Prepared in cooperation with the U.S. Navy

Groundwater-Level Monitoring from January 17 to March 3, 2022, Hālawa Area, Oʻahu, Hawaiʻi

Open-File Report 2022–1069

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

Cover. Photograph of Red Hill and Moanalua Valley, Oʻahu, Hawaiʻi. U.S. Geological Survey photograph by Rylen Nakama, June 19, 2022.

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

Suggested citation:
Nakama, R.K., Mitchell, J.N., and Oki, D.S., 2022, Groundwater-level monitoring from January 17 to March 3, 2022, Hālawa area, O‘ahu, Hawai‘i: U.S. Geological Survey Open-File Report 2022–1069, 29 p., https://doi.org/10.3133/ofr20221069.

Associated data for this publication:
U.S. Geological Survey, 2022, USGS water data for the nation: U.S. Geological Survey National Water Information System database, https://doi.org/10.5066/F7P55KJN.

ISSN 2331-1258 (online)

Acknowledgments

The U.S. Navy and Honolulu Board of Water Supply provided timely access to wells for this study. The contributions of Lhiberty D. Pagaduan, James T. Mifflin, James K. Stack, Kolja Rotzoll, and Heather A. Jeppesen (U.S. Geological Survey) enabled timely collection and processing of data.

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:

°F = (1.8 × °C) + 32.

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

°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
NOAA	National Oceanic and Atmospheric Administration
NWISWeb	National Water Information System database
USGS	U.S. Geological Survey
USN	U.S. Navy

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Groundwater-Level Monitoring from January 17 to March 3, 2022, Hālawa Area, Oʻahu, Hawaiʻi

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Abstract

A reported fuel release in November 2021 at the Red Hill Bulk Fuel Storage Facility within the naval reservation at Red Hill led to the shutdown of several production wells in the Hālawa area, Oʻahu, Hawaiʻi. Red Hill Shaft—one of the high-capacity production wells that shut down—was reactivated on January 29, 2022. Submersible pressure transducers were deployed at 20 wells in the Hālawa area to measure groundwater levels and evaluate the regional groundwater-level response to the resumption of groundwater withdrawals from Red Hill Shaft. Groundwater levels measured in wells from January 17 to March 3, 2022, ranged between 16 and 20 feet at all sites and generally between 17 and 19 feet at most sites. Average groundwater-level decreases measured in wells 10 days after the January 29, 2022, resumption of withdrawal from Red Hill Shaft ranged from about 0.1 to 0.4 foot. In general, greatest decreases in groundwater levels occurred in wells closest to Red Hill Shaft.

The groundwater-level data contain uncertainty because of several potential sources of error associated with (1) the accuracy of the measuring tapes and submersible pressure transducers used, (2) the accuracy of the measuring-point altitude at the top of each well, (3) the stability of the submersible pressure transducers' suspension depth in each well, (4) well plumbness and alignment, and (5) human error. Because of the potential sources of error, comparability of groundwater-level data may be affected. Some sources of uncertainty, including the accuracy of measuring-point altitudes, can be addressed and lead to improved accuracy and comparability of groundwater levels. Data collected for this study are available in the U.S. Geological Survey National Water Information System database.

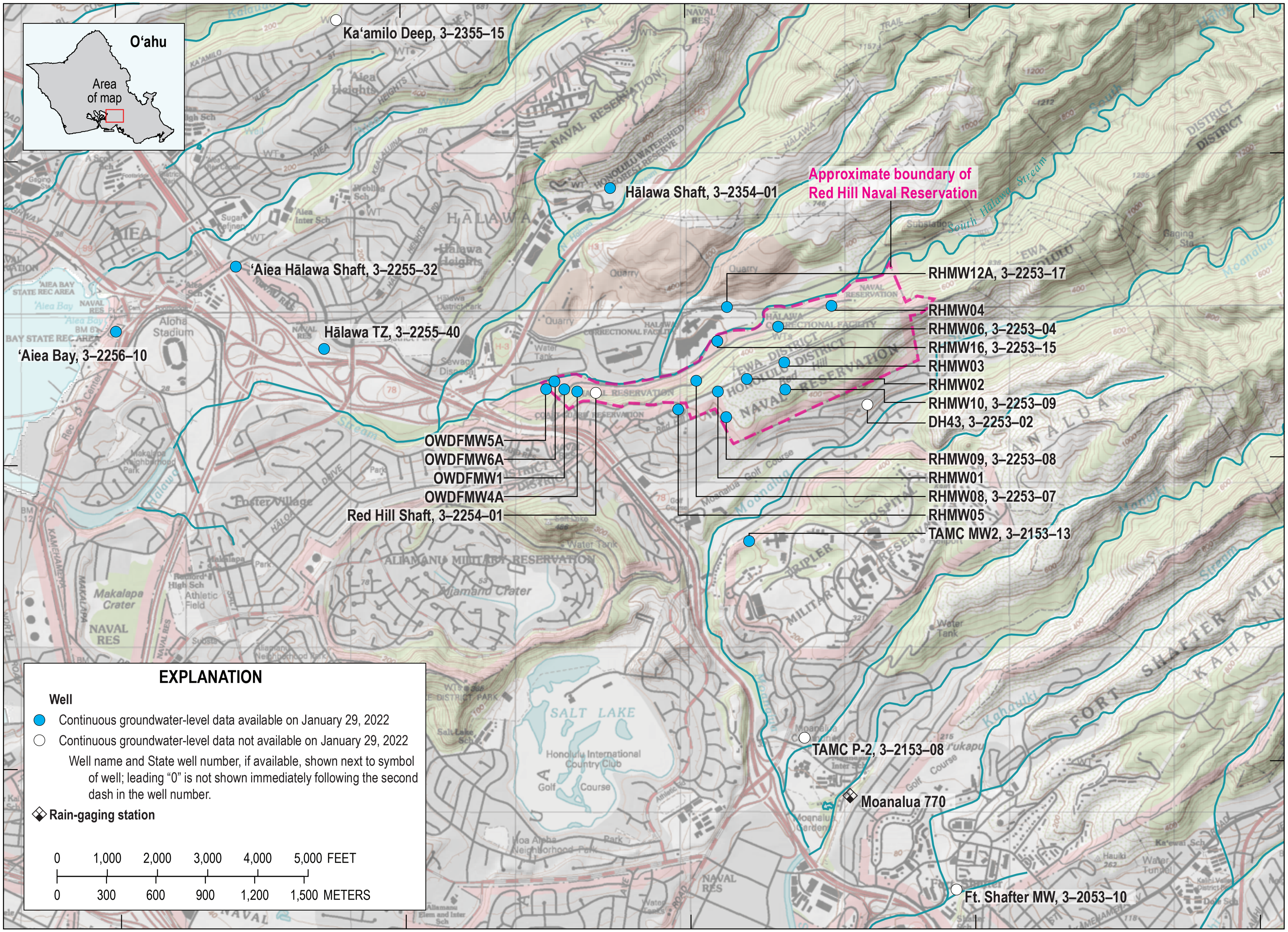
Introduction

A reported fuel release in November 2021 at the Red Hill Bulk Fuel Storage Facility within the naval reservation at Red Hill (State of Hawaiʻi, 2021) led to the shutdown of several production wells in the Hālawa area, Oʻahu, Hawaiʻi. The wells that were shut down included two high-capacity production facilities: the Red Hill Shaft (well 3–2254–01), which was shut down on November 28, 2021, and the Hālawa Shaft (well 3–2354–01), which was shut down on December 3, 2021, except for weekly, short-duration operations for water-quality sampling. During the period when the wells were shut down, groundwater levels (shortened herein to "water levels") in 30 wells were measured in two multiagency synoptic water-level surveys: on December 23, 2021 (Nakama and others, 2022a), and January 18, 2022 (Nakama and others, 2022b). These synoptic water-level surveys provided snapshots of regional aquifer conditions while high-capacity production wells were shut down in the Hālawa area.

On January 29, 2022, the Red Hill Shaft resumed withdrawal of groundwater at a rate of about 4.5 million gallons per day, although the water produced by Red Hill Shaft has not been introduced into the Navy drinking water distribution system as of June 2022. Instead, water from Red Hill Shaft was pumped out of the tunnel facility, filtered through a granular-activated-carbon system, and then discharged into South Hālawa Stream near monitoring well OWDFMW6A (fig. 1). Resumption of withdrawal at the Red Hill Shaft was intended to remove possible fuel-related contaminants from the aquifer beneath and surrounding the Red Hill Bulk Fuel Storage Facility. For this study, water levels in selected wells were measured continuously for about a month, starting just prior to the resumption of withdrawal at the Red Hill Shaft and ending during a period of consistent withdrawal. Measurement of water levels in response to the resumption of withdrawal at Red Hill Shaft can be used to evaluate the potential effectiveness of the contaminant removal. As of June 2022, normal operations at Hālawa Shaft have not resumed since the shutdown on December 3, 2021.

Purpose and Scope

The purpose of this report is to document water-level data collected within the target period from January 17 to March 3, 2022, in the Hālawa area, Oʻahu, Hawaiʻi. Water levels in the Hālawa area were recorded at 10-minute intervals using submersible pressure transducers (shortened herein to "transducers") to characterize the water-level change immediately following the resumption of withdrawal at Red Hill Shaft on January 29, 2022. Continuous data for the target



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. Map of selected wells measured during the January 17 to March 3, 2022, water-level data collection period and surrounding geographic features, Hālawa, O‘ahu, Hawai‘i.

period are available from 20 of the 23 wells (fig. 1) identified for monitoring (discrete, monthly measurements are available at two additional wells). Continuous data from Ka‘amilo Deep (3–2355–15) and DH43 (3–2253–02) were incomplete. Continuous data from Red Hill Shaft (3–2254–01) were unusable due to equipment problems. The U.S. Geological Survey (USGS) also measures monthly water levels in two additional wells in the Hālawa area: TAMC P-2 (3–2153–08) and Fort Shafter MW (3–2053–10), not incorporated in this study. The scope of this report is limited to data from the 20 wells that can be used to characterize the water-level change following the resumption of withdrawal at Red Hill Shaft on January 29, 2022. For 15 wells, the period of recorded data is contained within the overall period from January 17 to March 3, 2022, and depends on when the transducers were installed and removed from the well. For the remaining five wells, the period of recorded data includes the entire period from January 17 to March 3, 2022, and extends before and after the overall period.

Methods

Usable data were collected at 20 sites: two Maui-type shafts (‘Aiea Hālawa Shaft and Hālawa Shaft; Stearns and Vaksvik, 1935) and 18 monitoring wells (fig. 1). The data collected for this study include discrete water-level data, continuous water-level data, and barometric-pressure data. A transducer installed in Red Hill Shaft (another Maui-type shaft) did not collect usable data during the period of interest.

Discrete Water Levels

Discrete water levels were measured during periodic site visits to deploy and remove equipment. 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 one measurement is typically 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 calibrated, graduated steel tapes and electric tapes accurate to 0.01 foot (ft; Cunningham and Schalk, 2011). Steel tapes were generally used at all sites; however, certain site conditions precluded the use of a steel tape (for example, wet casing that would lead to a poorly defined chalk mark on a steel tape necessitated use of an electric tape instead of a steel tape in some wells). When feasible, the same steel tape was used at a given site throughout the study.

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 for this study 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 study.

Gyroscopic-Survey Corrections

Naval Facilities Engineering Command (NAVFAC) Hawaii used gyroscopic surveys at 9 of the 20 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 to water and true vertical depth to water in 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

Transducers were installed in each well and programmed to continuously record pressure at 10-minute intervals, at an even 10-minute time (for example, 8:50 a.m., 9:00 a.m., 9:10 a.m.).

Equipment

Vented transducers were deployed at 19 sites and two nonvented transducers were deployed at one site (RHMW01; the two nonvented transducers consisted of a primary and a backup transducer). Each vented 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. For most of the deployments, the vented cable was suspended from a length of stainless-steel cable secured to a fixed mount at the top of the well. The installation at Hālawa Shaft required the vented cable to be draped over a staff-gage bracket and secured to a bolt at an access port at the facility.

