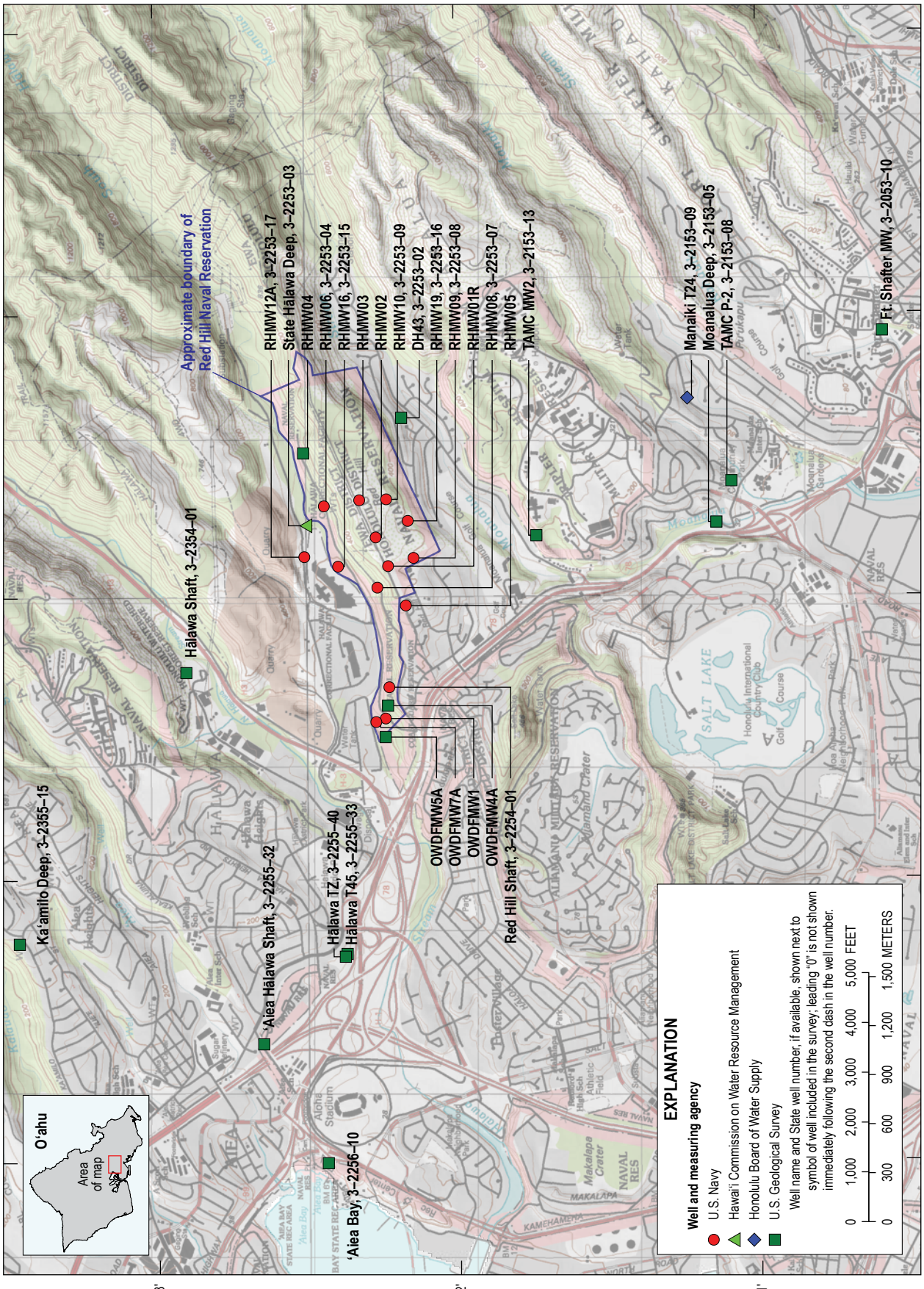
A synoptic groundwater-level survey (shortened herein to "synoptic survey") provides a snapshot of groundwater levels (shortened herein to "water levels") in wells in the surveyed area. On January 18, 2022, mainly during the three-hour period between 9:00 a.m. and 12:00 p.m. (Hawaiʻi standard time), water levels were measured in selected wells in the Hālawa area, Oʻahu, Hawaiʻi (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 Hawaiʻi, 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 Hālawa 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 groundwater-withdrawal conditions. The January 18, 2022, synoptic survey provides a snapshot of water levels when Red Hill Shaft and Hālawa Shaft—the two largest production wells in the area—were shut down for about 7 weeks.

