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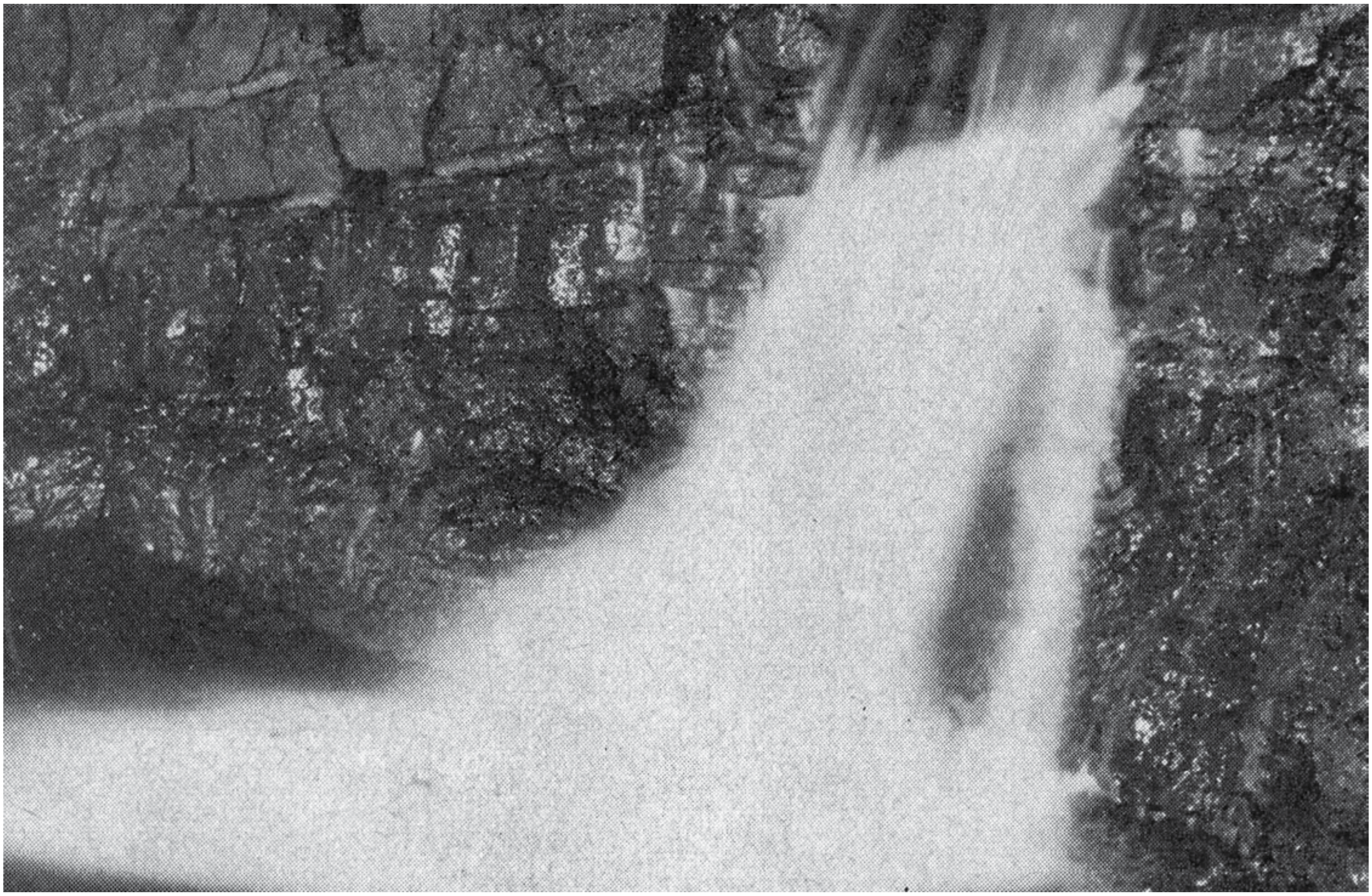
Groundwater-Level, Groundwater-Temperature, and Barometric-Pressure Data, July 2017 to February 2018, Hālawa Area, O‘ahu, Hawai‘i



Open-File Report 2018–1147

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

Front cover. Photo of groundwater discharging from lava flows that were exposed in the Hālawa Shaft development tunnel, when the tunnel was being excavated and dewatered. From Honolulu Board of Water Supply (1945, p. 65).

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By Jackson N. Mitchell and Delwyn S. Oki

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U.S. Department of the Interior
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U.S. Department of the Interior
RYAN K. ZINKE, Secretary

U.S. Geological Survey
James F. Reilly II, Director

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Acknowledgments

The U.S. Navy and Honolulu Board of Water Supply generously provided information on relative withdrawal rates shown in this report. At the time of publication, the withdrawal rates had not been published by the U.S. Navy or the Honolulu Board of Water Supply. The U.S. Army, U.S. Navy, Honolulu Board of Water Supply, and Hawaiʻi Commission on Water Resource Management provided access to several of the monitoring sites. The authors wish to thank Tineill Dudoit, Joe Kennedy, Rylen Nakama, and Sarah Rosa for their contributions to data collection. The authors also wish to thank Heather Jeppesen for her help with data management.

State of Hawaiʻi Well Numbers

From 1971 to 2012, Hawaiʻi's well-numbering system contained seven digits. The first digit identifies the island, which is then followed by a dash separator. The next four digits represent the grid system: the first two digits represent minutes of latitude and the second two digits represent minutes of longitude for that grid (leading zeroes are used for minute values less than 10). To distinguish wells within a minute grid, two digits follow the 4-digit minute-grid numbers with a dash separator; these are sometimes referred to as a sequence number.

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

Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Pressure	
atmosphere, standard (atm)	101.3	kilopascal (kPa)
bar	100	kilopascal (kPa)
pound per square foot (lb/ft^2)	0.04788	kilopascal (kPa)
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 mean sea level.

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

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

Abbreviations

AOC Administrative Order on Consent

EPA U.S. Environmental Protection Agency

DOH Hawai‘i Department of Health

MP measuring point

NAVFAC Naval Facilities Engineering Command

NWIS National Water Information System

psi pounds per square inch

RHSF Red Hill Bulk Fuel Storage Facility

USGS U.S. Geological Survey

UST underground storage tank

Groundwater-Level, Groundwater-Temperature, and Barometric-Pressure Data, July 2017 to February 2018, Hālawa Area, O‘ahu, Hawai‘i

By Jackson N. Mitchell and Delwyn S. Oki

Abstract

The Red Hill Bulk Fuel Storage Facility, operated by the U.S. Navy and located in the Hālawa area, O‘ahu, Hawai‘i, includes 20 underground storage tanks that can hold a total of 250 million gallons of fuel. In January 2014, the U.S. Navy notified the Hawai‘i Department of Health and U.S. Environmental Protection Agency of release of an estimated 27,000 gallons of fuel from the Red Hill Bulk Fuel Storage Facility. In response to past and potential future fuel releases, data are needed to evaluate groundwater flow in the surrounding area. During July 2017–February 2018, the U.S. Geological Survey collected groundwater-level data at 24 sites near the Red Hill Bulk Fuel Storage Facility. At 14 of the 24 sites, groundwater-temperature data were also collected, and at 6 of the 24 sites, barometric-pressure data were collected. During the data-collection period, a regional aquifer test was conducted in coordination with the operators of three production wells in the area. The recorded water-level changes in response to planned withdrawal changes during December 2017–February 2018 can be used to improve understanding of the groundwater-flow system. The scope of this report is limited to a non-interpretive presentation of the data and a brief discussion of the factors affecting the water-level data.