The vented transducers had an accuracy of about 0.01 ft (In-Situ Inc., 2018c). The two nonvented transducers (primary

Table 1. List of monitoring equipment type, well open intervals, and measuring-point altitudes for selected wells, 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; MP, measuring point; nr, near; Res, Reservation; --, not applicable or not available]

Common name	USGS site identification number	USGS site name	Transducer type	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[1], in feet	Source of MP altitude	Gyroscopic-survey correction to be added to depth-to-water measurement[2], in feet
RHMW01	212214157535401	Red Hill RHMW01, Oahu, HI	nonvented	12	2	102.00	U.S. Navy	--[3]
RHMW02	212216157534701	Red Hill RHMW02, Oahu, HI	vented	21	6	104.60	U.S. Navy	−0.06
RHMW03	212219157533901	Red Hill RHMW03, Oahu, HI	vented	19	4	120.90	U.S. Navy	−0.04
RHMW04	212231157532901	Red Hill RHMW04, Oahu, HI	vented	23	8	312.11	U.S. Navy	−0.02
RHMW05	212210157540201	Red Hill RHMW05, Oahu, HI	vented	24	9	101.31	U.S. Navy	−0.01
RHMW06	212226157534101	3-2253-04 Red Hill RHMW06, Oahu, HI	vented	27	−3	259.26	U.S. Navy	−0.01
RHMW08	212216157535801	3-2253-07 Red Hill RHMW08, Oahu, HI	vented	29	−1	310.62	U.S. Navy	−0.03
RHMW09	212209157535201	3-2253-08 Red Hill RHMW09, Oahu, HI	vented	29	−1	395.57	U.S. Navy	−0.24
RHMW10	212213157533901	3-2253-09 Red Hill RHMW10, Oahu, HI	vented	29	−1	495.78	U.S. Navy	−0.09
RHMW12A	212230157535202	3-2253-17 Red Hill RHMW12A, Oahu, HI	vented	−175	−195	238.62	U.S. Navy	--[3]
RHMW16	212224157535401	3-2253-15 Red Hill RHMW16, Oahu, HI	vented	−273	−293	219.13	U.S. Navy	--[3]
OWDFMW1	212214157542601	Red Hill OWDFMW1, Oahu, HI	vented	6	−5	138.14	U.S. Navy	−0.03
OWDFMW4A	212214157542301	Red Hill OWDFMW4A, Oahu, HI	vented	15	−5	166.84	U.S. Navy	--[3]
OWDFMW5A	212214157543001	Red Hill OWDFMW5A, Oahu, HI	vented	−4	−24	118.78	U.S. Navy	--[3]
OWDFMW6A	212216157542801	Red Hill OWDFMW6A, Oahu, HI	vented	−74	−94	119.51	U.S. Navy	--[3]
Hālawa Shaft	212305157542601	3-2354-01 Halawa Shaft (S12), Oahu, HI	vented	--	--	23.21	USGS	--[4]
ʻAiea Hālawa Shaft	212253157554301	3-2255-32 Halawa Shaft (S5), Oahu, HI	vented	--	--	28.05	U.S. Navy	--[4]

Table 1. List of monitoring equipment type, well open intervals, and measuring-point altitudes for selected wells, Hālawa area, O‘ahu, Hawai‘i.—Continued

Common name	USGS site identification number	USGS site name	Transducer type	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[1], in feet	Source of MP altitude	Gyroscopic-survey correction to be added to depth-to-water measurement[2], in feet
Hālawa TZ	212233157552302	3-2255-40 Halawa TZ Well, Oahu, HI	vented	0	−955	60.04	USGS	--[4]
‘Aiea Bay	212238157561101	3-2256-10 Aiea Bay nr Naval Res (187-B), Oahu, HI	vented	−133	−163	26.07	USGS	--[4]
TAMC MW2	212144157534701	3-2153-13 TAMC MW2, Oahu, HI	vented	26	16	179.70	USGS	--[3]

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

[2]Gyroscopic-survey correction (Naval Facilities Engineering Command Hawaii, 2018).

[3]Gyroscopic-survey correction not available.

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

and backup) were used at RHMW01 because the small well diameter (about 1 inch) precluded use of a vented-transducer system. The nonvented transducers had an accuracy of about 0.03 ft (In-Situ Inc., 2018b).

On-site pressure-depth calibrations of the transducers were conducted by 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. At Hālawa Shaft, an on-site pressure-depth calibration of the transducer could not be conducted. 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).

Barometric-Pressure Data

Barometers were installed at RHMW01 and the ‘Aiea Bay well and programmed to continuously record pressure at 10-minute intervals, at an even 10-minute time (for example, 8:50 a.m., 9:00 a.m., 9:10 a.m.). Barometric-pressure data were collected concurrently with the data from the pressure transducers. The barometers had an accuracy of about 0.015 pounds per square inch (psi; In-Situ Inc., 2018a). The nonvented transducers at RHMW01 required an external barometer to compensate for the effects of barometric pressure.

Data Processing

The transducers were programmed to record pressure values in units of psi. For the vented transducers, barometric-pressure compensation was achieved using the vent tube connected to the transducer. For the nonvented transducers, barometric-pressure changes were accounted for by subtracting the barometric pressure—recorded by a separate barometer—from the absolute pressures recorded by the transducer. 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-depth 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 ending of the record period. The offset-correction values were prorated linearly between consecutive site visits.

Data

Water-level data collected during this study are stored in the publicly accessible USGS National Water Information System (NWISWeb) database (U.S. Geological Survey, 2022). The data can be accessed on the NWISWeb database using the USGS site identifiers listed in this report (table 1).

Water levels were recorded at 20 sites during the January to March 2022 study period. Recorded water levels were between 16 to 20 ft and generally between 17 and 19 ft at most sites (figs. 2–21). Discrete water-level measurements were collected during each site visit, both prior to equipment deployment and following equipment retrieval. Measured water levels during deployment site visits (January 17–24) were generally similar to water-level measurements collected at common sites during the synoptic survey on January 18, 2022 (Nakama and others, 2022b).

On January 29, 2022, withdrawal from Red Hill Shaft resumed at a rate of about 4.5 million gallons per day. Following the resumption of withdrawal at Red Hill Shaft, water levels in the monitored wells generally decreased. Relative to the average water level during the 1-hour period from 1:20 to 2:10 p.m. on January 29, 2022, prior to the resumption of withdrawal at Red Hill Shaft, the average water level about 10 days later (during the period from 2:20 p.m. on February 7, 2022, to 2:10 p.m. on February 8, 2022) at the monitored wells decreased by about 0.11 to 0.41 ft (fig. 22). In general, greatest decreases in water levels occurred in wells closest to Red Hill Shaft.

In addition to being affected by groundwater withdrawals, water levels can be affected by natural factors such as variations in barometric pressure and groundwater recharge from rainfall. Barometric-pressure variations recorded by barometers installed across the monitor-well network were generally similar (Mitchell and Oki, 2018). Barometric pressure recorded at the ‘Aiea Bay well was generally representative of barometric-pressure variations in the Hālawa area. National Oceanic and Atmospheric Administration (NOAA) rain-gaging station MOANALUA 770, HI US, located about 1.6 miles southeast of the Red Hill Bulk Fuel Storage Facility, recorded a total of 0.47 inches of rain from January 17 to March 3, 2022 (NOAA, 2022).

Limitations

The water-level data are reported to a precision of a hundredth of a foot, although the absolute accuracy may be affected by several factors. The continuous water-level data are only as accurate as the discrete water-level data because the beginning and ending of each individual water-level record collected between site visits are referenced to depth-to-water measurements. 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, and (4) human error. After accounting for the accuracy of the discrete water-level measurements, the accuracy of the continuous water-level data may be further limited by (1) the accuracy of the pressure sensors, (2) internal drift of the pressure sensors, and (3) minor changes to the submergence depth that occur as suspension cables stretch. Excessive moisture in the vent tube attached to a vented transducer can potentially lead to equipment malfunction and unreliable data.

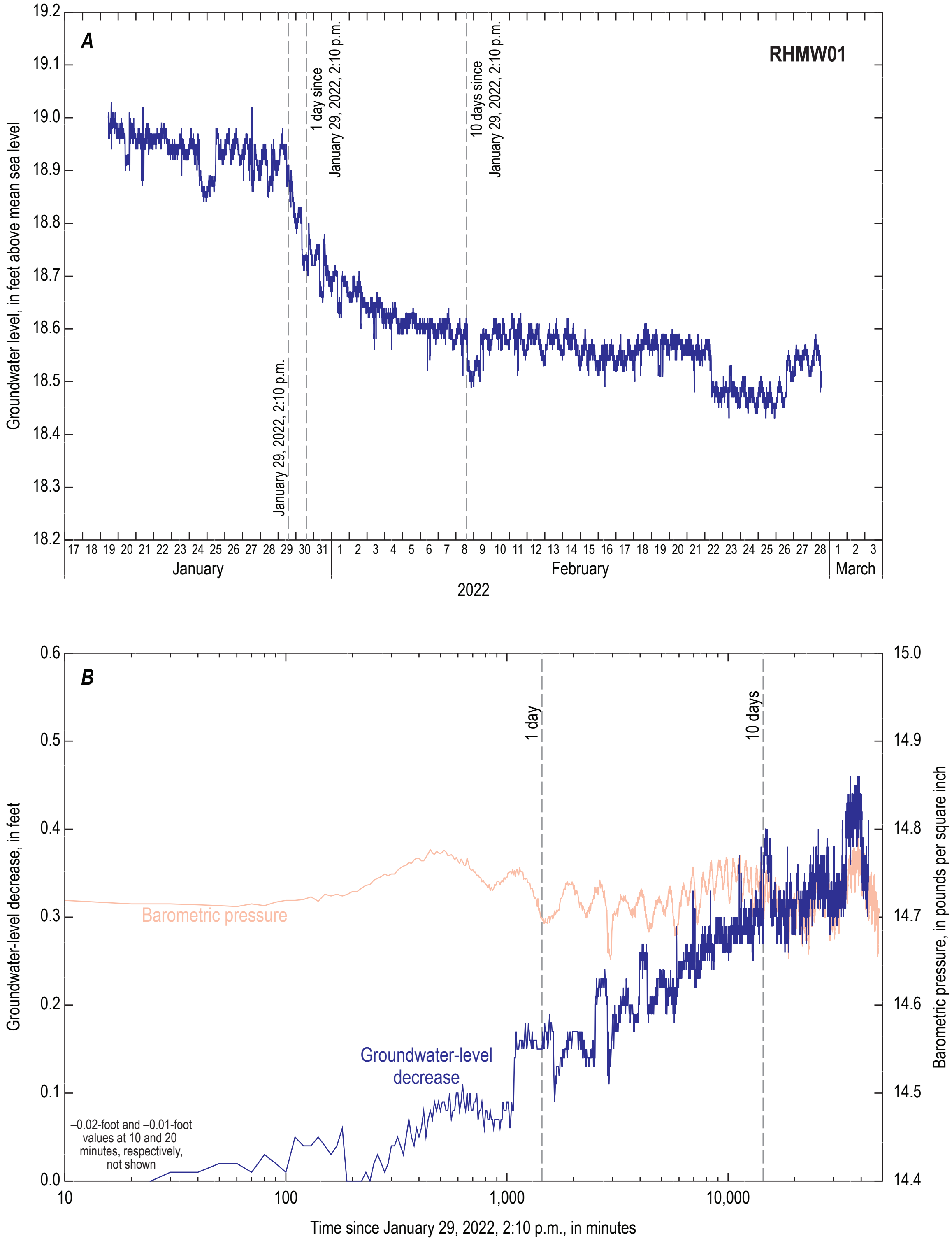


Figure 2. Graphs of groundwater level in well RHMW01. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, Oʻahu, Hawaiʻi.

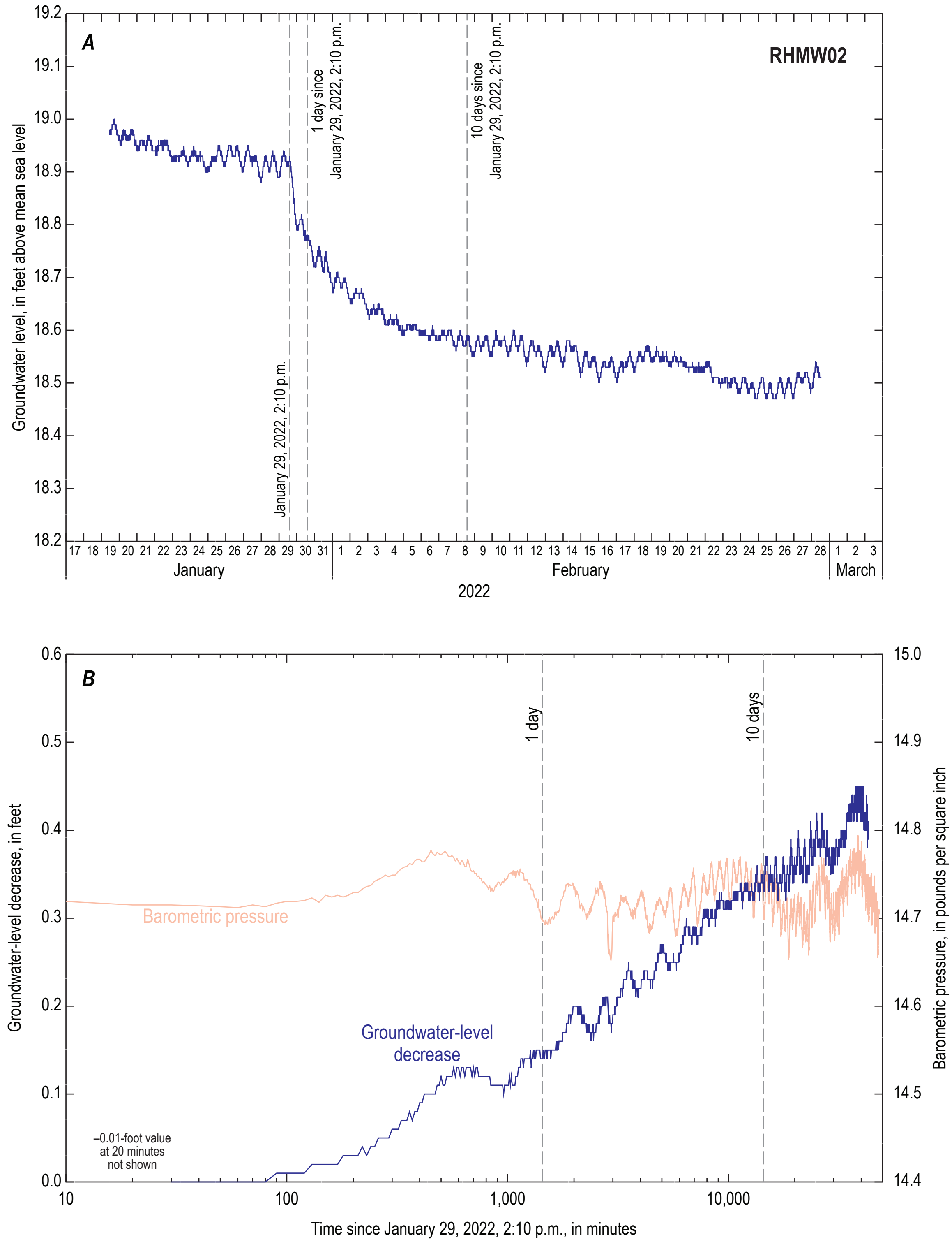


Figure 3. Graphs of groundwater level in well RHMW02. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, O‘ahu, Hawai‘i.