The U.S. Geological Survey (USGS) maintains a network of groundwater monitoring sites in the greater Hālawa area. Continuous water-level data are available in 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 Hālawa area during a period when withdrawals from Hālawa Shaft and Red Hill Shaft were temporally variable. Nakama and others (2022) documented water levels measured during a December 23, 2021, synoptic survey in the Hālawa area, which covers the same area as the synoptic survey described in this report. The December 23, 2021, synoptic survey provides a snapshot of water levels when Red Hill Shaft and Hālawa Shaft were shut down for about 3 weeks.

## Purpose and Scope

This report presents data collected during a synoptic survey on January 18, 2022, 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 25 wells and data from 5 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 eight selected sites: once near the beginning of the survey period and a second time near the end of the survey period.




Base modifed 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.

**Figure 1.** Wells included in the January 18, 2022, Red Hill synoptic groundwater-level survey in the Hālawa area, O'ahu, Hawai'i.

**Table 1.** List of wells and open intervals, measuring-point altitudes, and groundwater levels measured during the January 18, 2022, Red Hill synoptic groundwater-level survey in the Hālawa 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/F7P55KJN. 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 number | 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[2], in feet | Approximate bottom altitude of open or screened well interval[2], 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RHMW01R | 212214157535402 | Red Hill RHMW01R, Oahu, HI | 9:30 a.m. | 18.98 | Electric tape | U.S. Navy | 28 | 8 | 101.76 | U.S. Navy | 82.79 | --[5] | −0.01 |
| RHMW02 | 212216157534701 | Red Hill RHMW02, Oahu, HI | 9:16 a.m. | 18.97 | Electric tape | U.S. Navy | 21 | 6 | 104.60 | U.S. Navy | 85.70 | −0.06 | −0.01 |
| RHMW03 | 212219157533901 | Red Hill RHMW03, Oahu, HI | 9:02 a.m. | 18.99 | Electric tape | U.S. Navy | 19 | 4 | 120.90 | U.S. Navy | 101.96 | −0.04 | −0.01 |
| RHMW03 | 212219157533901 | Red Hill RHMW03, Oahu, HI | 12:06 p.m. | 18.97 | Electric tape | U.S. Navy | 19 | 4 | 120.90 | U.S. Navy | 101.98 | −0.04 | −0.01 |
| RHMW04 | 212231157532901 | Red Hill RHMW04, Oahu, HI | 9:00 a.m. | 18.92 | Transducer | USGS | 23 | 8 | 312.11 | U.S. Navy | -- | --[6] | -- |
| RHMW04 | 212231157532901 | Red Hill RHMW04, Oahu, HI | 12:00 p.m. | 18.95 | Transducer | USGS | 23 | 8 | 312.11 | U.S. Navy | -- | --[6] | -- |
| RHMW05 | 212210157540201 | Red Hill RHMW05, Oahu, HI | 9:45 a.m. | 18.97 | Electric tape | U.S. Navy | 24 | 9 | 101.31 | U.S. Navy | 82.36 | −0.01 | −0.01 |
| RHMW06 | 212226157534101 | 3-2253-04 Red Hill RHMW06, Oahu, HI | 10:37 a.m. | 18.78 | Electric tape | U.S. Navy | 27 | −3 | 259.26 | U.S. Navy | 240.52 | −0.01 | −0.03 |
| RHMW08 | 212216157535801 | 3-2253-07 Red Hill RHMW08, Oahu, HI | 9:00 a.m. | 18.82 | Electric tape | U.S. Navy | 29 | −1 | 310.62 | U.S. Navy | 291.87 | −0.03 | −0.04 |
| RHMW08 | 212216157535801 | 3-2253-07 Red Hill RHMW08, Oahu, HI | 11:45 a.m. | 18.84 | Electric tape | U.S. Navy | 29 | −1 | 310.62 | U.S. Navy | 291.85 | −0.03 | −0.04 |
| RHMW09 | 212209157535201 | 3-2253-08 Red Hill RHMW09, Oahu, HI | 9:26 a.m. | 18.83 | Electric tape | U.S. Navy | 29 | −1 | 395.57 | U.S. Navy | 377.03 | −0.24 | −0.05 |