Introduction

The Red Hill Bulk Fuel Storage Facility (RHSF), operated by the U.S. Navy, is located about 2.3 miles east of Pearl Harbor and includes 20 cylindrical underground storage tanks (USTs). Each UST is about 250 feet (ft) tall, 100 ft in diameter, and capable of storing 12.5 million gallons of fuel, resulting in a facility-wide capacity of about 250 million gallons (Brown, 2014). The RHSF was constructed in the 1940s and is still operational. As of 2018, 18 of the 20 tanks are active. On January 13, 2014, the U.S. Navy notified the Hawai‘i Department of Health (DOH) and U.S. Environmental Protection Agency (EPA) of a release of JP-8, a jet-propulsion fuel, from tank 5 (U.S. Environmental Protection Agency and Hawai‘i Department of Health, 2015). The volume of the released fuel was estimated by the U.S. Navy to be about 27,000 gallons. Following the January 2014 fuel release, DOH and EPA entered into a binding legal agreement, known as an Administrative Order on Consent (AOC), with the U.S. Navy and Defense Logistics Agency (U.S. Environmental Protection Agency and Hawai‘i Department of Health, 2015). Because of concerns of groundwater contamination, the AOC stipulates that, in part, data are needed to better understand and protect groundwater resources near the RHSF.

Problem

The bottoms of the USTs at the RHSF are about 100 ft above the water table of the freshwater-lens system, which is near an altitude of about 20 ft. A few high-capacity production wells near the RHSF commonly withdraw a total of more than 15 million gallons per day from the freshwater-lens system in the Hālawa area. The freshwater-lens system is an important source of drinking water for O‘ahu residents and could be adversely affected by groundwater contamination resulting from fuel releases at the RHSF. Because of the importance of the groundwater resources near the RHSF, additional groundwater-level data are needed to improve the understanding of groundwater-flow directions in the area and possible subsurface geologic barriers that may affect flow. Furthermore, data collected by this study can be used for the calibration of numerical groundwater-flow models.

Purpose and Scope

This report presents data collected by the U.S. Geological Survey at 24 monitoring sites in the Hālawa area, O‘ahu, Hawai‘i, during July 2017–February 2018 (fig. 1; table 1). Groundwater-level data were collected at each site, groundwater-temperature data were collected at 14 of the 24 sites, and barometric-pressure data were collected at 6 of the 24 sites. References to specific sites within the report will use the site’s common name (see table 1). As part of this study, a regional aquifer test was conducted by coordinating changes in withdrawal rates at selected wells in the Hālawa area at planned times and monitoring changes in groundwater levels in nearby observation wells.

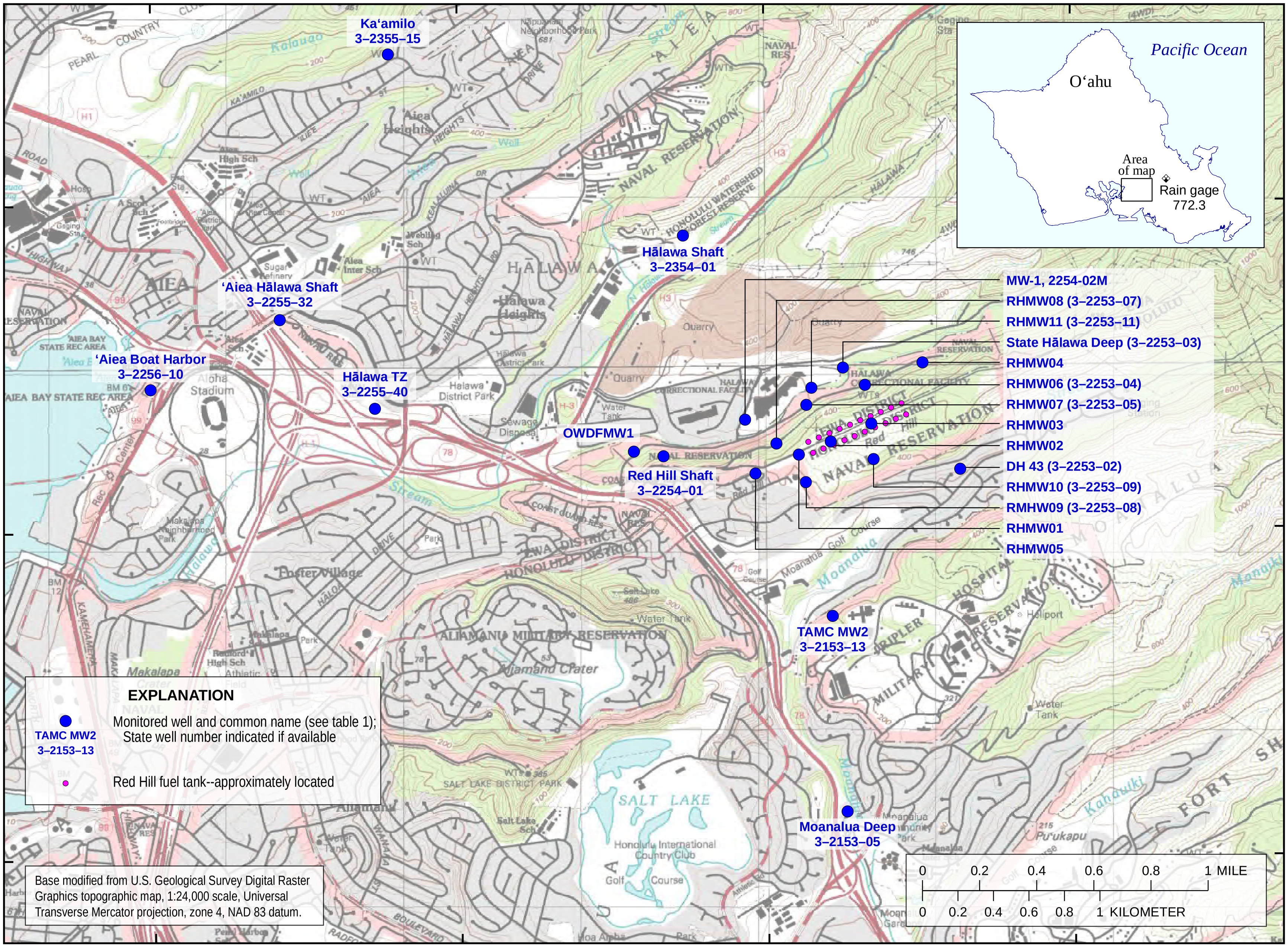

Figure 1. Wells monitored during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i. State Hālawa Deep Chase Tube is colocated with State Hālawa Deep. Location of U.S. Geological Survey rain-gaging station 212359157502601 (State key number 772.3, Moanalua rain gage no. 1) shown in inset map. The Moanalua Wells are located within 150 feet of Moanalua Deep.

Table 1. Selected characteristics of wells monitored during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i.

[Site locations are provided in figure 1. The USGS site names lack Hawaiian punctuation due to limitations within the USGS National Water Information System database. Data can be accessed using the hyperlinks provided in the USGS site name column. Abbreviations: --, not applicable or not available; float, float-activated recorder; MP, measuring point; NVT, non-vented submersible pressure transducer; VT, vented submersible pressure transducer; USGS, U.S. Geological Survey]