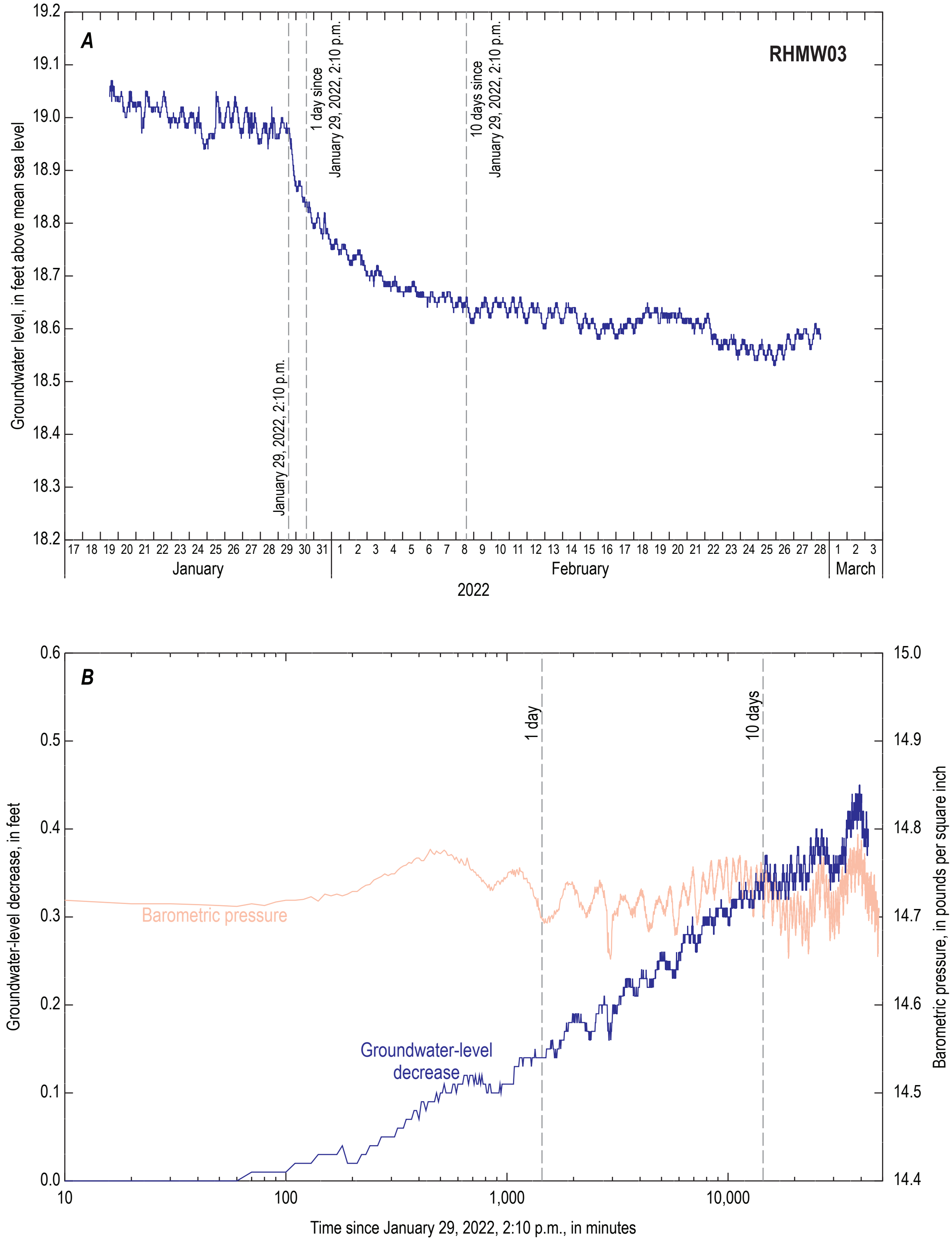


Figure 4. Graphs of groundwater level in well RHMW03. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, Oʻahu, Hawaiʻi.

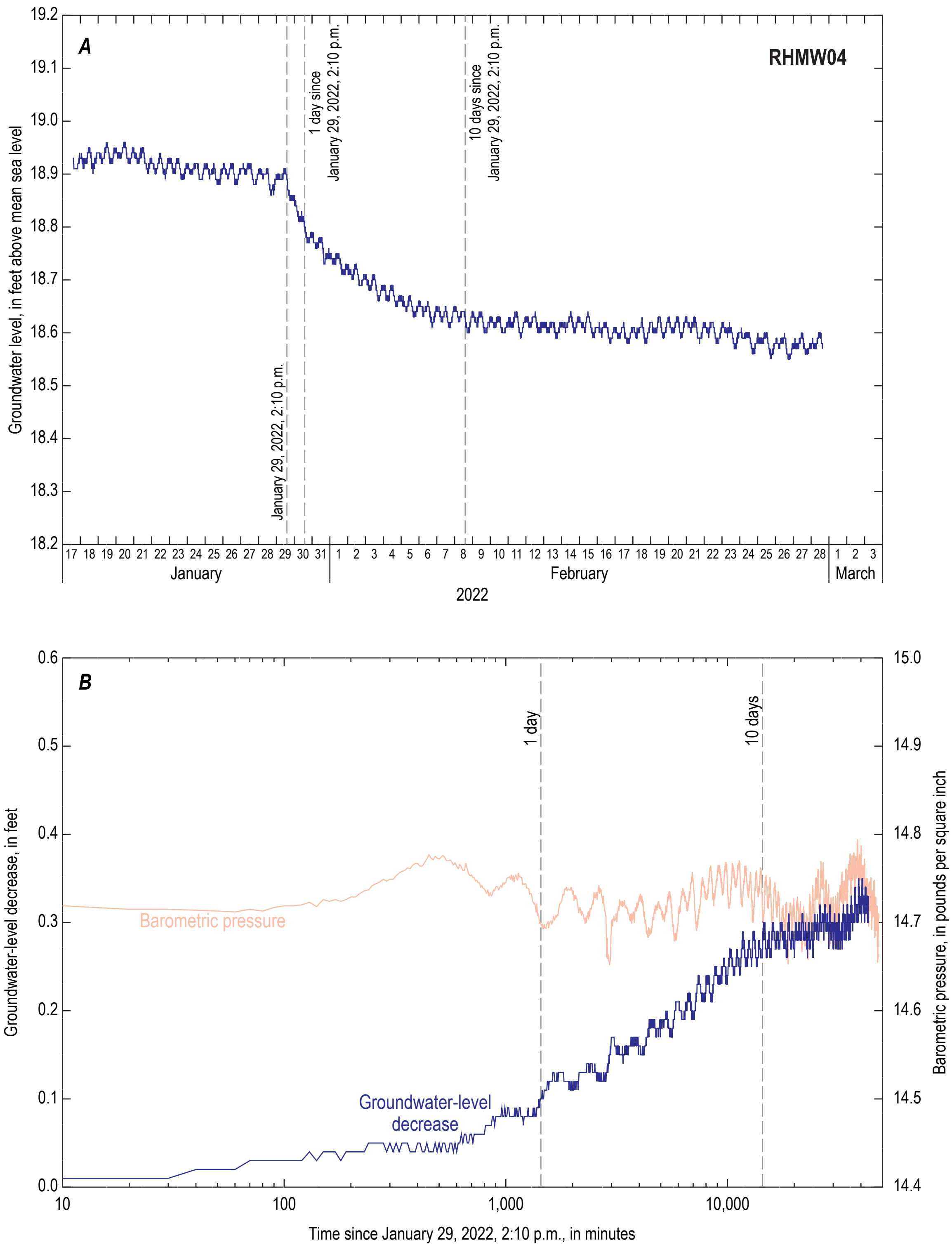


Figure 5. Graphs of groundwater level in well RHMW04. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, O‘ahu, Hawai‘i.

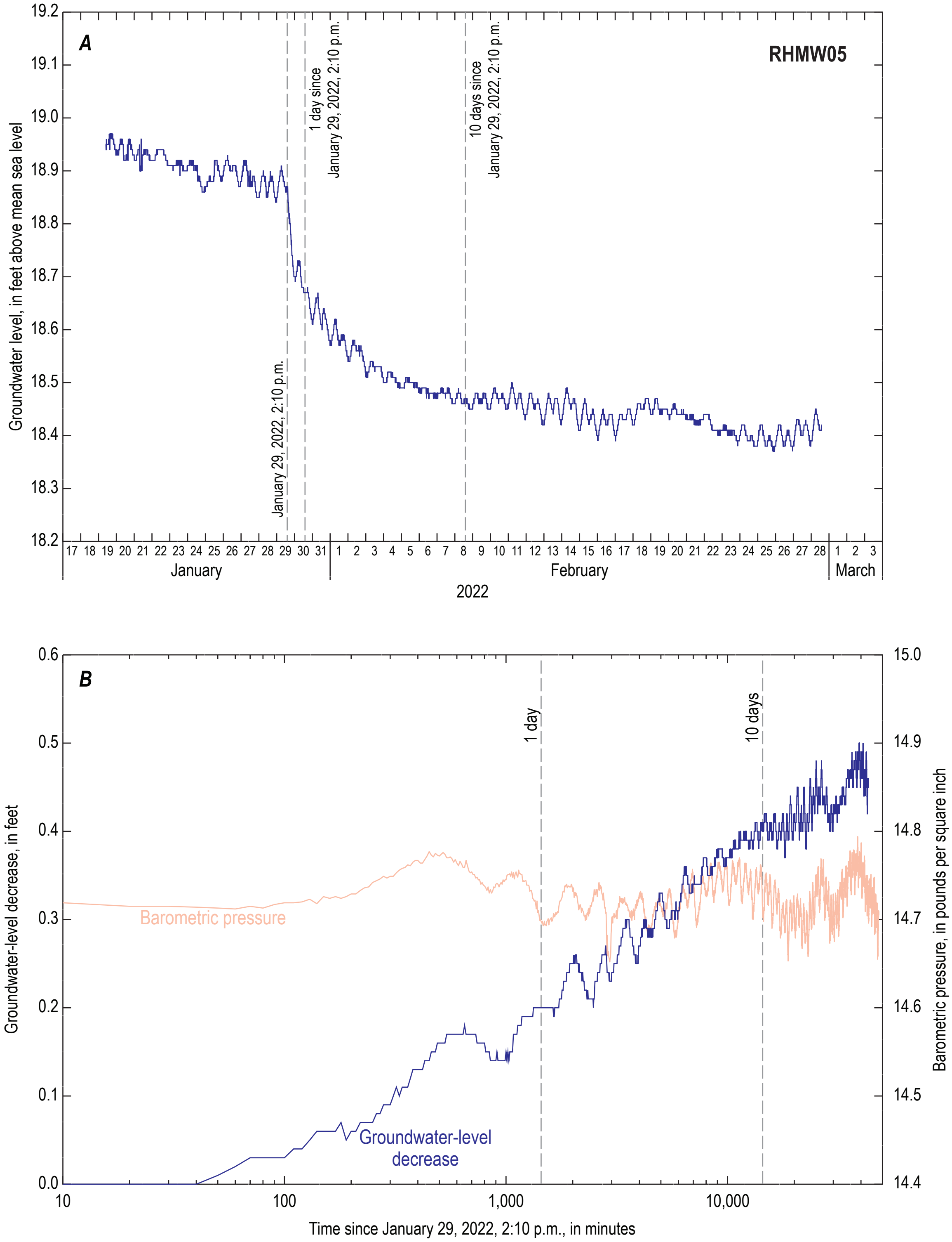


Figure 6. Graphs of groundwater level in well RHMW05. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, O‘ahu, Hawai‘i.