**Table 1.** List of wells and open intervals, measuring-point altitudes, and groundwater levels measured during the January 18, 2022, Red Hill synoptic groundwater-level survey in the Hālawa area, O'ahu, Hawai'i.—Continued

| Common name | USGS site identification number | 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[2], in feet | Approximate bottom altitude of open or screened well interval[2], 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RHMW10 | 212213157533901 | 3-2253-09 Red Hill RHMW10, Oahu, HI | 10:05 a.m. | 18.84 | Electric tape | U.S. Navy | 29 | −1 | 495.78 | U.S. Navy | 477.09 | −0.09 | −0.06 |
| RHMW12A | 212230157535202 | 3-2253-17 Red Hill RHMW12A, Oahu, HI | 11:23 a.m. | 18.60 | Electric tape | U.S. Navy | −175 | −195 | 238.62 | U.S. Navy | 220.05 | --[5] | −0.03 |
| RHMW16 | 212224157535401 | 3-2253-15 Red Hill RHMW16, Oahu, HI | 10:58 a.m. | 17.91 | Electric tape | U.S. Navy | −273 | −293 | 219.13 | U.S. Navy | 201.25 | --[5] | −0.03 |
| RHMW19 | 212212157534601 | 3-2253-16 Red Hill RHMW19, Oahu, HI | 9:45 a.m. | 18.83 | Electric tape | U.S. Navy | 28 | −2 | 444.82 | U.S. Navy | 426.05 | --[5] | −0.06 |
| OWDFMW1 | 212214157542601 | Red Hill OWDFMW1, Oahu, HI | 11:44 a.m. | 18.83 | Electric tape | U.S. Navy | 6 | −5 | 138.14 | U.S. Navy | 119.36 | −0.03 | −0.02 |
| OWDFMW4A | 212214157542301 | Red Hill OWDFMW4A, Oahu, HI | 9:00 a.m. | 18.83 | Transducer | USGS | 15 | −5 | 166.84 | U.S. Navy | -- | --[5] | -- |
| OWDFMW4A | 212214157542301 | Red Hill OWDFMW4A, Oahu, HI | 12:00 p.m. | 18.82 | Transducer | USGS | 15 | −5 | 166.84 | U.S. Navy | -- | --[5] | -- |
| OWDFMW5A | 212214157543001 | Red Hill OWDFMW5A, Oahu, HI | 9:00 a.m. | 18.93 | Transducer | USGS | −4 | −24 | 118.78 | U.S. Navy | -- | --[5] | -- |
| OWDFMW5A | 212214157543001 | Red Hill OWDFMW5A, Oahu, HI | 12:00 p.m. | 18.93 | Transducer | USGS | −4 | −24 | 118.78 | U.S. Navy | -- | --[5] | -- |
| OWDFMW7A | 212216157542701 | Red Hill OWDFMW7A, Oahu, HI | 10:40 a.m. | 18.87 | Electric tape | U.S. Navy | −104 | −124 | 119.64 | U.S. Navy | 100.78 | --[5] | −0.01 |
| Red Hill Shaft | 212225157542601 | 3-2254-01 Red Hill Shaft (S11), Oahu, HI | 10:06 a.m. | --[7] | Electric tape | U.S. Navy | -- | -- | --[7] | U.S. Navy | 86.86 | --[8] | −0.01 |
| Ka'amilo Deep | 212340157552301 | 3-2355-15 Kaamilo Deep, Oahu, HI | 10:11 a.m. | 16.81 | Steel tape | USGS | 11 | −1,126 | 493.29 | USGS | 476.47 | --[5] | 0.01 |

**Table 1.** List of wells and open intervals, measuring-point altitudes, and groundwater levels measured during the January 18, 2022, Red Hill synoptic groundwater-level survey in the Hālawa area, Oʻahu, Hawaiʻi.—Continued