Common name	USGS site identification	USGS site name	Water-level recorder	Water-temperature record	Barometric-pressure record	[1]MP altitude, in feet	Source of MP altitude	[2]Gyroscopic-survey correction, in feet	[3]Approximate well depth, in feet
RHMW01	212214157535401	Red Hill RHMW01, Oahu, HI	NVT	--	Yes	102.00	U.S. Navy	--	100
RHMW02	212216157534701	Red Hill RHMW02, Oahu, HI	VT	Yes	--	104.60	U.S. Navy	-0.06	99
RHMW03	212219157533901	Red Hill RHMW03, Oahu, HI	VT	Yes	Yes	120.90	U.S. Navy	-0.04	117
RHMW04	212231157532901	Red Hill RHMW04, Oahu, HI	VT	Yes	--	312.11	U.S. Navy	-0.02	305
RHMW05	212210157540201	Red Hill RHMW05, Oahu, HI	VT	Yes	--	101.31	U.S. Navy	-0.01	93
RHMW06	212226157534101	3-2253-04 Red Hill RHMW06, Oahu, HI	VT	Yes	--	259.26	U.S. Navy	-0.01	260
RHMW07	212222157535201	3-2253-05 Red Hill RHMW07, Oahu, HI	VT	Yes	--	220.58	U.S. Navy	-0.01	214
RHMW08	212216157535801	3-2253-07 Red Hill RHMW08, Oahu, HI	VT	Yes	--	310.62	U.S. Navy	-0.03	309
RHMW09	212209157535201	3-2253-08 Red Hill RHMW09, Oahu, HI	VT	Yes	--	395.57	U.S. Navy	-0.24	397
RHMW10	212213157533901	3-2253-09 Red Hill RHMW10, Oahu, HI	VT	Yes	--	495.78	U.S. Navy	-0.09	494
RHMW11	212226157535001	3-2253-11 Red Hill RHMW11 (Zone 8), Oahu, HI	VT	--	--	210.13	U.S. Navy	-0.05	[4]204
OWDFMW1	212214157542601	Red Hill OWDFMW1, Oahu, HI	VT	--	--	138.14	U.S. Navy	-0.03	143
State Hālawa Deep	212241157535501	3-2253-03 State Halawa Deep, Oahu, HI	VT	--	--	226.68	U.S. Navy	-0.01	[5]1,575
State Hālawa Deep Chase Tube	212241157535502	3-2253-03 State Halawa Deep (Chase Tube), Oahu, HI	VT	--	--	225.26	U.S. Navy	--	237
MW-1	212229157541501	S. Halawa alluvium MW-1 (3-2254-02M), Oahu, HI	VT	Yes	--	178.89	U.S. Navy	--	31
Red Hill Shaft	212225157542601	3-2254-01 Red Hill Shaft (S11), Oahu, HI	VT	Yes	Yes	100.45	U.S. Navy	--	--
‘Aiea Hālawa Shaft	212253157554301	3-2255-32 Halawa Shaft (S5), Oahu, HI	VT	Yes	--	28.05	U.S. Navy	--	--
Moanalua Deep	212123157535501	3-2153-05 Moanalua Fresh Water Mon. Well, Oahu, HI	VT	--	Yes	37.03	USGS	--	[5]1,246
Hālawa TZ	212233157552302	3-2255-40 Halawa TZ Well, Oahu, HI	VT	--	--	60.04	USGS	--	[5]1,014
Ka‘amilo	212340157552301	3-2355-15 Kaamilo Deep, Oahu, HI	VT	--	Yes	493.29	USGS	--	[5]1,617
Hālawa Shaft	212305157542601	3-2354-01 Halawa Shaft (S12), Oahu, HI	VT	Yes	--	13.72	USGS	--	--
TAMC MW2	212144157534701	3-2153-13 TAMC MW2, Oahu, HI	VT	Yes	--	179.70	USGS	--	161
DH 43	212225157533001	3-2253-02 Moanalua DH 43, Oahu, HI	VT	--	--	234.32	USGS	--	275
‘Aiea Boat Harbor	212238157561101	3-2256-10 Aiea US Navy (187-B), Oahu, HI	Float	--	Yes	26.07	USGS	--	173

[1]Altitude refers to feet above mean sea level

[2]NAVFAC Hawaii, 2018

[3]Depth refers to feet below land surface

[4]Depth of open pumping port in multi-level well

[5]Depth includes open hole

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

Methods

Data were collected at 24 sites: three Maui-type shafts (‘Aiea Hālawa Shaft, Hālawa Shaft, and Red Hill Shaft), and 21 monitoring wells (fig. 1; table 1). The data collected for this study include groundwater-level data, groundwater-temperature data, and barometric-pressure data.

Water Level

Discrete and continuous water-level data, in units of feet above mean sea level, were collected at all 24 sites following procedures consistent with those described by Cunningham and Schalk (2011).

Discrete Water Levels

Discrete water levels were measured during periodic site visits to deploy equipment, retrieve data and check sensors, or remove equipment. The depth to water was measured from an established measuring point (MP) at each site (table 1). The depth-to-water measurements were converted to groundwater-level altitudes by subtracting the measured depth-to-water value from the MP altitude and then accounting for any applicable tape correction or gyroscopic-survey correction.

Equipment

Discrete water levels mainly were measured using chalked, graduated steel tapes accurate to 0.01 ft (Cunningham and Schalk, 2011). In general, the same steel tape was used at a given site throughout the study. The water level at Hālawa Shaft was above the MP, which precluded the use of a steel tape; instead, a ruler was placed on the MP and the shortest observed distance to the water level was recorded as a negative depth-to-water value. The ruler used at Hālawa Shaft was graduated in hundredths of feet and is presumed to be accurate to 0.01 ft.

Tape Corrections

The accuracy of water-level tapes tends to decrease through time due to general wear and the development of bends and kinks. A water-level tape can be compared to a reference tape of known accuracy to evaluate the accuracy of the water-level tape and potentially determine tape-correction values. Tape corrections used during the current study were derived from a down-hole calibration of water-level tapes in September 2017. 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 (NIST). 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-deviation surveys at 12 of the 21 monitoring wells to evaluate the plumbness and alignment of each well (NAVFAC Hawaii, 2018). The gyroscopic data consisted of sets of horizontal and vertical coordinates measured at 10-foot intervals along the length of each well, each 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 made at wells included in the gyroscopic-deviation survey (NAVFAC Hawaii, 2018) (table 1).

Continuous Water Levels

Each site was equipped with a data logger, most commonly a submersible pressure transducer (hereinafter referred to as transducer), which was programmed to continuously record pressure (or water level, in the case of the float-activated recorder) at 10-minute intervals, generally at an even 10-minute time (for example, 13:10, 13:20, 13:30). Early in the data-collection period, four data loggers (located at Moanalua Deep, RHMW02, RHMW05, and RHMW07) recorded data beginning at a non-even 10-minute time stamp, but still at 10-minute intervals (for example, 13:13, 13:23, 13:33). Because of a programming error, water levels at ‘Aiea Boat Harbor were recorded at 15-minute intervals until November 28, 2017. The temporal discrepancies did not affect data quality and these data were not modified.

Equipment

Vented transducers were deployed at 22 sites, a non-vented transducer was deployed at one site, and a float-activated recorder was deployed at one site (table 1). Each vented transducer was attached to a vented cable (ranging in length from 15 to 25 ft), to which a desiccant pack was connected at the top to prevent moisture from entering the venting system and adversely affecting the equipment. The vented transducer cable was connected to stainless-steel cable, which was secured to a fixed mount at the top of the well or shaft, except at Hālawa Shaft, where the transducer was secured by draping the vented cable over a staff-gage bracket. Each transducer was suspended about 4–8 ft below the lowest expected water level to ensure that the transducer would always remain submerged.

Most of the vented transducers had an accuracy of about 0.01 ft (In-Situ Inc., 2018d); however, the vented transducer at MW-1 was a different model and had an accuracy of about 0.02 ft (In-Situ Inc., 2018b). A non-vented transducer was used at one site (RHMW01) because the small well diameter (about 1 inch) precluded use of a vented-transducer system. The non-vented transducer had an accuracy of about 0.03 ft (In-Situ Inc., 2018c). The float-activated recorder, used at one site (‘Aiea Boat Harbor), consisted of a weight-balanced float attached to a shaft encoder and had an accuracy of about 0.01 ft (Cunningham and Schalk, 2011).

Transducer Calibration

Field calibrations were conducted for each transducer to determine the linear relation between submergence pressure, in pounds per square inch (psi), and submergence depth, in feet (Freeman and others, 2004). A field calibration could not be performed at Hālawa Shaft because of site restrictions; instead, a pressure calibration was performed by placing the transducer in a transparent cylinder with a graduated tape and incrementally filling the cylinder with water while recording the submergence depth.