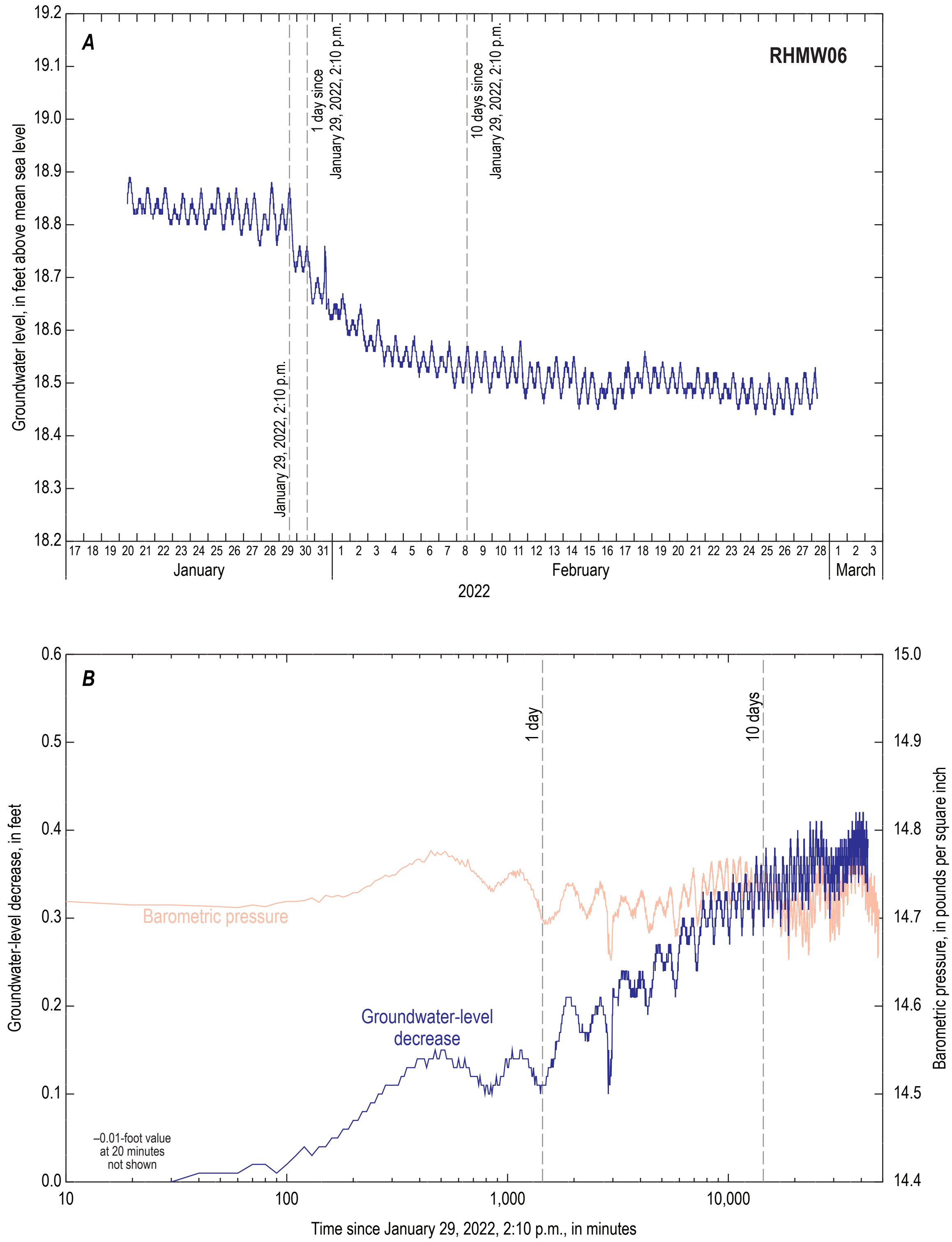


Figure 7. Graphs of groundwater level in well RHMW06. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, O‘ahu, Hawai‘i.

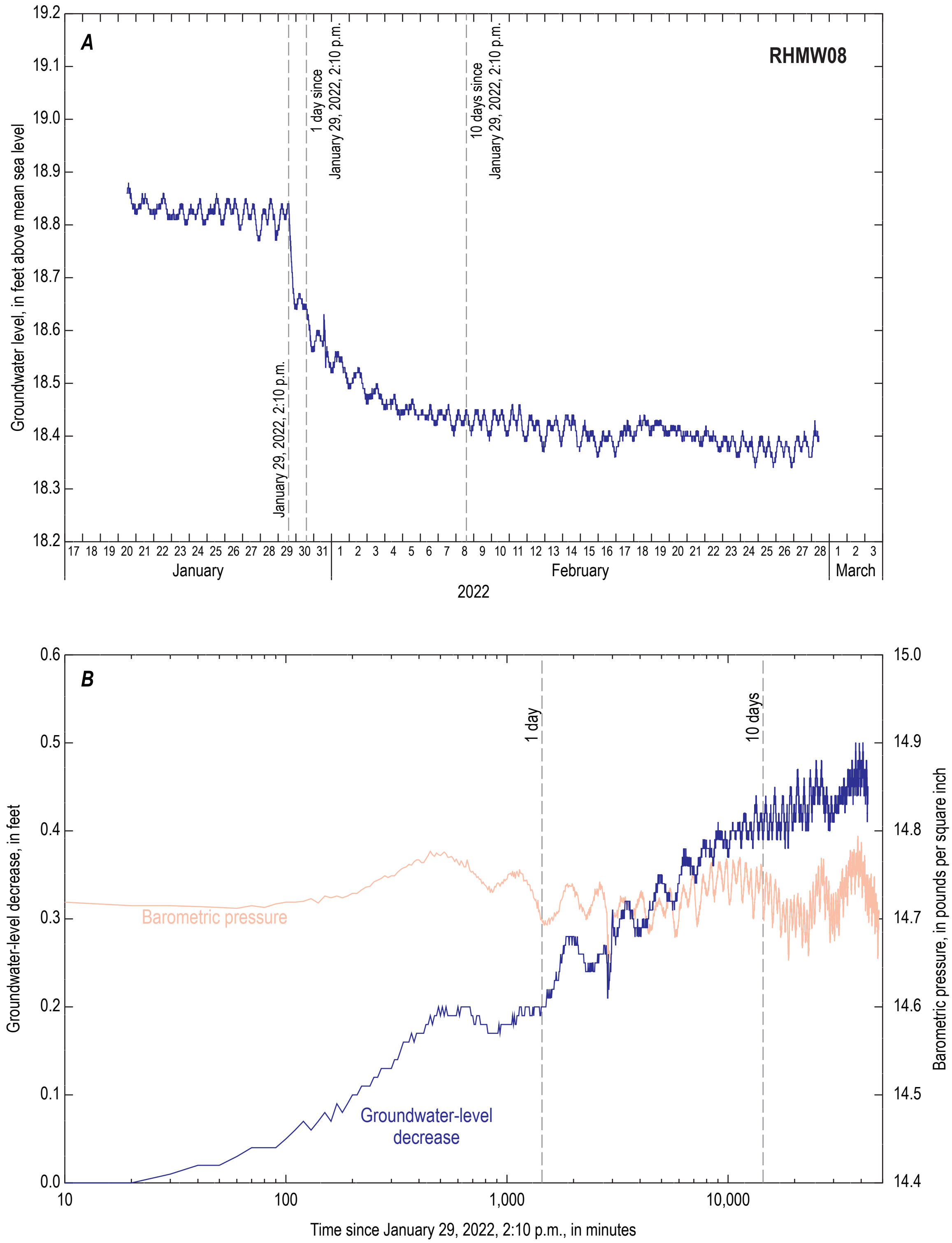


Figure 8. Graphs of groundwater level in well RHMW08. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, O‘ahu, Hawai‘i.

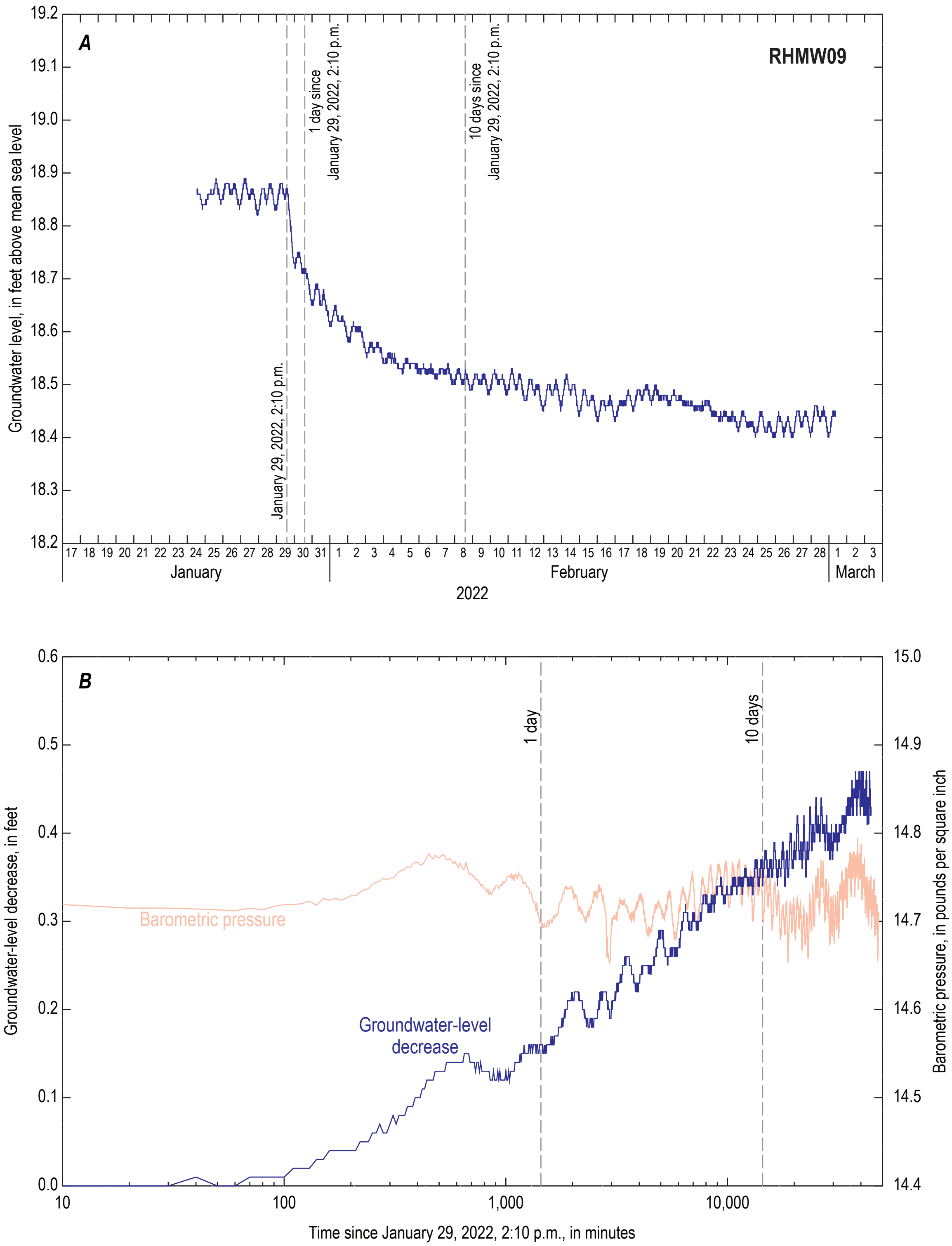


Figure 9. Graphs of groundwater level in well RHMW09. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, O‘ahu, Hawai‘i.