| Common name | USGS site identification number | 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[2], in feet | Approximate bottom altitude of open or screened well interval[2], 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hālawa Shaft | 212305157542601 | 3-2354-01 Halawa Shaft (S12), Oahu, HI | 9:00 a.m. | 17.46 | Transducer | USGS | -- | -- | 23.21 | USGS | -- | --[8] | -- |
| Hālawa Shaft | 212305157542601 | 3-2354-01 Halawa Shaft (S12), Oahu, HI | 12:00 p.m. | 17.50 | Transducer | USGS | -- | -- | 23.21 | USGS | -- | --[8] | -- |
| ʻAiea Hālawa Shaft | 212253157554301 | 3-2255-32 Halawa Shaft (S5), Oahu, HI | 9:00 a.m. | 17.07 | Steel tape | USGS | -- | -- | 28.05 | U.S. Navy | 10.98 | --[8] | 0.00 |
| ʻAiea Bay | 212238157561101 | 3-2256-10 Aiea Bay nr Naval Res (187-B), Oahu, HI | 9:00 a.m. | 17.01 | Steel tape | USGS | −133 | −163 | 26.07 | USGS | 9.06 | --[8] | 0.00 |
| ʻAiea Bay | 212238157561101 | 3-2256-10 Aiea Bay nr Naval Res (187-B), Oahu, HI | 11:11 a.m. | 17.01 | Steel tape | USGS | −133 | −163 | 26.07 | USGS | 9.06 | --[8] | 0.00 |
| Hālawa TZ | 212233157552302 | 3-2255-40 Halawa TZ Well, Oahu, HI | 10:41 a.m. | 17.20 | Steel tape | USGS | 0 | −955 | 60.04 | USGS | 42.84 | --[8] | 0.00 |
| Hālawa T45 | 212233157552301 | 3-2255-33 Halawa Observation Well (T45), Oahu, HI | 10:48 a.m. | 17.23 | Steel tape | USGS | −2 | −28 | 57.85 | USGS | 40.62 | --[8] | 0.00 |
| State Hālawa Deep | 212241157535501 | 3-2253-03 State Halawa Deep, Oahu, HI | 9:28 a.m. | 19.48 | Electric tape | CWRM | −25 | −1,350 | 226.68 | U.S. Navy | 207.29 | −0.01 | −0.08 |
| State Hālawa Deep | 212241157535501 | 3-2253-03 State Halawa Deep, Oahu, HI | 12:15 p.m. | 19.52 | Electric tape | CWRM | −25 | −1,350 | 226.68 | U.S. Navy | 207.25 | −0.01 | −0.08 |
| DH 43 | 212225157533001 | 3-2253-02 Moanalua DH 43, Oahu, HI | 10:33 a.m. | 20.19 | Steel tape | USGS | < −10 | −42 | 234.32 | USGS | 214.14 | --[5] | −0.01 |
| TAMC MW2 | 212144157534701 | 3-2153-13 TAMC MW2, Oahu, HI | 9:46 a.m. | 19.60 | Steel tape | USGS | 26 | 16 | 179.70 | USGS | 160.11 | --[5] | −0.01 |

**Table 1.** List of wells and open intervals, measuring-point altitudes, and groundwater levels measured during the January 18, 2022, Red Hill synoptic groundwater-level survey in the Hālawa area, O'ahu, Hawai'i.—Continued

| Common name | USGS site identification number | 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[2], in feet | Approximate bottom altitude of open or screened well interval[2], 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moanalua Deep | 212123157535501 | 3-2153-05 Moanalua Fresh Water Mon. Well, Oahu, HI | 9:30 a.m. | [9]19.57 | Steel tape | USGS | −31 | −1,284 | 37.03 | USGS | 17.46 | --[8] | 0.00 |
| TAMC P-2 | 212117157534601 | 3-2153-08 TAMC P-2 (W154-1B), Oahu, HI | 9:29 a.m. | 19.64 | Steel tape | USGS | −27 | −276 | 33.21 | USGS | 13.57 | --[8] | 0.00 |
| Manaiki T24 | 212127157532001 | 3-2153-09 Manaiki (T24), Oahu, HI | 9:00 a.m. | [10]19.52 | Transducer | BWS | −8 | −57 | 60.90 | BWS | -- | -- | -- |
| Ft. Shafter MW | 212046157531401 | 3-2053-10 Ft. Shafter MW, (W146), Oahu, HI | 9:07 a.m. | 19.69 | Steel tape | USGS | −147 | −257 | 24.79 | USGS | 5.10 | --[8] | 0.00 |

[1]Water level is computed from the following equation: Water level = MP altitude – (Depth to water relative to MP + Gyroscopic-survey correction + Tape-specific correction).

[2]Altitude refers to feet above local mean sea level.

[3]Gyroscopic-survey correction (Naval Facilities Engineering Command Hawaii, 2018) is added to depth-to-water value (or subtracted from the uncorrected water-level value).

[4]Tape-specific correction is added to depth-to-water value (or subtracted from the uncorrected water-level value).

[5]Gyroscopic-survey correction not available.

[6]Gyroscopic-survey correction for this well (–0.02 foot) was indirectly incorporated in the indicated water-level value through its dependence on discrete water-level measurements.