Data Processing

All pressure transducers were programmed to record pressure values in units of psi. The vented transducers internally compensated for barometric-pressure changes, resulting in an output of submergence pressure. The pressure data recorded by the non-vented transducer at RHMW01 were converted to submergence pressure by subtracting the concurrent barometric pressure recorded by the on-site barometer. Submergence-pressure values were converted to submergence-depth values (in feet of water) using the equipment-specific pressure-depth calibration relation.

The continuous water-level data were adjusted to approximately match the discrete water-level measurements collected during site visits by applying offset-correction values to the data recorded immediately before and after each site visit. The offset-correction values were prorated linearly between consecutive site visits. To determine the offset-correction values, the continuous water-level records were visually extrapolated to the nearest discrete water-level measurement. Such extrapolation was necessary because the water levels can change by a few hundredths of a foot during the time between the discrete water-level measurement and the first recording by a transducer. Most often, the extrapolation spanned 20 minutes or less.

In a few cases, a longer extrapolation between the discrete water-level measurement and the continuous water-level record was necessary. At RHMW04, a reliable, discrete water-level measurement was not collected until two hours after the transducer was removed from the well on February 27, 2018. At RHMW10, a discrete water-level measurement was not collected until one hour after the transducer was removed from the well on August 4, 2017. At RHMW11, the water levels recorded immediately after deploying the transducer on January 12 and 26, 2018 were considered unreliable (inconsistent with the discrete water-level measurement) and were deleted, resulting in an extrapolation of about an hour.

At Red Hill Shaft, a transducer malfunction beginning on December 19, 2017 necessitated the deletion of data until January 18, 2018. Consequently, there was no discrete water-level measurement at the end of the continuous water-level record on December 19, 2017 to use as a reference for the determination of the offset-correction value. To determine the offset-correction value assigned to the end of the continuous water-level record on December 19, 2017, the value was adjusted until the relative position of water levels at Red Hill Shaft during the period from August 4, 2017 to December 19, 2017, compared to water levels at nearby wells, was generally consistent with adjacent periods.

Water Temperature

Water-temperature data, in units of degrees Celsius (ºC), were recorded by each transducer system at 10-minute intervals and had an accuracy of about 0.1 ºC (In-Situ Inc., 2018b, 2018d). Water-temperature data were not reported if the transducer was suspended within the part of the borehole with solid casing because the recorded temperature in the mostly stagnant water column may not accurately reflect the groundwater temperature. As a result, water-temperature data were only reported for 14 sites (table 1). The temperature accuracy of each transducer was tested before and after the data-collection period using a NIST-certified thermistor.

Barometric Pressure

Barometric-pressure data, in units of psi, were recorded by barometers at six sites (table 1). The barometers were either suspended above water within the top part of the well or shaft, or placed in the well vault at the surface. The barometers had an accuracy of about 0.015 psi (In-Situ Inc., 2018a). Erroneous data were deleted; no further adjustments were made to the barometric-pressure records.

Withdrawal Rates

Information on withdrawal rates during the study were provided by appropriate agencies for selected production wells: Moanalua Wells, Hālawa Shaft, Red Hill Shaft, and ‘Aiea Hālawa Shaft. These high-capacity production wells are located near the RHSF and withdrawals from these wells potentially could affect measured water levels. At the time of publication, the withdrawal rates had not been published by the U.S. Navy or the Honolulu Board of Water Supply. The timings of selected withdrawal-rate changes at Hālawa Shaft, Moanalua Wells, and Red Hill Shaft were coordinated with

Table 2. Dates and approximate times of scheduled withdrawal-rate changes at selected production wells during December 2017–February 2018, Hālawa Area, O‘ahu, Hawai‘i.

[Dates and times are listed in Hawai‘i Standard Time]

Well name	Start of well shutdown (zero withdrawal)	[1]Start of withdrawal-rate increase	Resumption of normal withdrawals
Hālawa Shaft	1/27/2018 12:00	2/6/2018 12:00	2/16/2018 14:00
[2]Moanalua Wells	[3]12/20/2017 12:00	12/27/2017 12:00	1/3/2018 07:00
Red Hill Shaft	1/10/2018 09:00	1/15/2018 12:00	1/20/2018 12:00

[1]Increased withdrawal rate was held as steady as practicable

[2]The Moanalua Wells are a production well field located within 150 feet of Moanalua Deep, the observation well that was monitored during this study

[3]Well was not used beginning on 12/19/2017

the well operators to facilitate understanding of the effects of withdrawals on water levels (table 2). This information can be used to provide insight into the aquifer hydraulic properties.

Data

All groundwater-level, groundwater-temperature, and barometric-pressure data collected during this study are stored in the publicly accessible USGS National Water Information System (NWIS) database (U.S. Geological Survey, 2018b). The data can be accessed on the NWIS database using the USGS site identifiers or hyperlinks provided in table 1.

Groundwater levels were recorded at 24 sites during various subperiods of the July 2017 to February 2018 study period (figs. 2–25). At 22 of the 24 sites, recorded groundwater levels from July 2017 through February 2018 were between 12 and 25 ft. At 2 of the 24 sites (RHMW11 and MW-1), water levels exceeded 100 ft during 2018 when water levels were recorded. Relative withdrawal rates (arbitrary scale from 0 to 1) from Hālawa Shaft, Moanalua Wells, Red Hill Shaft, and ‘Aiea Hālawa Shaft also are shown in relation to the recorded water levels (figs. 2–25). Water levels were recorded by a transducer at a monitoring well (Moanalua Deep) located within about 150 ft from the Moanalua Wells.

Groundwater temperatures, recorded at 14 sites using transducers that were not suspended within solid well casings, ranged from about 20.2 to 29.2 ºC (table 1; fig. 26). At most sites, groundwater temperature variations with time were less than 0.5 ºC during the monitored period. At RHMW05 and ‘Aiea Hālawa Shaft, groundwater-temperature variations exceeded 1 ºC.

Barometric-pressure variations at the six sites with barometers were similar (fig. 27). The most notable difference between sites was that the barometric pressure at Ka‘amilo was about 0.2 psi lower than the other sites. The barometer at Ka‘amilo was located at an altitude of about 490 ft; the other barometers were located at altitudes of about 25 to 120 ft.

Monthly rainfall during the study at USGS rain-gaging station 212359157502601 (State key number 772.3), located about 4 miles northeast of the RHSF, was lowest during September 2017 and highest during February 2018 (fig. 28) (USGS, 2018b).

Discussion of Water-Level Data

Factors Affecting Water Levels

Water levels in the study area can be affected by many factors that may be related to human activities or natural phenomena. These factors include, but may not be limited to, groundwater withdrawals, barometric pressure, earthquakes, and groundwater recharge.

Several high-capacity production wells withdraw groundwater in the Hālawa area and were active during the data-collection period. Water levels measured at sites located directly within or adjacent to pumping facilities (for example, Red Hill Shaft, ‘Aiea Hālawa Shaft, Moanalua Deep, and Hālawa Shaft) indicate short-term water-level changes that are consistent with the timing of withdrawal-rate changes (figs. 17, 18, 19, and 22; table 2). Water levels at other sites also may be affected by withdrawals, and the magnitude of the effects of withdrawals is expected to be dependent on factors that include the rate of withdrawal, the distance from the withdrawal site, and the hydraulic properties of the aquifer.

Because of the difference in air pressure between the air in the borehole and in the unsaturated zone near the borehole and because of the time-varying pressure loading of the aquifer caused by barometric-pressure changes, groundwater can flow into and out of the borehole in response to barometric-pressure changes, resulting in water-level changes in the borehole (Rojstaczer, 1988). Water level and barometric pressure commonly change in opposite directions; as barometric pressure at the surface increases, water level decreases. Barometric-pressure variations can affect groundwater levels over various time scales, including a semidiurnal time scale. All of the sites, except RHMW04, had a semidiurnal variation in water level characterized by changes that were in an opposite direction to barometric-pressure changes. The amplitude of the semidiurnal variation in water levels varied between sites, which may reflect well configuration and pneumatic and hydraulic properties of the rock near the well, but was generally a few hundredths of a foot.