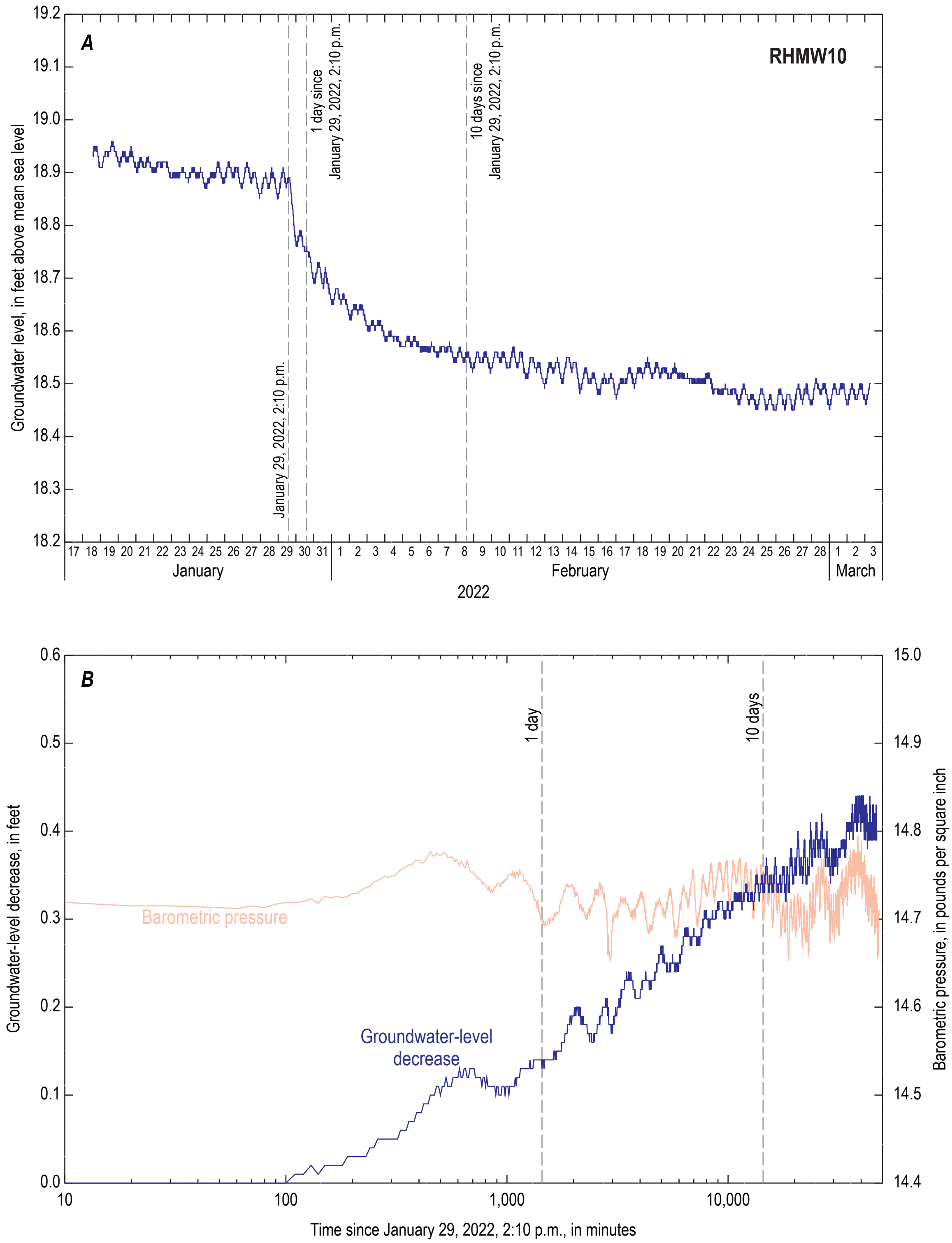


Figure 10. Graphs of groundwater level in well RHMW10. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, O‘ahu, Hawai‘i.

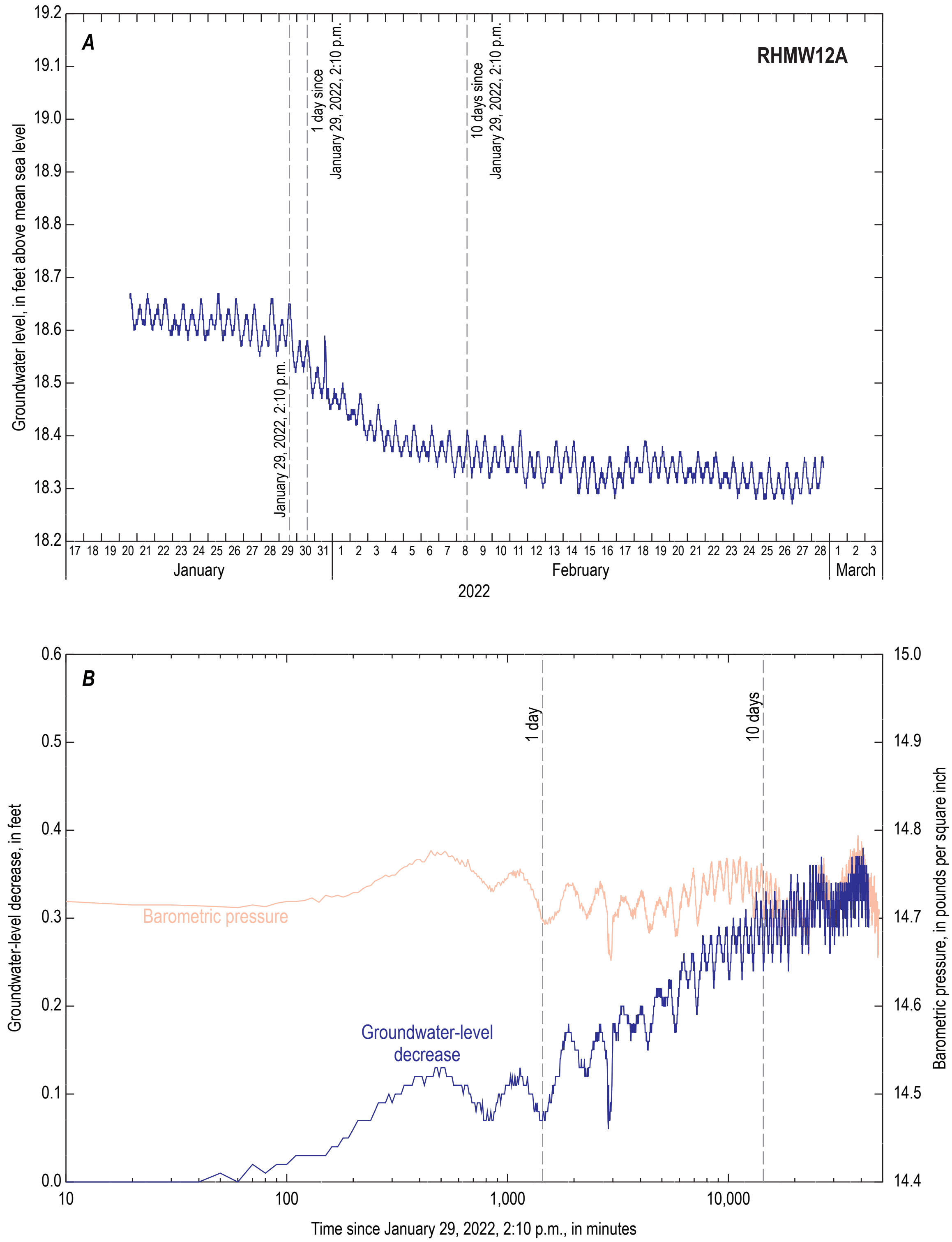


Figure 11. Graphs of groundwater level in well RHMW12A. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, Oʻahu, Hawaiʻi.

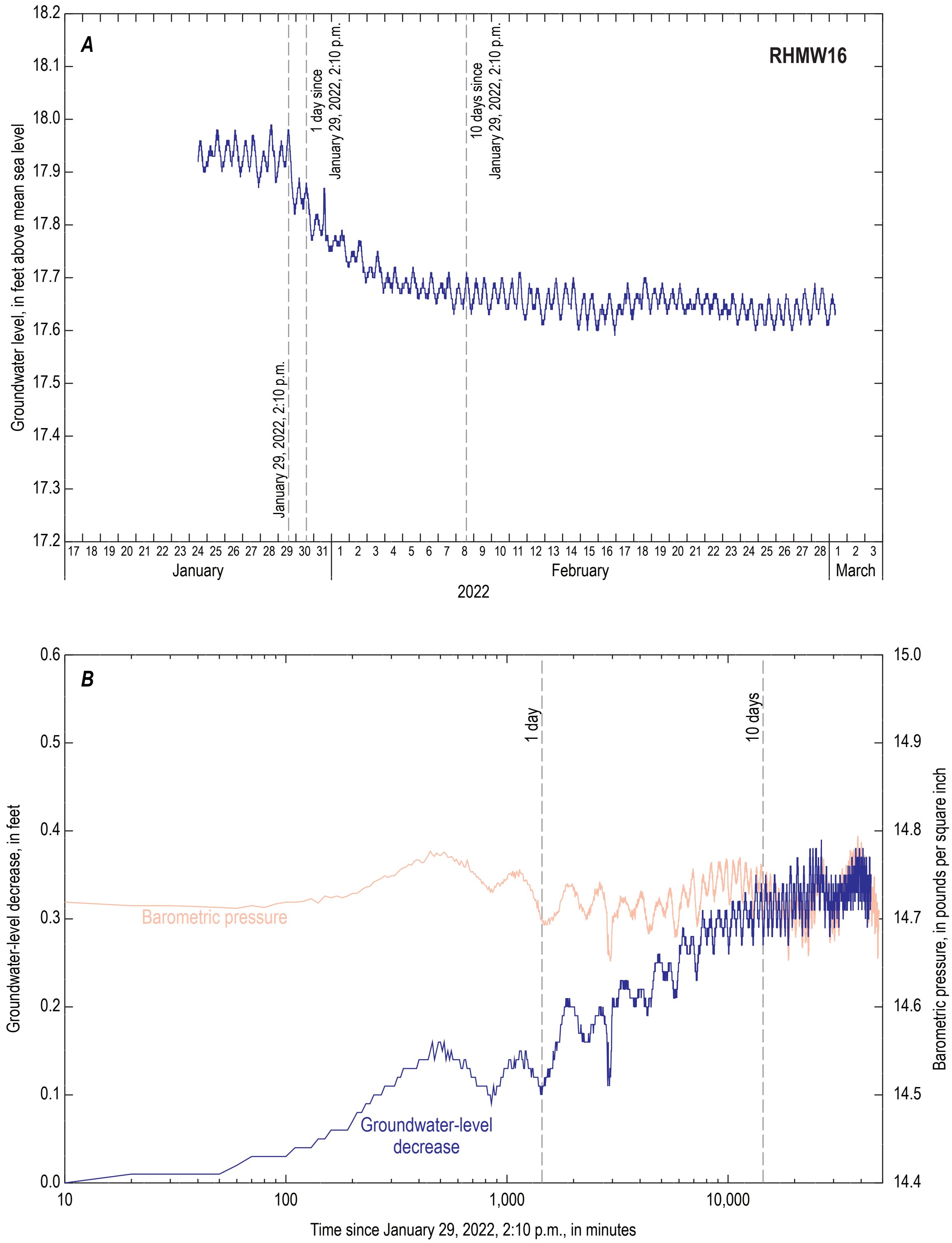


Figure 12. Graphs of groundwater level in well RHMW16. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, Oʻahu, Hawaiʻi.

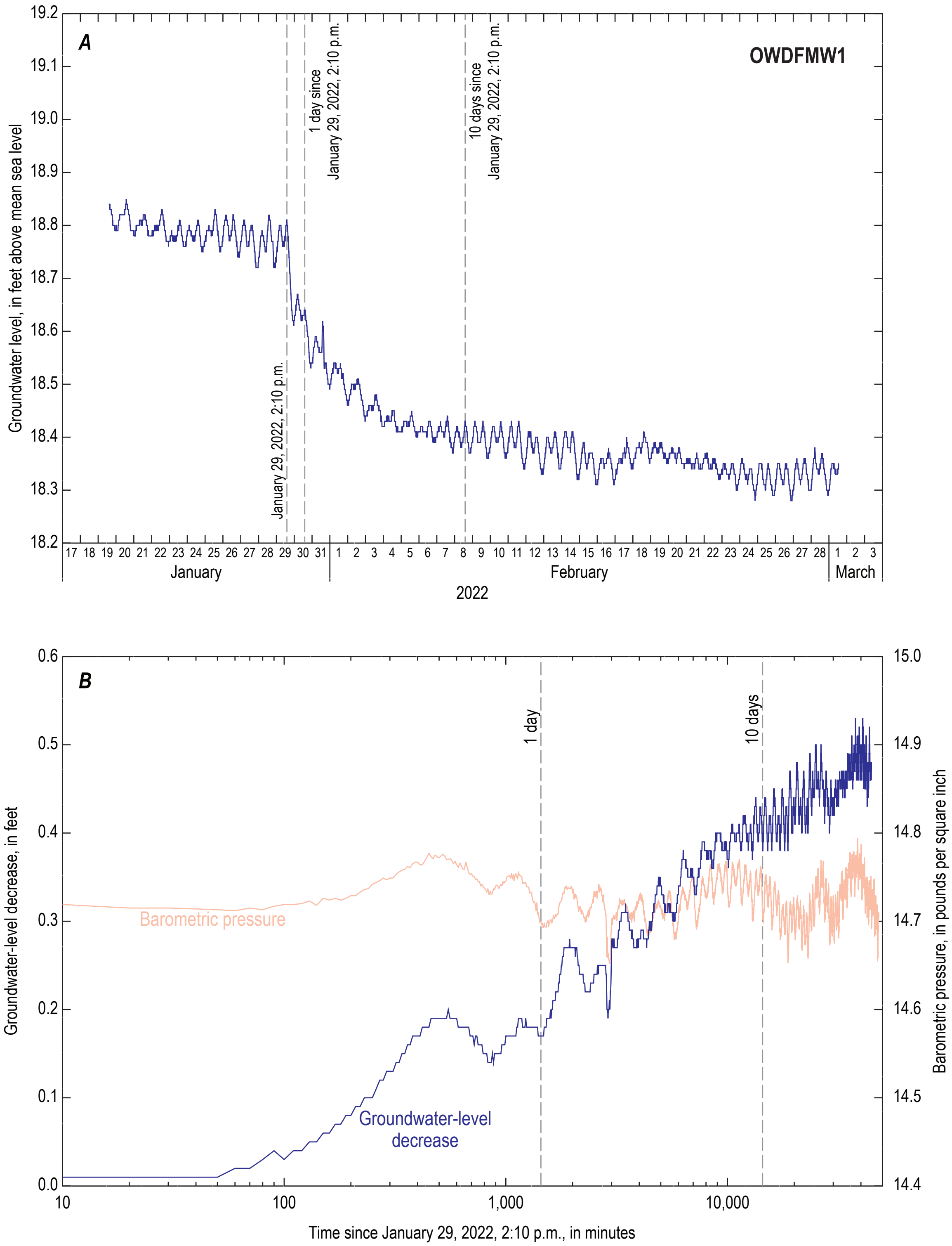


Figure 13. Graphs of groundwater level in well OWDFMW1. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, O‘ahu, Hawai‘i.