[7]Measuring-point altitude not available at the time this report was prepared.

[8]Gyroscopic-survey correction not applicable because measurement made in large-diameter well in which tape hangs freely or well with shallow depth to water.

[9]Measurement made while nearby production wells were in operation.

[10]Honolulu Board of Water Supply, 2022, written communication.

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 January 18, 2022, 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 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 eight sites (RHMW03, RHMW04, RHMW08, OWDFMW4A, OWDFMW5A, Hālawa Shaft, 'Aiea Bay, and State Hālawa Deep) 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 12:15 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, if available, 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 multiagency 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 30 monitored 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 five wells (Hālawa Shaft, RHMW04, OWDFMW4A, OWDFMW5A, 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 five wells were processed and reviewed by the measuring agency before use in the synoptic survey (table 1).

### Equipment

At Hālawa Shaft, RHMW04, OWDFMW4A, and OWDFMW5A, continuous water levels were recorded using vented submersible pressure transducers (shortened herein to "transducers"). The transducers recorded water pressure at 10-minute intervals (for example, 8:50 a.m., 9:00 a.m., 9:10 a.m.). The transducers have a manufacturer-stated water-level accuracy of 0.01 ft. Each transducer was attached to either a 15-ft or 25-ft vented cable. A desiccant pack was connected to the top of each vented cable to prevent moisture from entering the venting system and adversely affecting the equipment.

On-site pressure-depth calibrations of the transducers were conducted for RHMW04, OWDFMW4A, and OWDFMW5A before transducers were installed in the wells. Calibration of the transducers' pressure sensors involved temporarily deploying each transducer in its respective well, raising it by known increments in the water column, and comparing the incremental

distance change with the pressure recorded by the transducer. 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, 3:00 a.m., 9:00 a.m., 3:00 p.m.).

### Data Processing

The transducers at Hālawa Shaft, RHMW04, OWDFMW4A, and OWDFMW5A were programmed to record submergence-pressure values in units of pounds per square inch. The transducers 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 linear slope of the pressure-depth relation developed for the transducer during the pressure calibration. 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 from 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 12:15 p.m. Discrete water-level measurements were collected at 25 of these sites. For Hālawa Shaft, RHMW04, OWDFMW4A, and OWDFMW5A, 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 16.81 to 20.19 ft above mean sea level (table 1; fig. 2). The water levels measured on January 18, 2022 were about 0.3 to 0.6 ft higher than those measured at common sites during a synoptic survey on December 23, 2021 (Nakama and others, 2022).