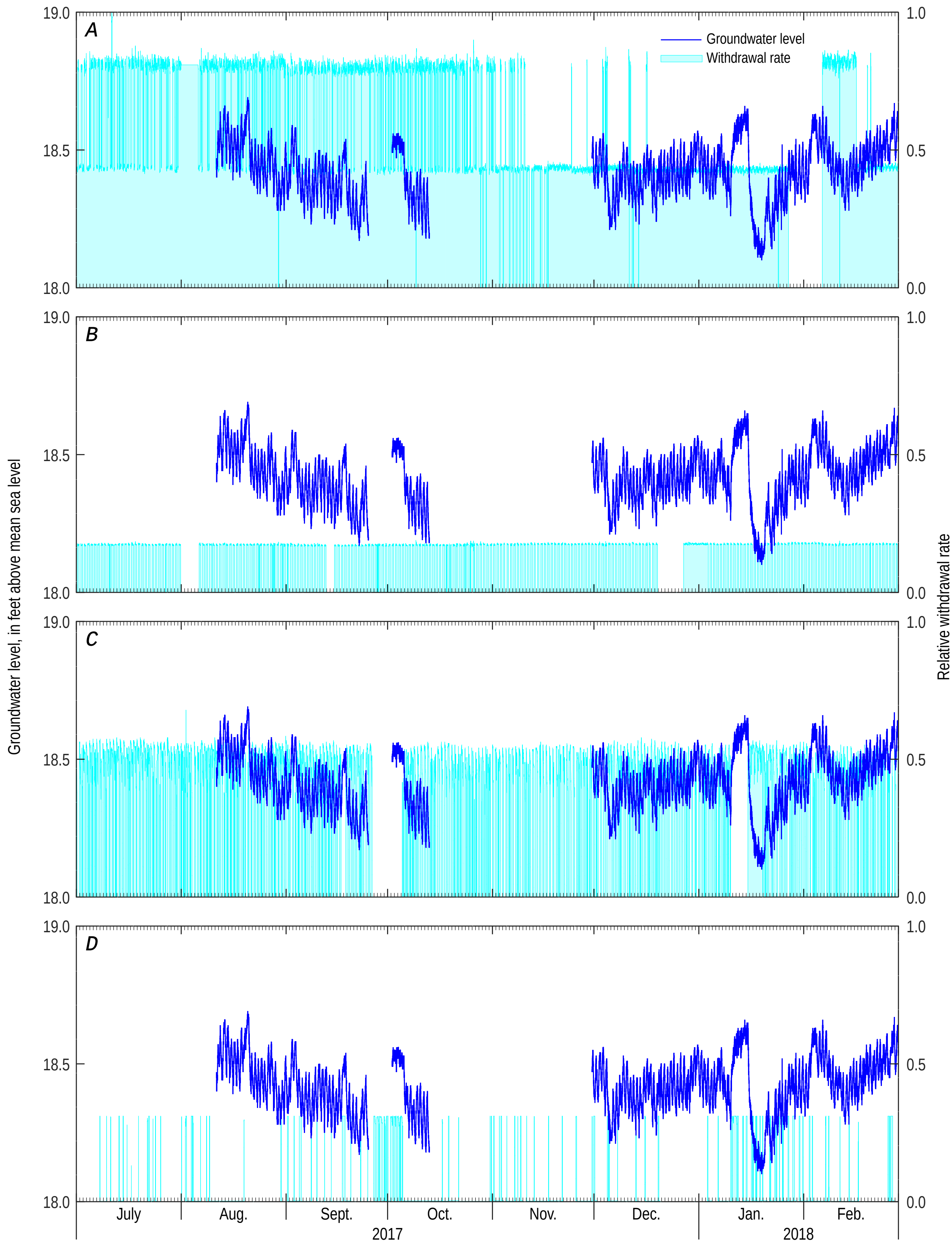

Figure 2. Measured groundwater level in well RHMW01 during July 2017–February 2018, Hālawa area, Oʻahu, Hawaiʻi, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ʻAiea Hālawa Shaft.

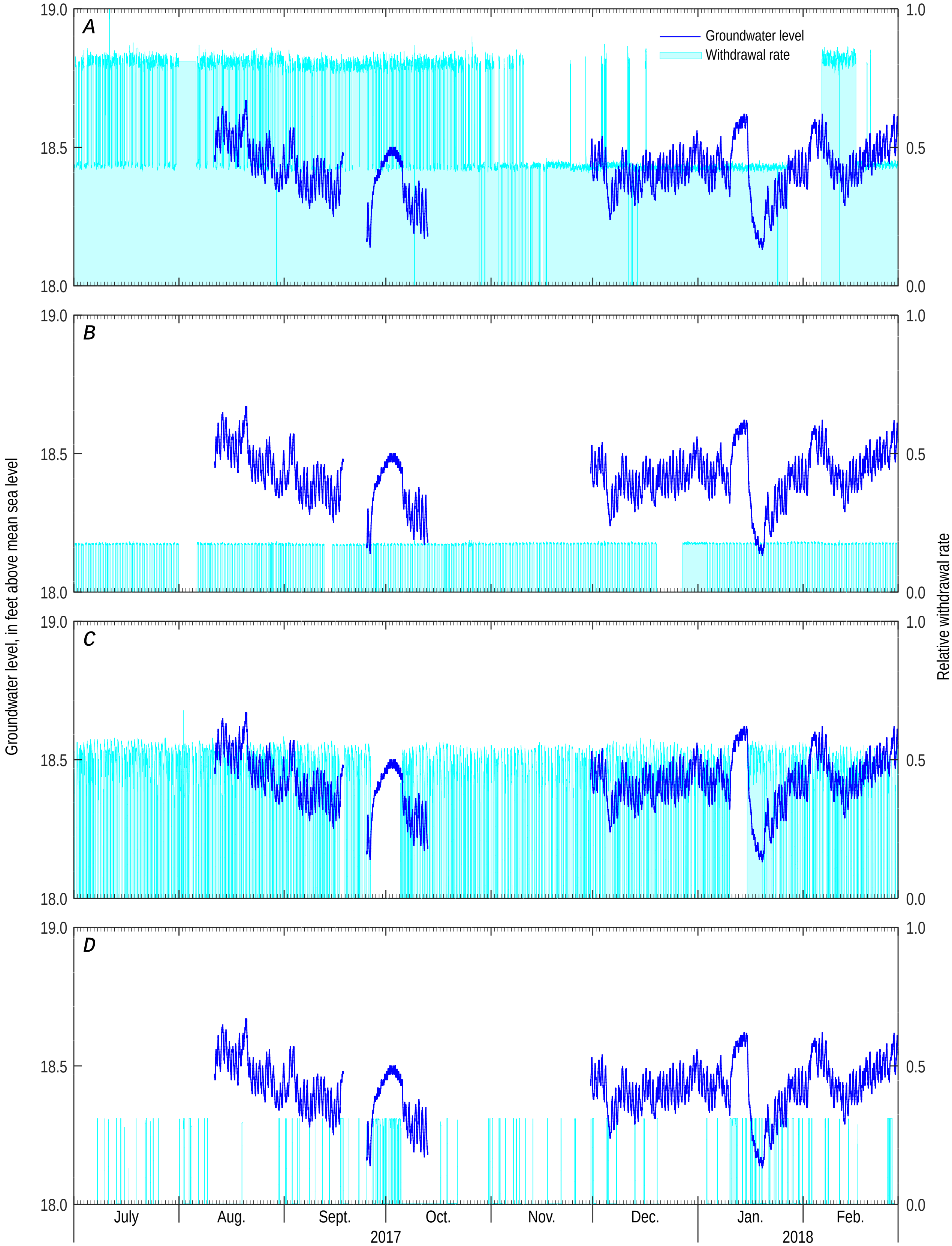

Figure 3. Measured groundwater level in well RHMW02 during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