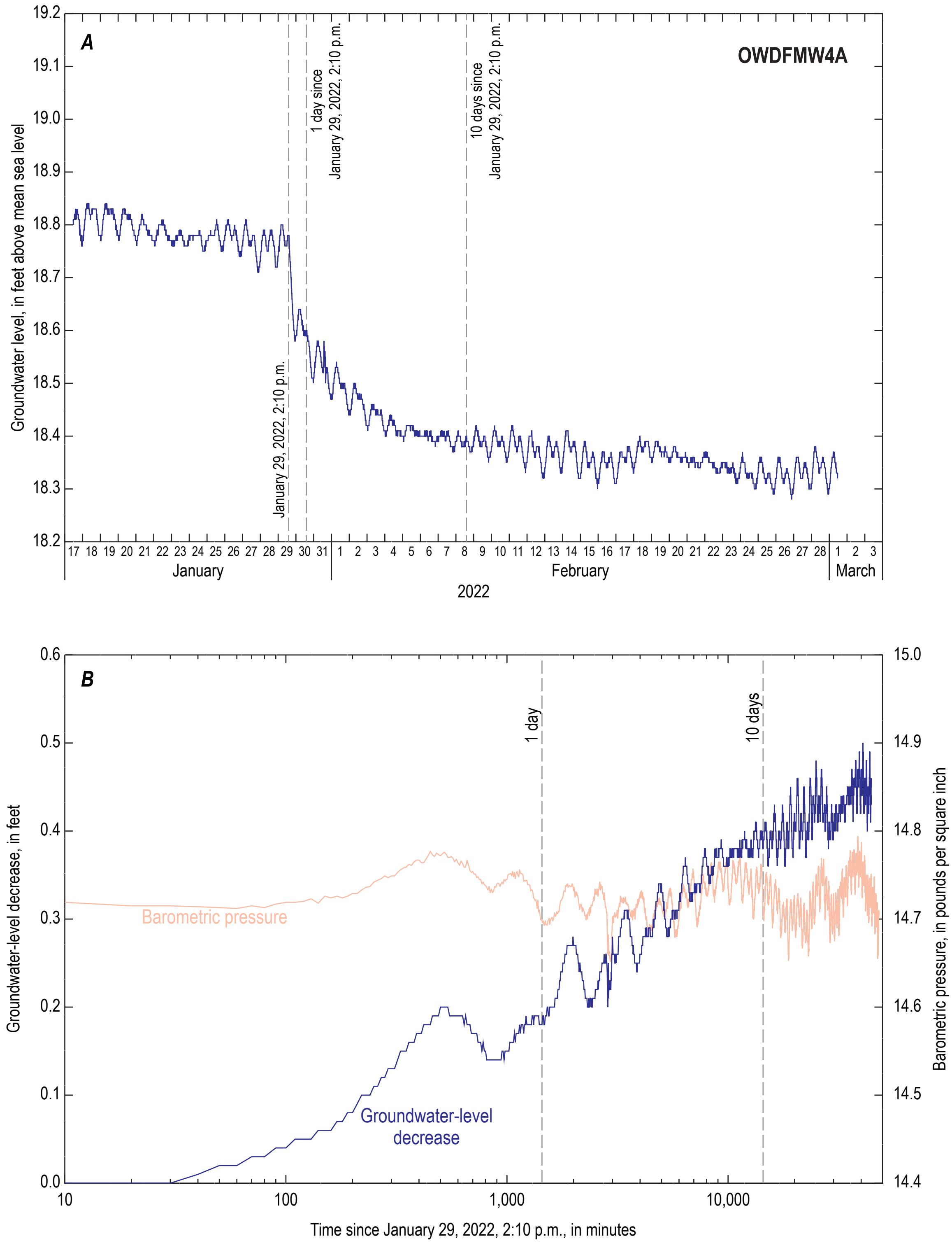


Figure 14. Graphs of groundwater level in well OWDFMW4A. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, Oʻahu, Hawaiʻi.

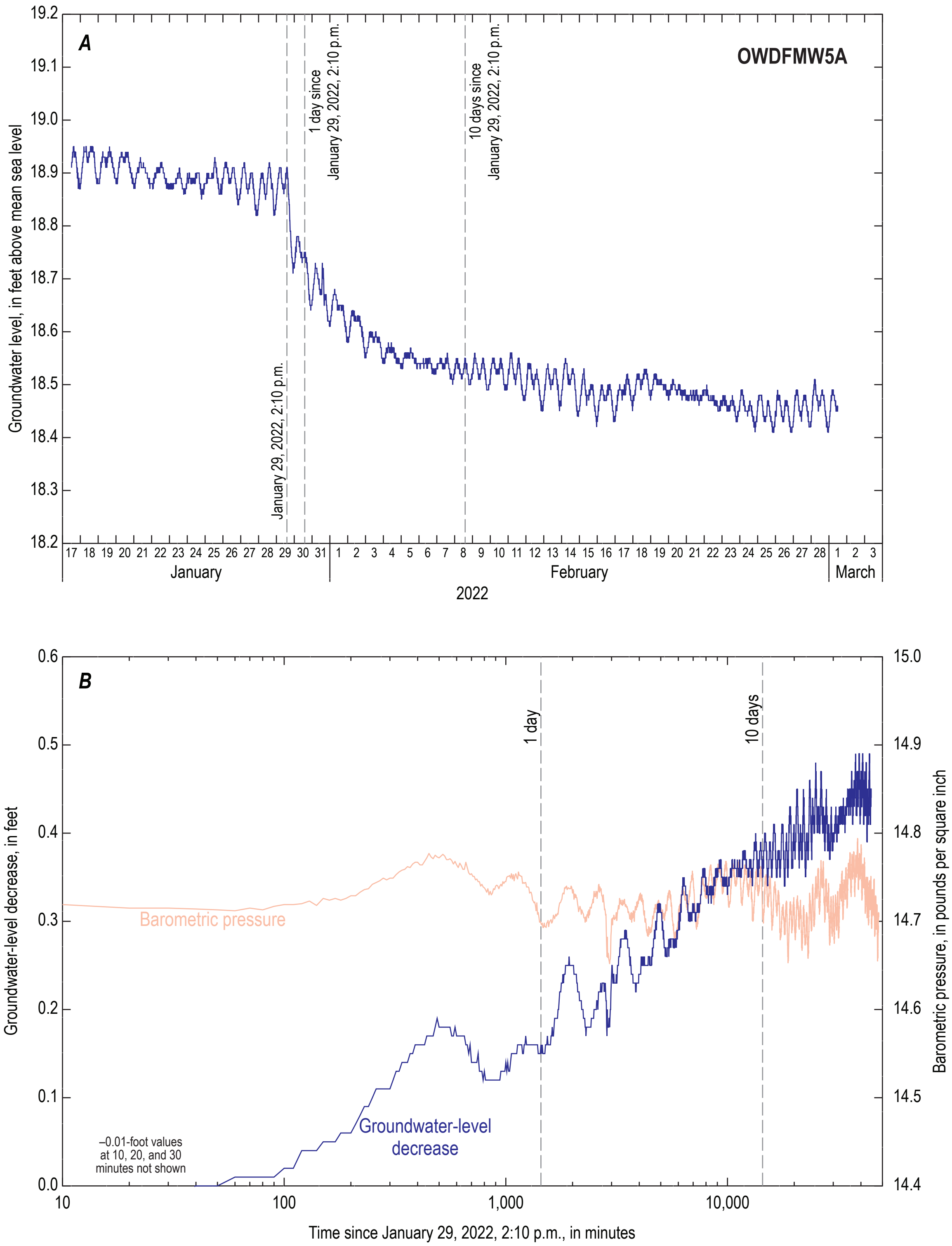


Figure 15. Graphs of groundwater level in well OWDFMW5A. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, O‘ahu, Hawai‘i.

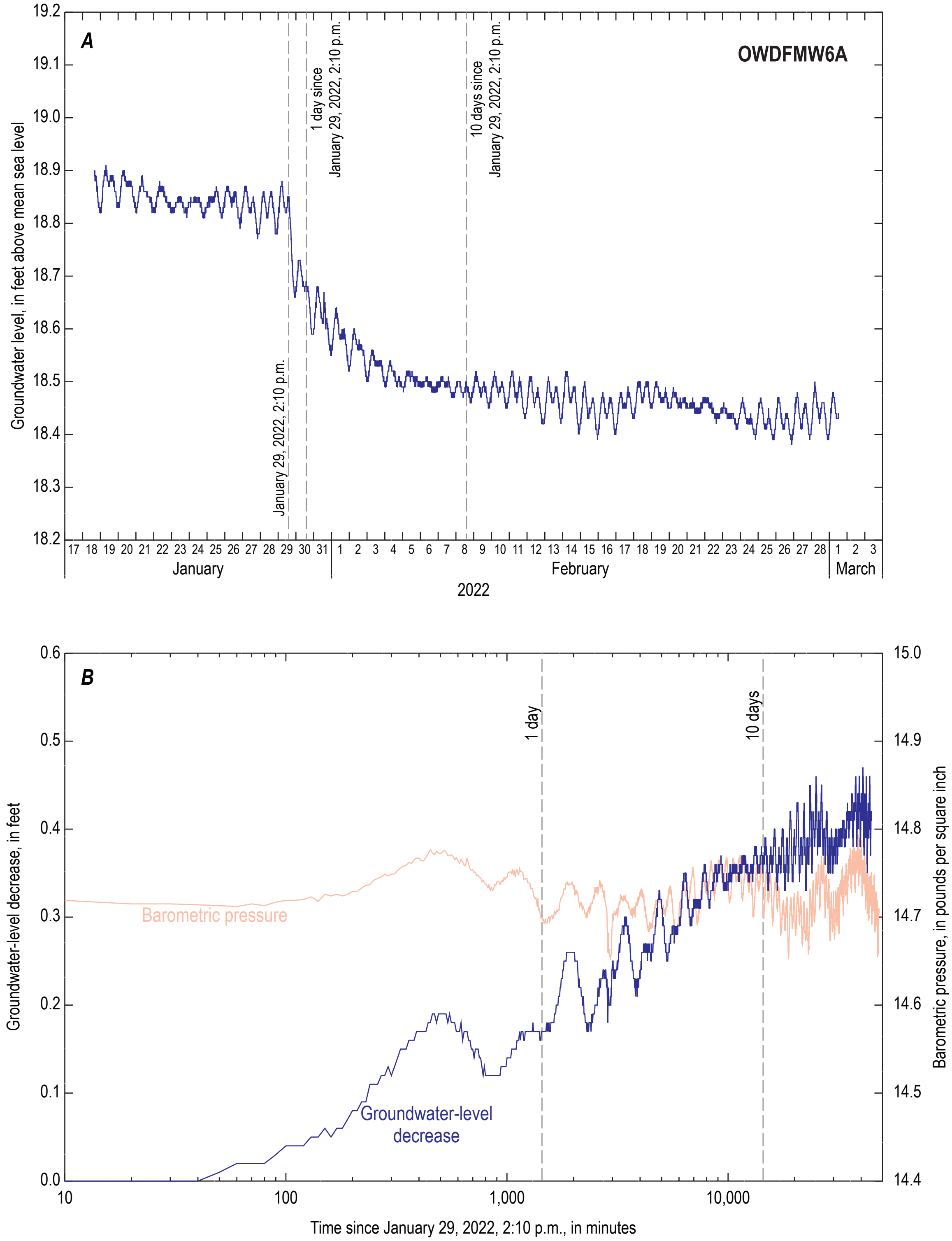


Figure 16. Graphs of groundwater level in well OWDFMW6A. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, Oʻahu, Hawaiʻi.