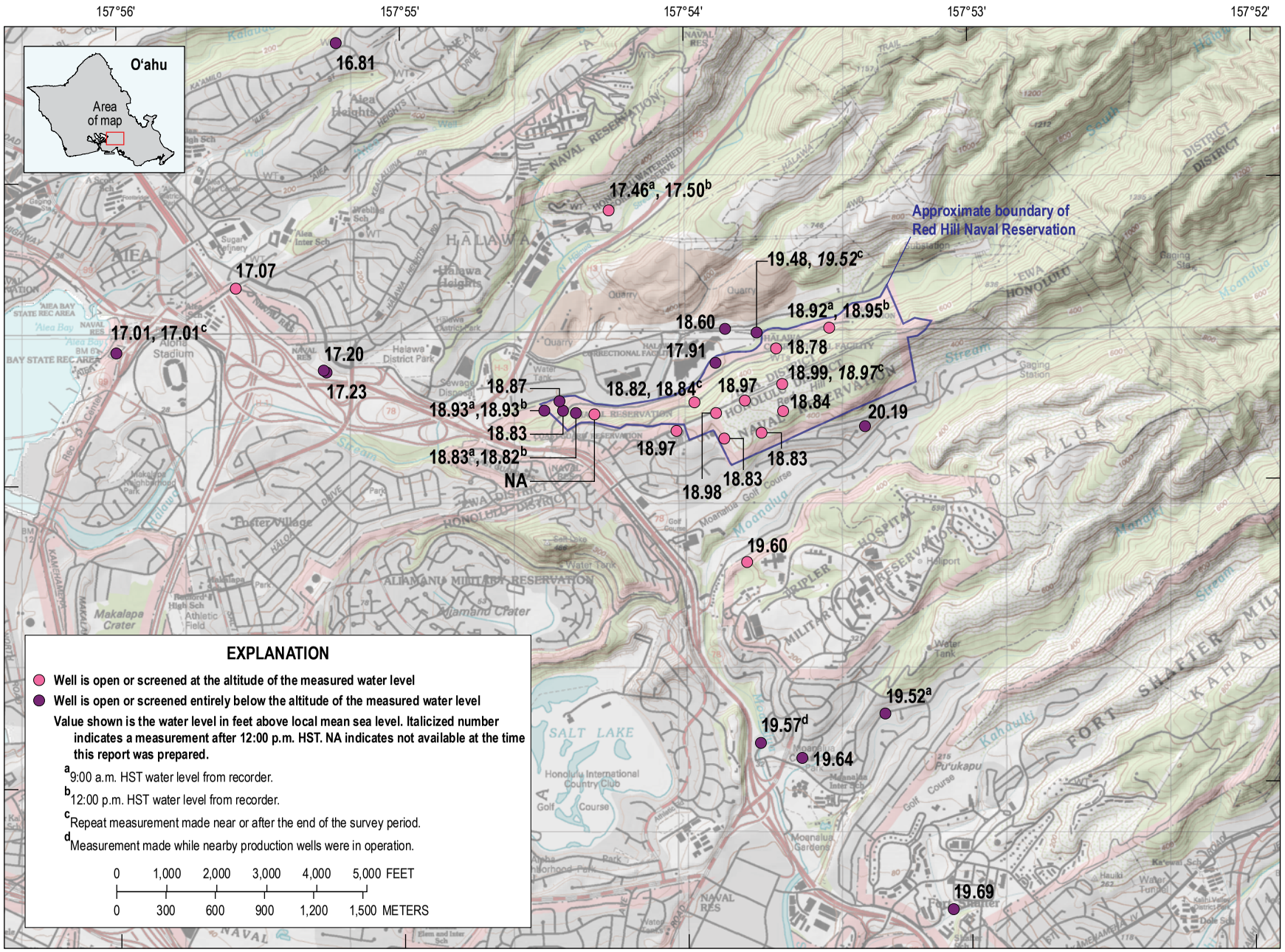
Two sets of discrete water-level measurements were collected at the following sites to characterize water-level changes during the synoptic survey: RHMW03, RHMW08, ‘Aiea Bay, and State Hālawa Deep. In addition, continuous water-level data from Hālawa Shaft, RHMW04, OWDFMW4A and OWDFMW5A can be used to evaluate water-level changes. Observed water-level changes between 9:00 a.m. and 12:15 p.m. ranged from –0.02 to 0.04 ft and indicate a generally increasing water-level trend during the synoptic survey (table 1; fig. 2). Recorded water levels at 9:00 a.m. and 12:00 p.m. from transducers at Hālawa Shaft, RHMW04, OWDFMW4A, and OWDFMW5A indicate water-level changes that are within the range of changes determined from the discrete water-level measurements.

## 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 0.00 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




Base modifed 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.

**Figure 2.** Measured groundwater levels in wells during the January 18, 2022, 9:00 a.m. to 12:00 p.m. Hawai'i standard time (HST), Red Hill synoptic groundwater-level survey in the Hālawa area, O'ahu, Hawai'i.

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. No MP altitude was available for the measurement collected at Red Hill Shaft. This measurement can be incorporated once leveling measurements are completed at the site.

The gyroscopic-survey data, available for 10 of the 30 monitored 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, Hālawa Shaft, ‘Aiea Hālawa 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 Hālawa Shaft, RHMW04, OWDFMW4A, OWDFMW5A, 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. 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 12:15 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 12:15 p.m.) likely differ from comparisons between water levels measured concurrently. The magnitude of water-level changes at the eight well sites with measurements at both the start and end of the synoptic survey (RHMW03, RHMW04, RHMW08, OWDFMW4A, OWDFMW5A, ‘Aiea Bay, State Hālawa Deep, and Hālawa Shaft) ranged from a decrease of 0.02 ft to an increase of 0.04 ft (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, Hālawa TZ, State Hālawa Deep, and Moanalua Deep; fig. 1). 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 Hālawa 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 Hālawa 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 Hālawa area on January 18, 2022, mostly within the targeted time period between 9:00 a.m. and 12:00 p.m. (Hawai‘i standard time). Water levels measured in wells during the synoptic survey ranged from 16.81 to 20.19 feet above mean sea level.

The water-level data collected during the synoptic survey are available in the USGS National Water Information System Web Interface 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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