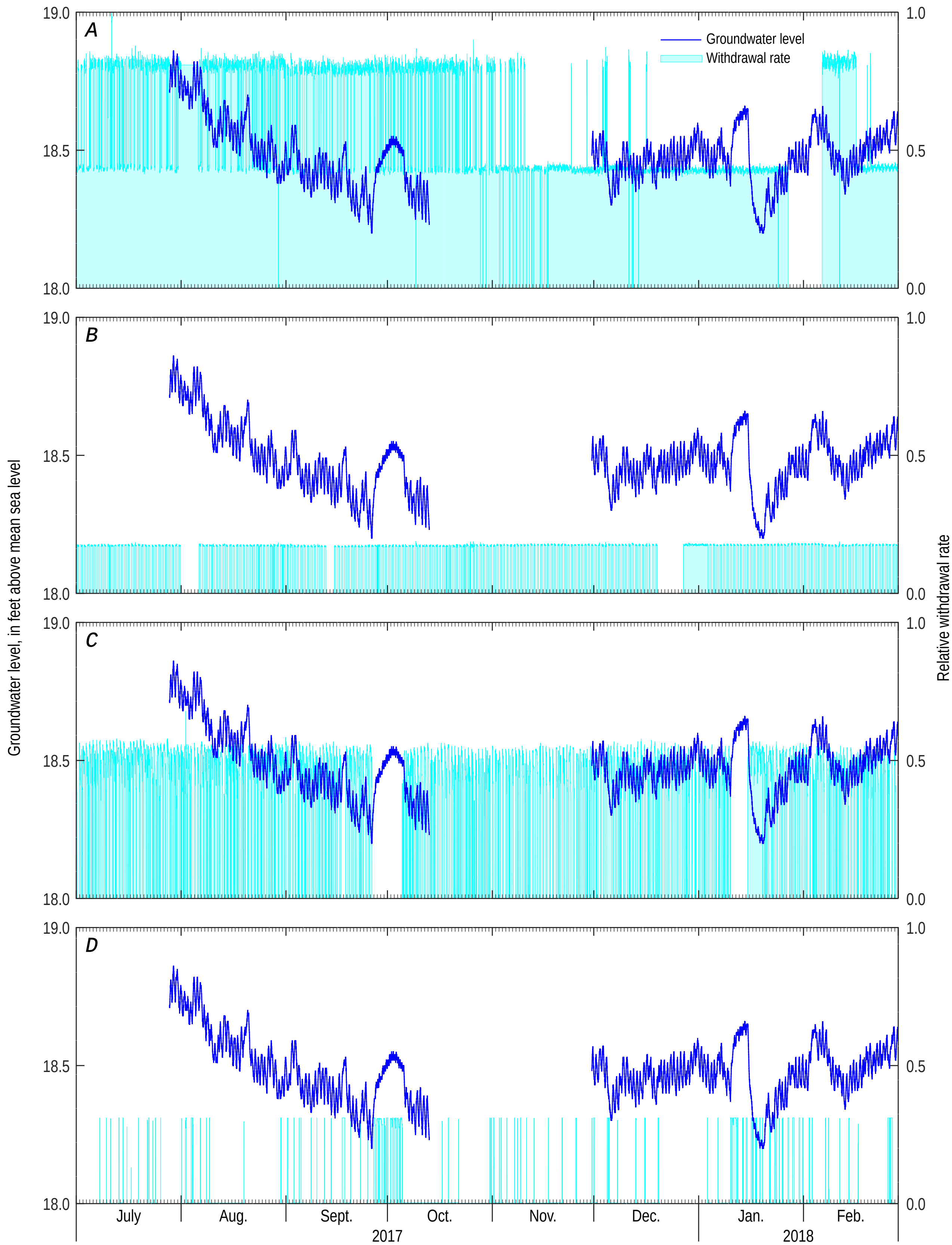

Figure 4. Measured groundwater level in well RHMW03 during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

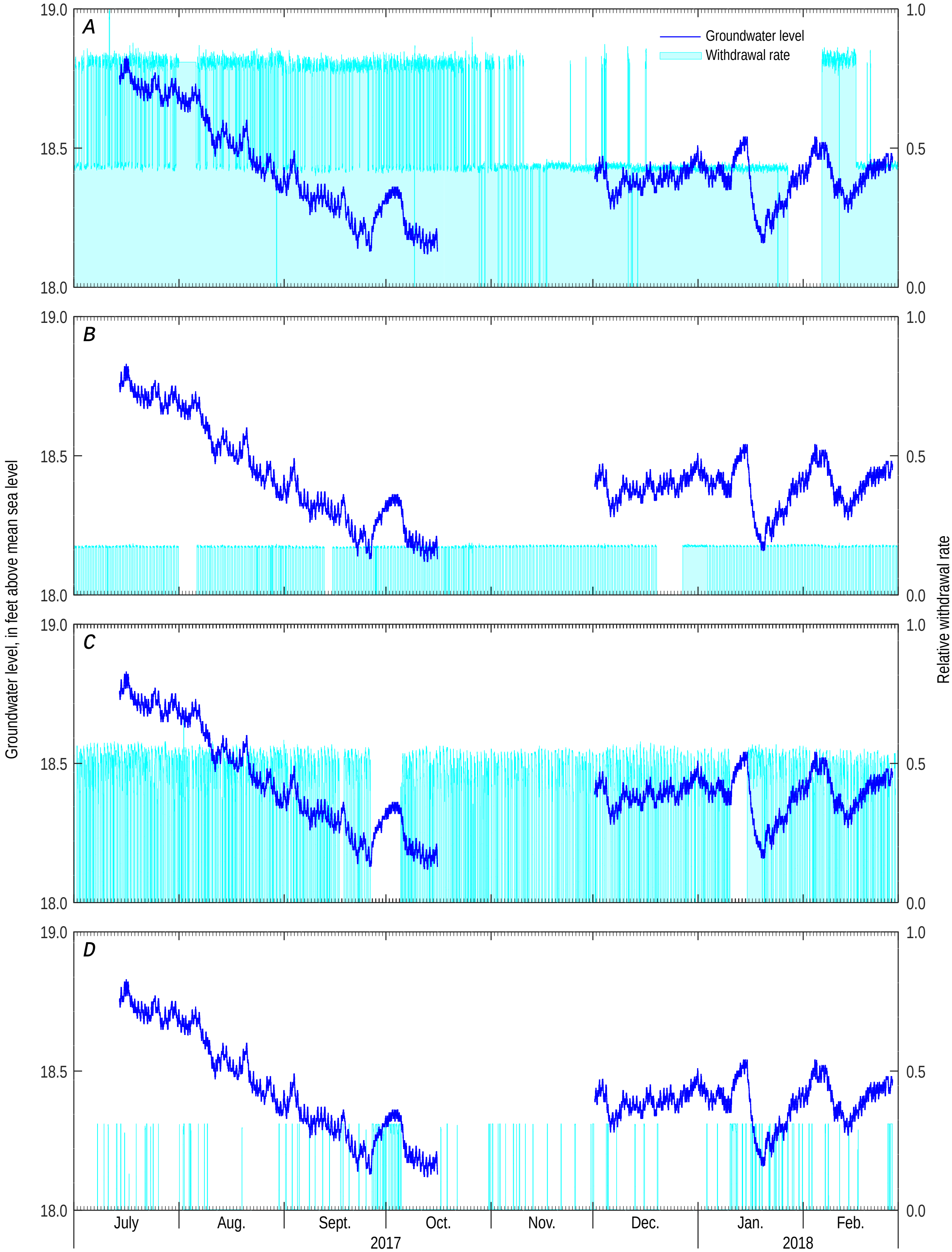

Figure 5. Measured groundwater level in well RHMW04 during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