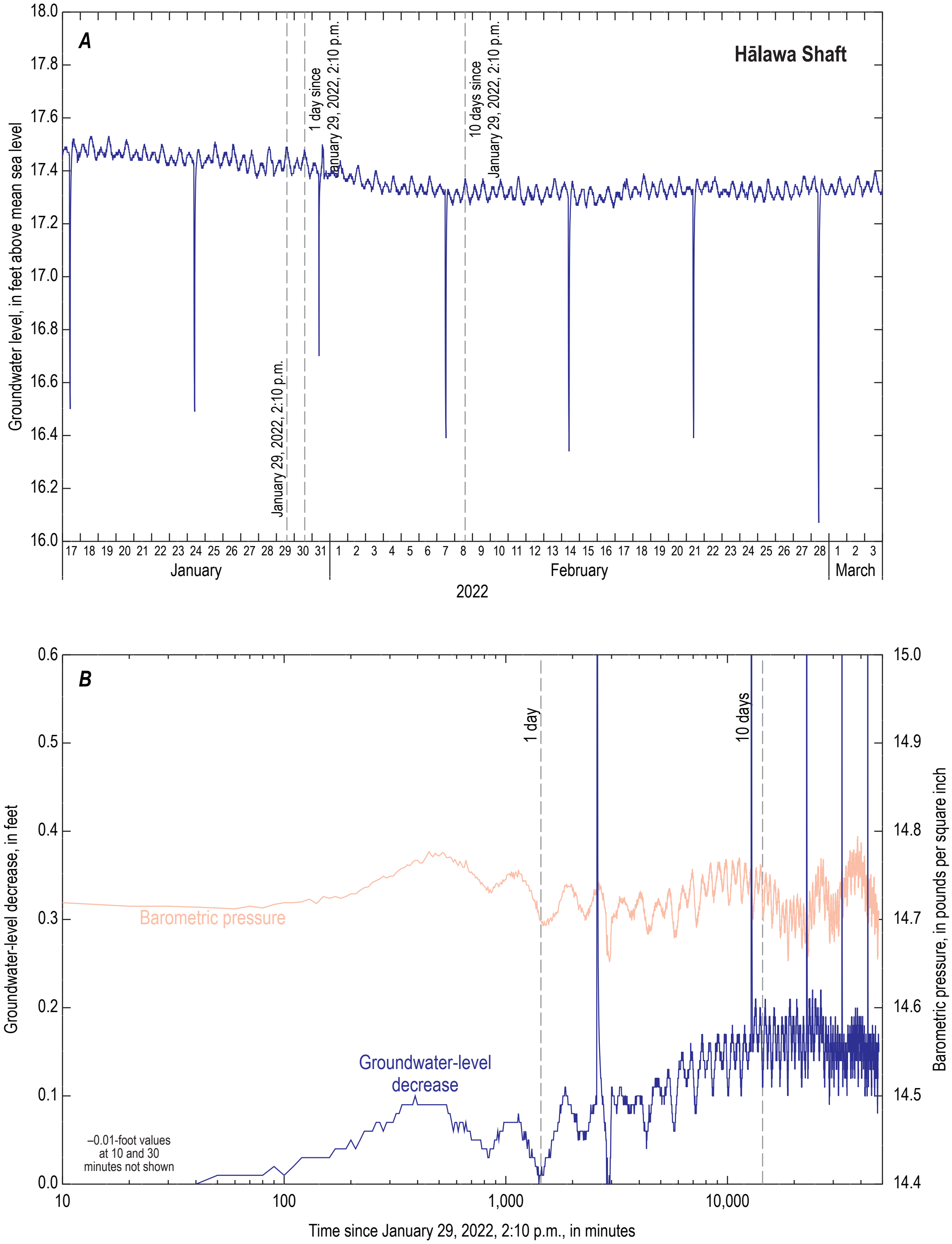


Figure 17. Graphs of groundwater level in well Hālawa Shaft. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, O‘ahu, Hawai‘i.

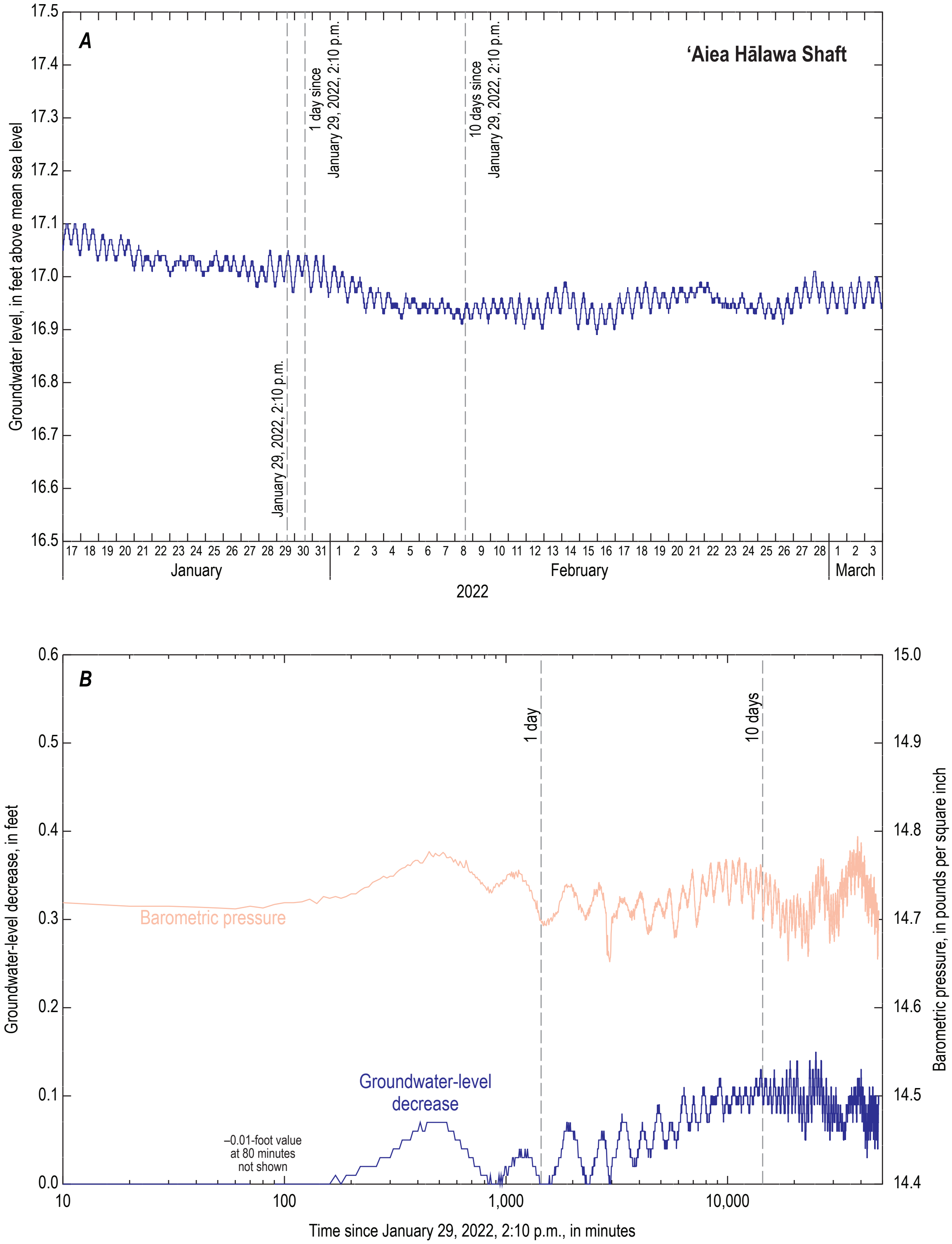


Figure 18. Graphs of groundwater level in well 'Aiea Hālawa Shaft. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, O'ahu, Hawai'i.

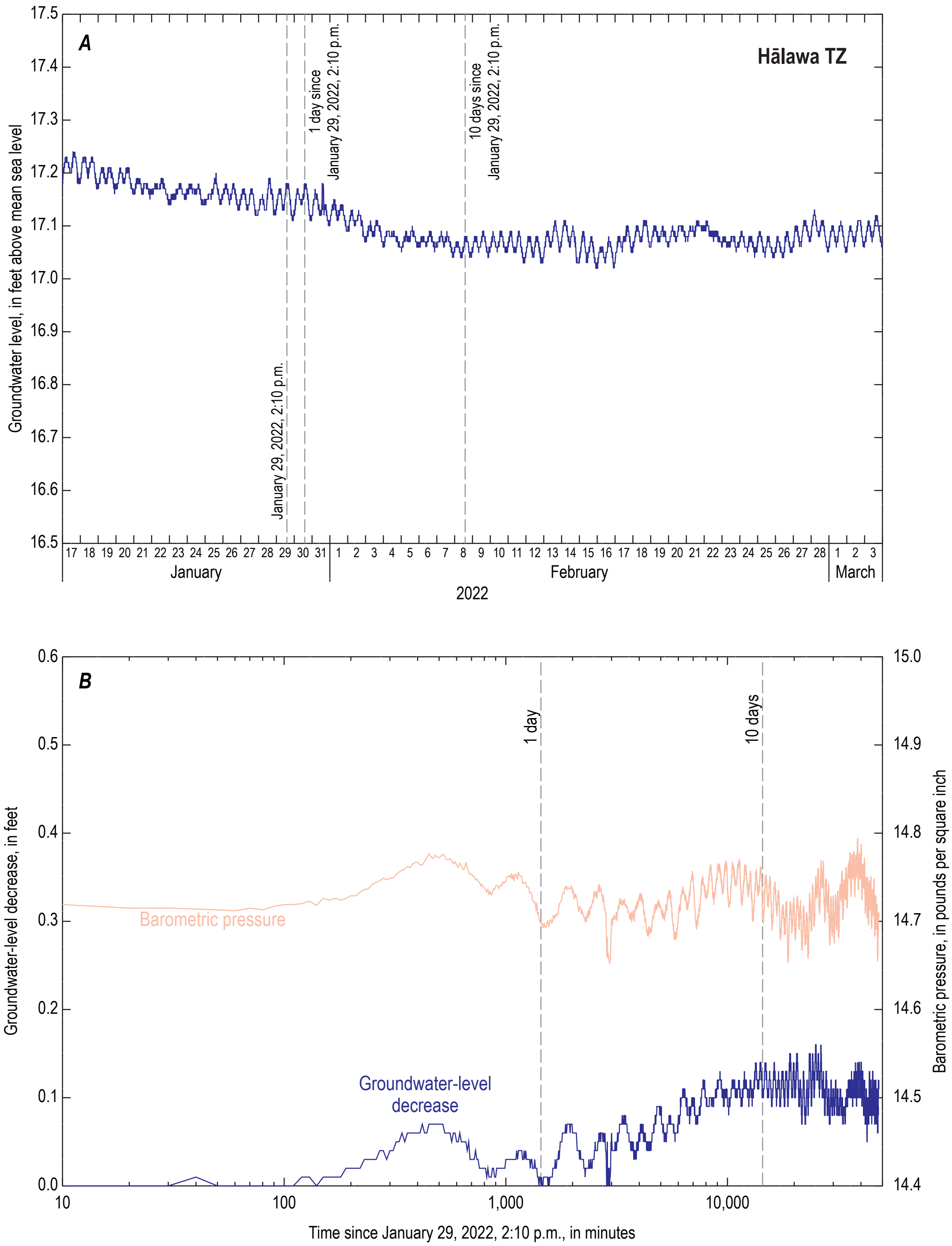


Figure 19. Graphs of groundwater level in well Hālawa TZ. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, Oʻahu, Hawaiʻi.

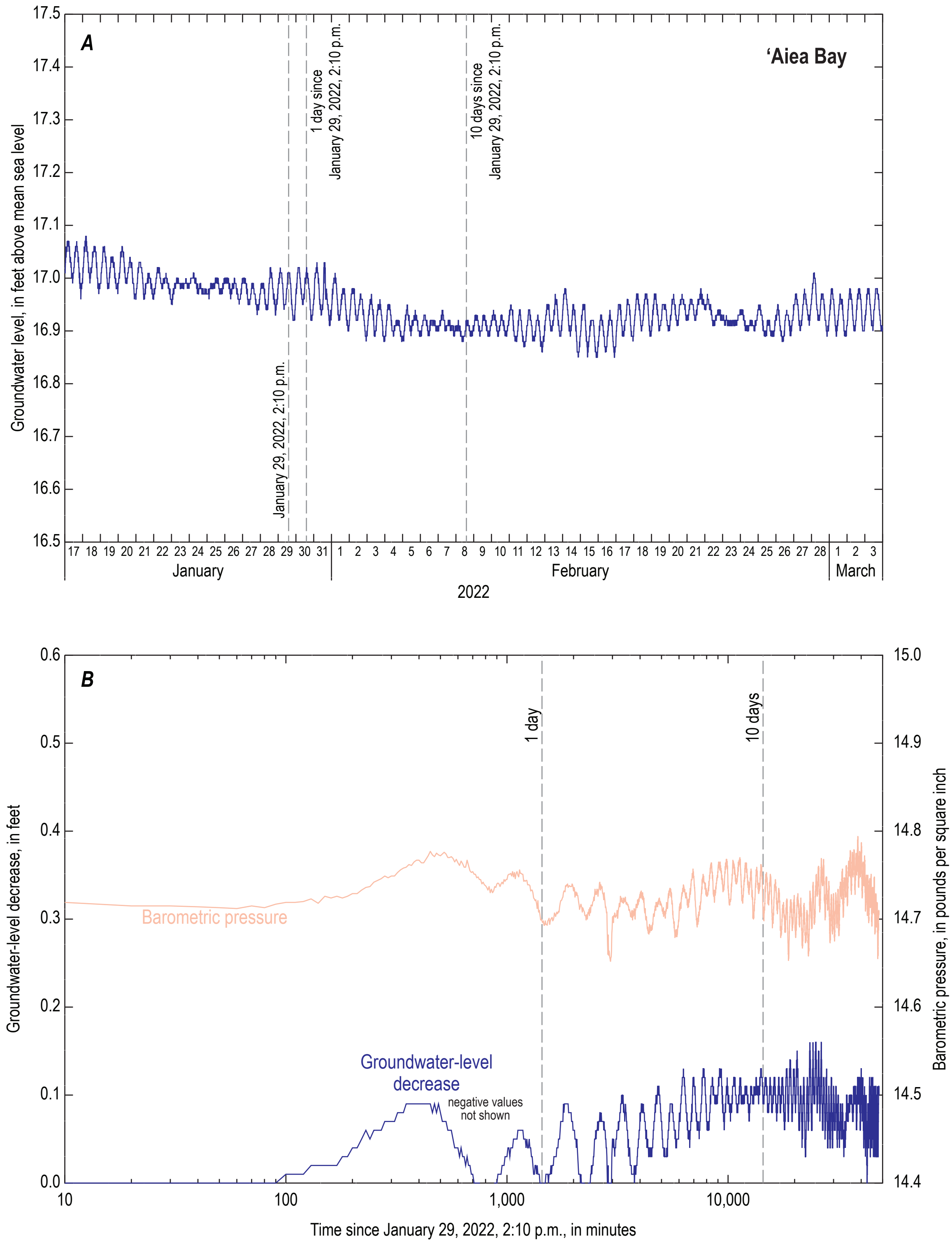


Figure 20. Graphs of groundwater level in well ʻAiea Bay. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, Oʻahu, Hawaiʻi.

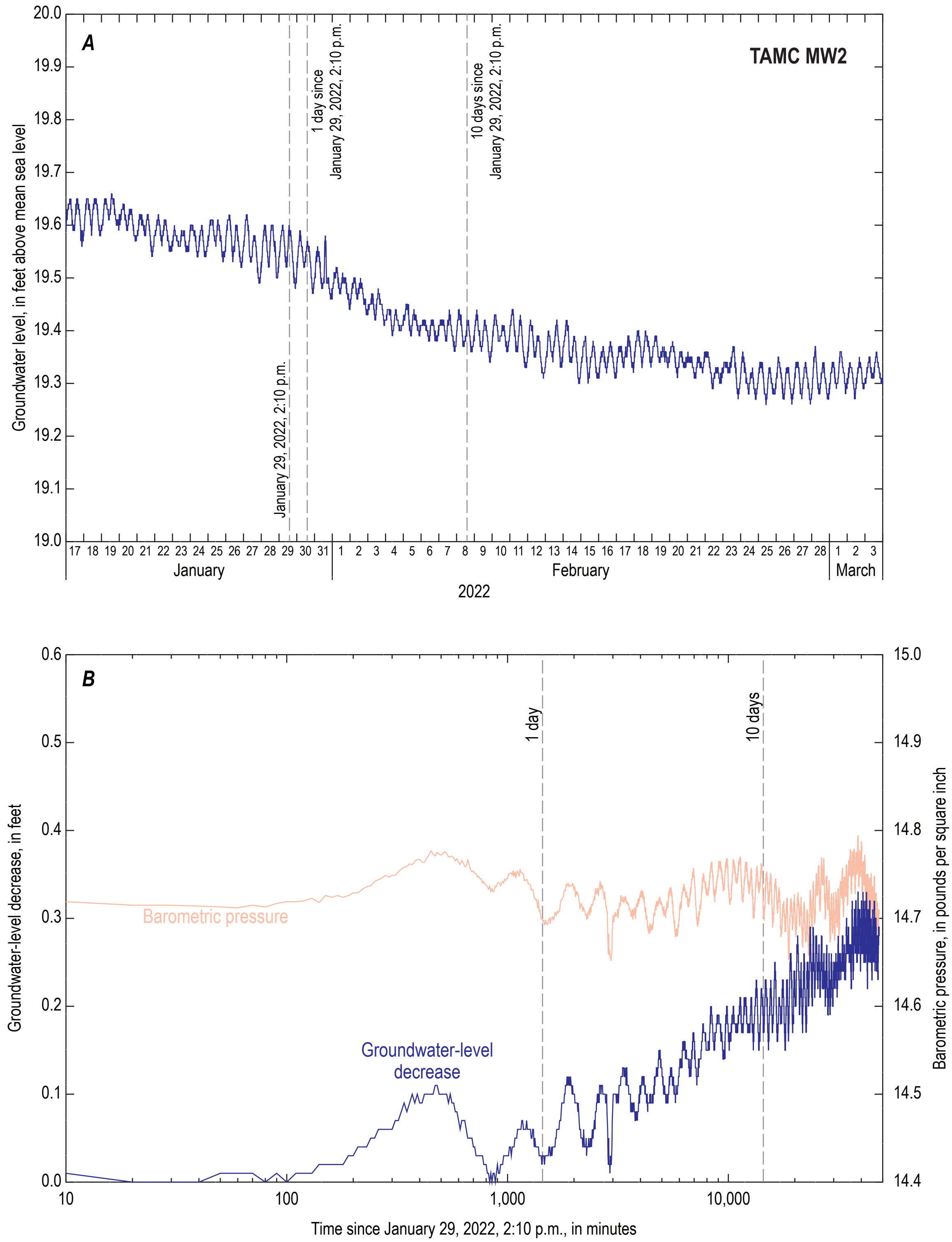
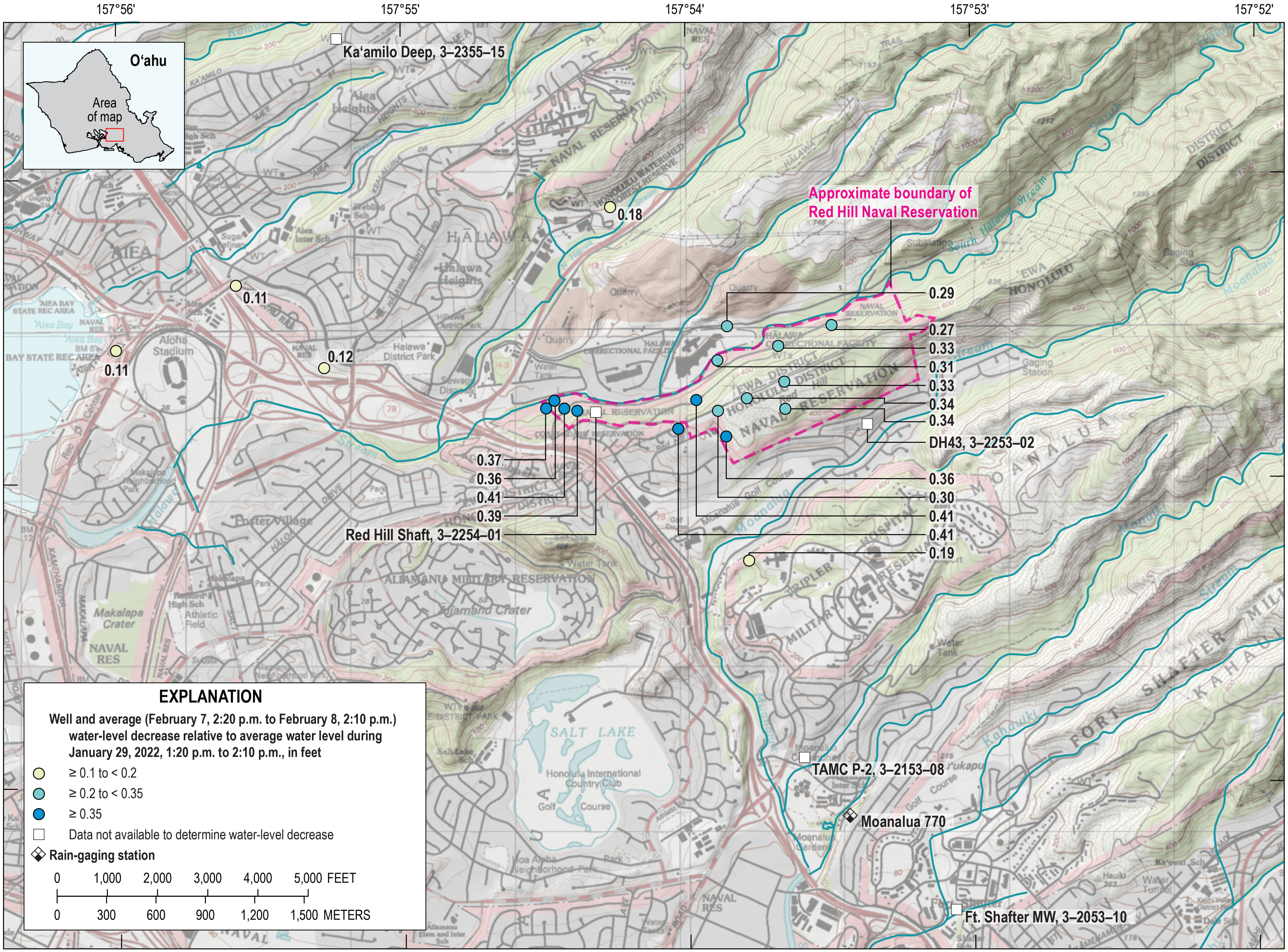


Figure 21. Graphs of groundwater level in well TAMC MW2. (*A*) Measured from January 17 through March 3, 2022, and (*B*) in terms of decrease (drawdown) relative to the mean value (rounded to the nearest hundredth of a foot) during the inclusive period from 1:20 p.m. to 2:10 p.m. on January 29, 2022, Hālawa area, O‘ahu, Hawai‘i.



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 22. Map of groundwater-level decreases measured in monitored wells 10 days after the resumption of withdrawal from Red Hill Shaft on January 29, 2022, Hālawa, O'ahu, Hawai'i.

The tape-correction values, applied to each depth-to-water measurement, reflect tape errors at specific depths and may not perfectly reflect errors at depths of each site in the study. The tapes used during this study were last calibrated in September 2019. Results of the tape calibration in September 2019 indicated that tape corrections ranged in magnitude from −0.09 to 0.01 ft for depths measured at the 20 sites discussed in this report. 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 this study. A planned biennial 2021 tape calibration prior to this study 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 Oʻahu—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 this study can be revised if the MP altitudes are resurveyed using consistent methods that incorporate the adjusted benchmark altitudes.

The gyroscopic-survey data, available for 9 of the 20 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, Hālawa Shaft and ʻAiea 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 9 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 vented cables and stainless-steel cables used to suspend the transducers in the water are subject to mechanical relaxation, stretching, and slippage, particularly in the periods immediately after deployment (Cunningham and Schalk, 2011). The correction values applied to the continuous water-level records, derived from the discrete water-level measurements, account for (1) vertical movement of the transducers in the water column during the record, and (2) internal drift of the pressure sensor. The correction values were prorated linearly between discrete water-level measurements; however, introduced errors may not have occurred linearly.

The nonvented transducers deployed at RHMW01 have a lower reported water-level accuracy than the vented transducers (In-Situ Inc., 2018b, c). In addition, the nonvented transducers required an external barometer to compensate for the effects of barometric pressure, further introducing possible error.

Comparability among the water levels may be affected by vertical hydraulic gradients in the aquifer. Not all wells represent conditions at the water table. Several 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

The November 2021, fuel release at the Red Hill Bulk Fuel Storage Facility led to the subsequent shutdown of several production wells in the Hālawa area, including the Red Hill Shaft (3–2254–01) and the Hālawa Shaft (3–2354–01). The shutdown of these high-capacity production wells initiated a change in regional aquifer conditions. Two multiagency synoptic groundwater-level surveys on December 23, 2021 (Nakama and others, 2022a), and January 18, 2022 (Nakama and others, 2022b), documented groundwater levels during the shutdown period when groundwater levels started to recover.

On January 29, 2022, the Red Hill Shaft resumed withdrawal of groundwater with the intention of removing possible fuel-related contaminants from the aquifer beneath and surrounding the Red Hill Bulk Fuel Storage Facility. Submersible pressure transducers were installed in 20 wells in the Hālawa area to collect groundwater-level data during the overall period from January 17 to March 3, 2022. Recorded groundwater levels in the 20 monitored wells were between 16 and 20 feet and generally between 17 and 19 feet at most sites. The average groundwater level in the monitored wells 10 days after the January 29, 2022, resumption of withdrawal at Red Hill Shaft indicated a decrease of about 0.1 to 0.4 foot from the groundwater levels immediately prior to the resumption of withdrawal. Measurement of groundwater levels in response to the resumption of withdrawal at Red Hill Shaft can be used to evaluate the potential effectiveness of the contaminant removal. Data collected for this study are available in the U.S. Geological Survey (USGS) National Water Information System database (U.S. Geological Survey, 2022); the data can be found using the USGS site identifiers listed in table 1 of this report.

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Moffett Field Publishing Service Center
Manuscript approved July 12, 2022
Edited by Mitchell Phillips
Illustrative support by Kimber Peterson
Layout by Katie Sullivan

Nakama and others—**Groundwater-Level Monitoring from January 17 to March 3, 2022, Hālawa Area, Oʻahu, Hawaiʻi**—Open-File Report 2022–1069

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20221069