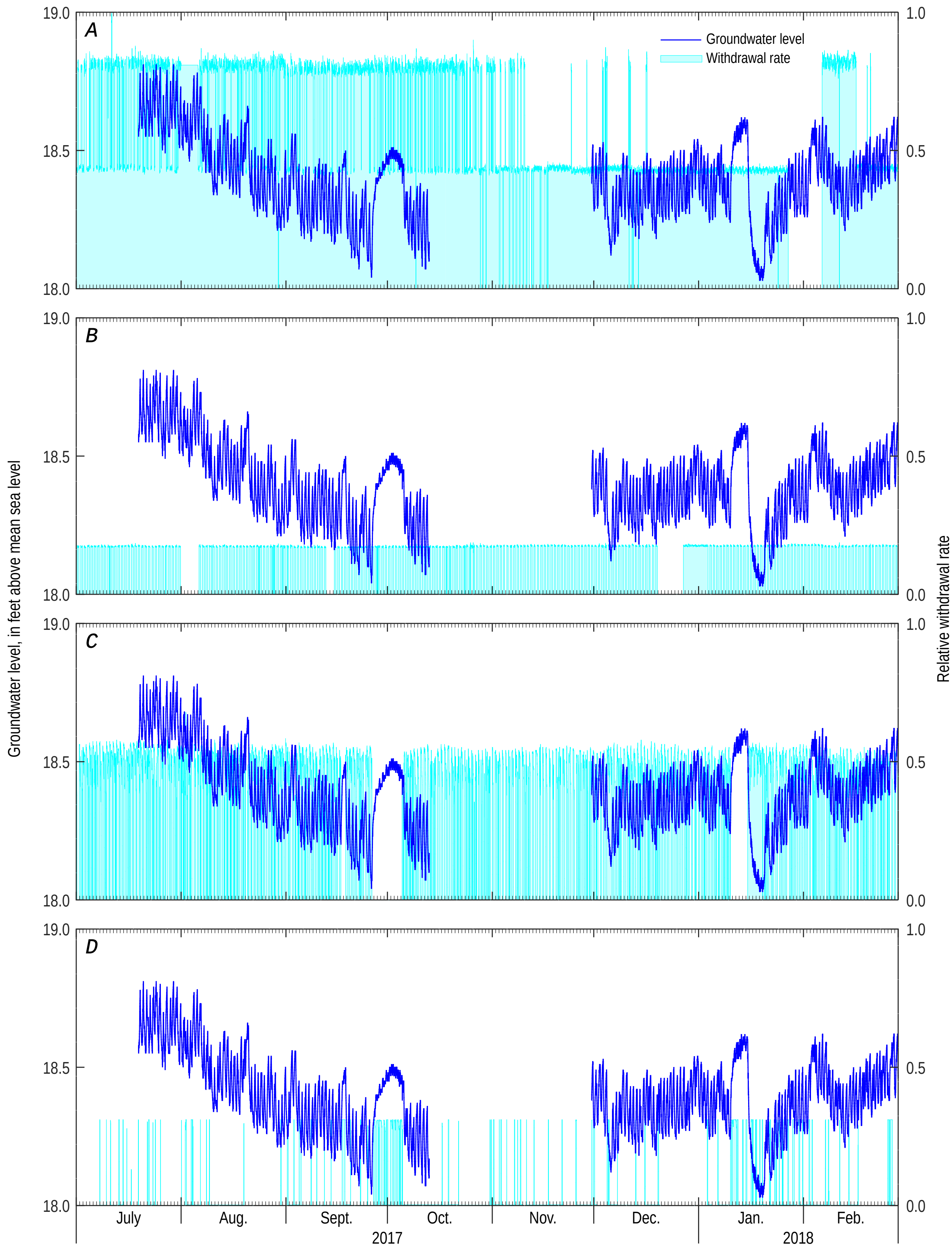

Figure 6. Measured groundwater level in well RHMW05 during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

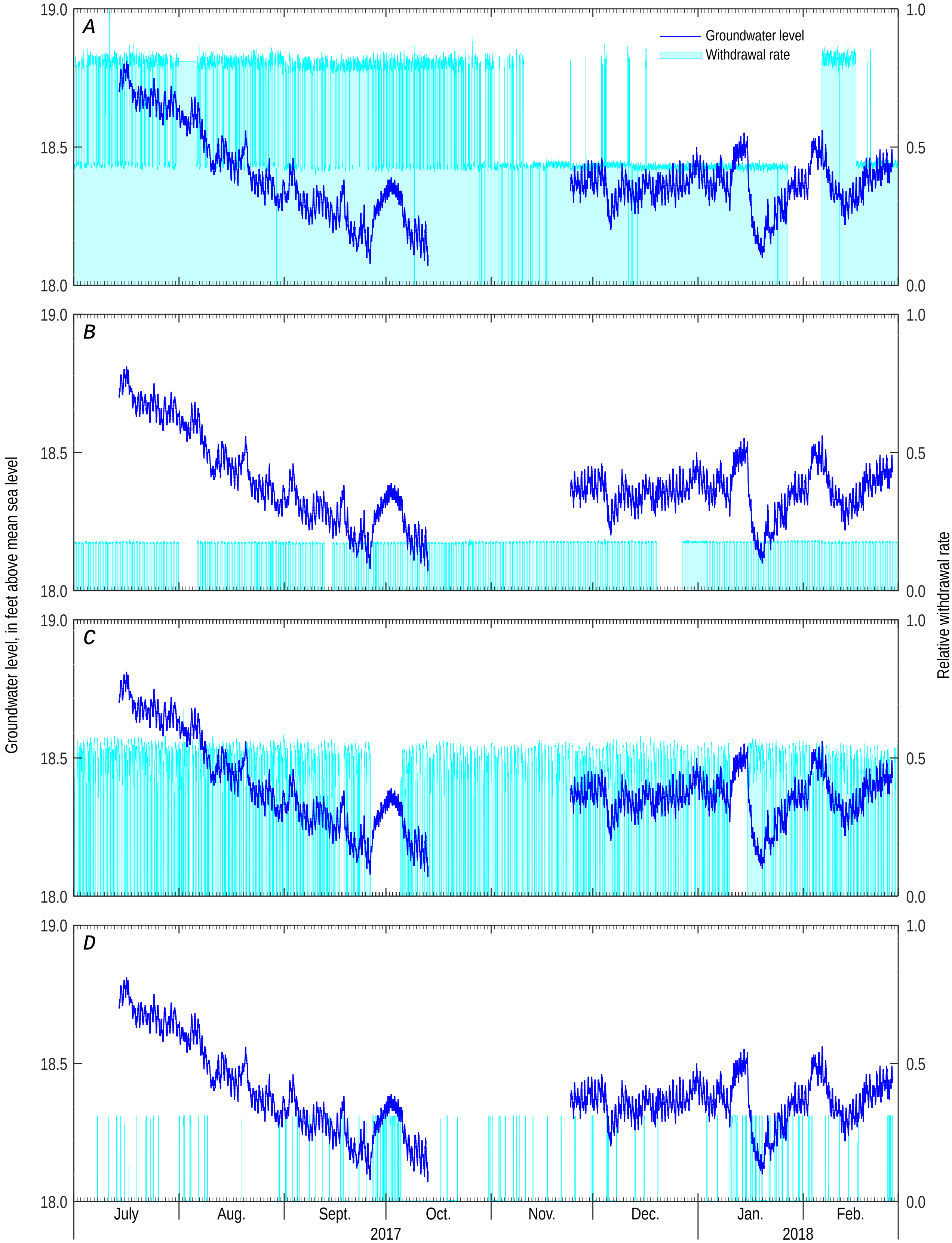

Figure 7. Measured groundwater level in well RHMW06 during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

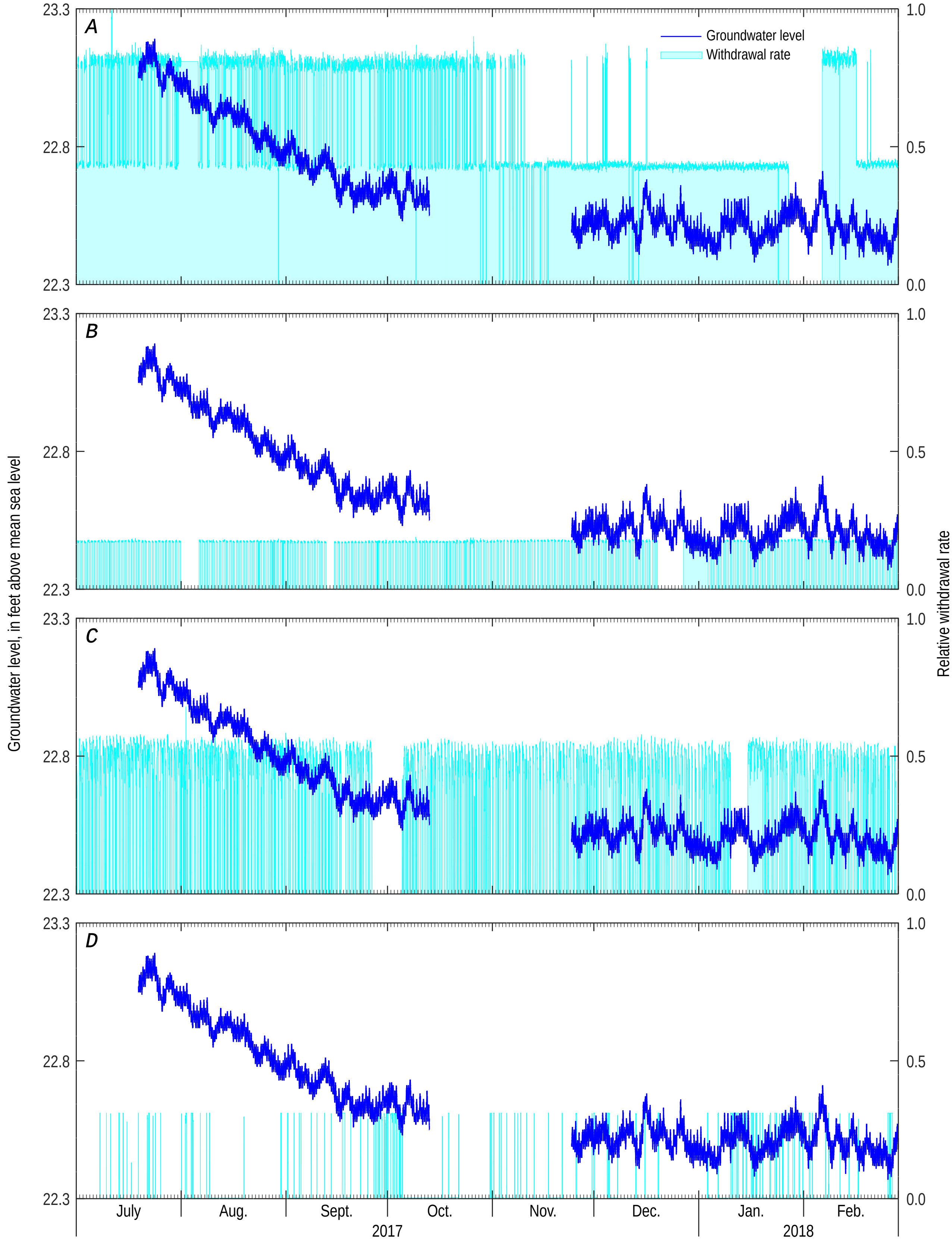

Figure 8. Measured groundwater level in well RHMW07 during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

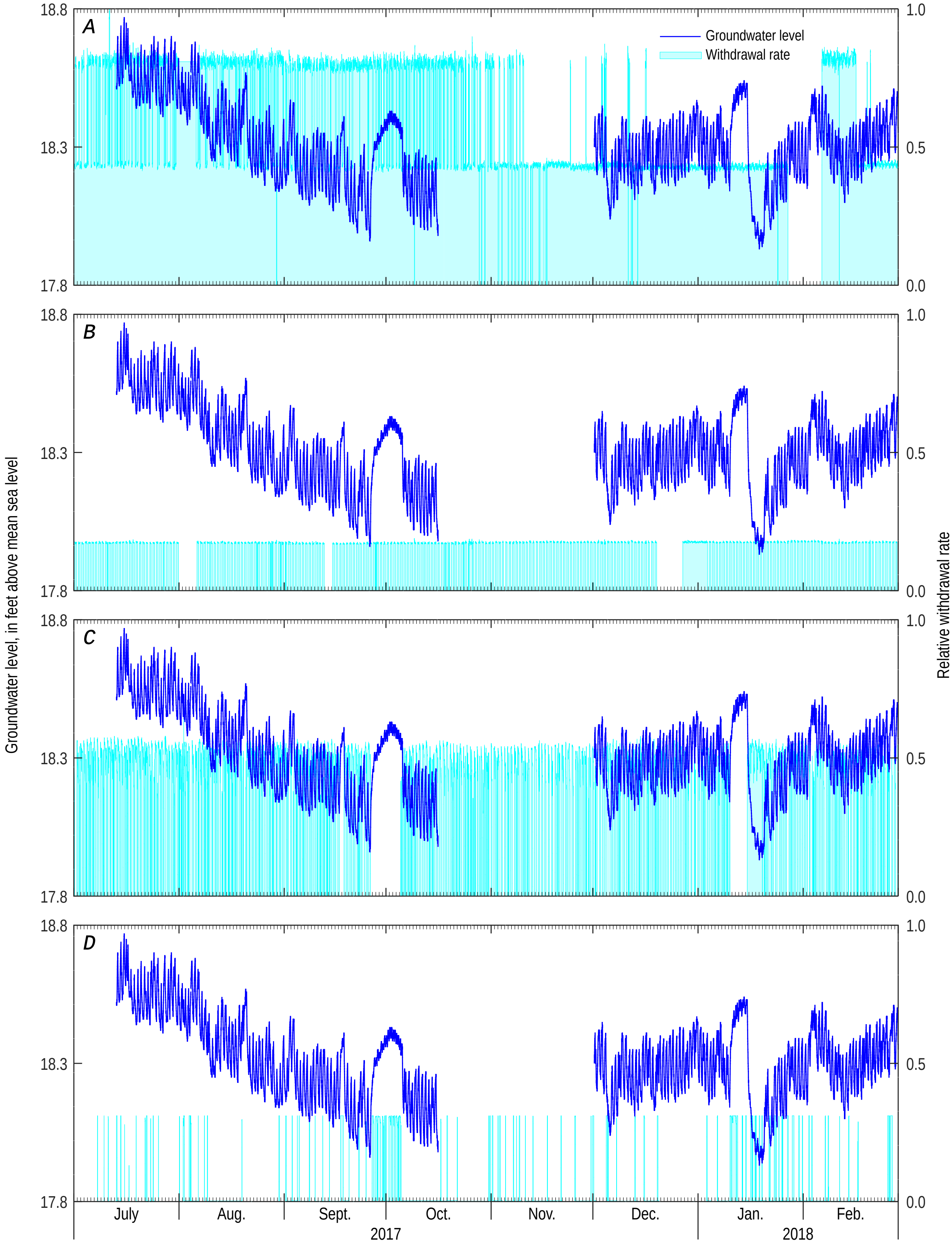

Figure 9. Measured groundwater level in well RHMW08 during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

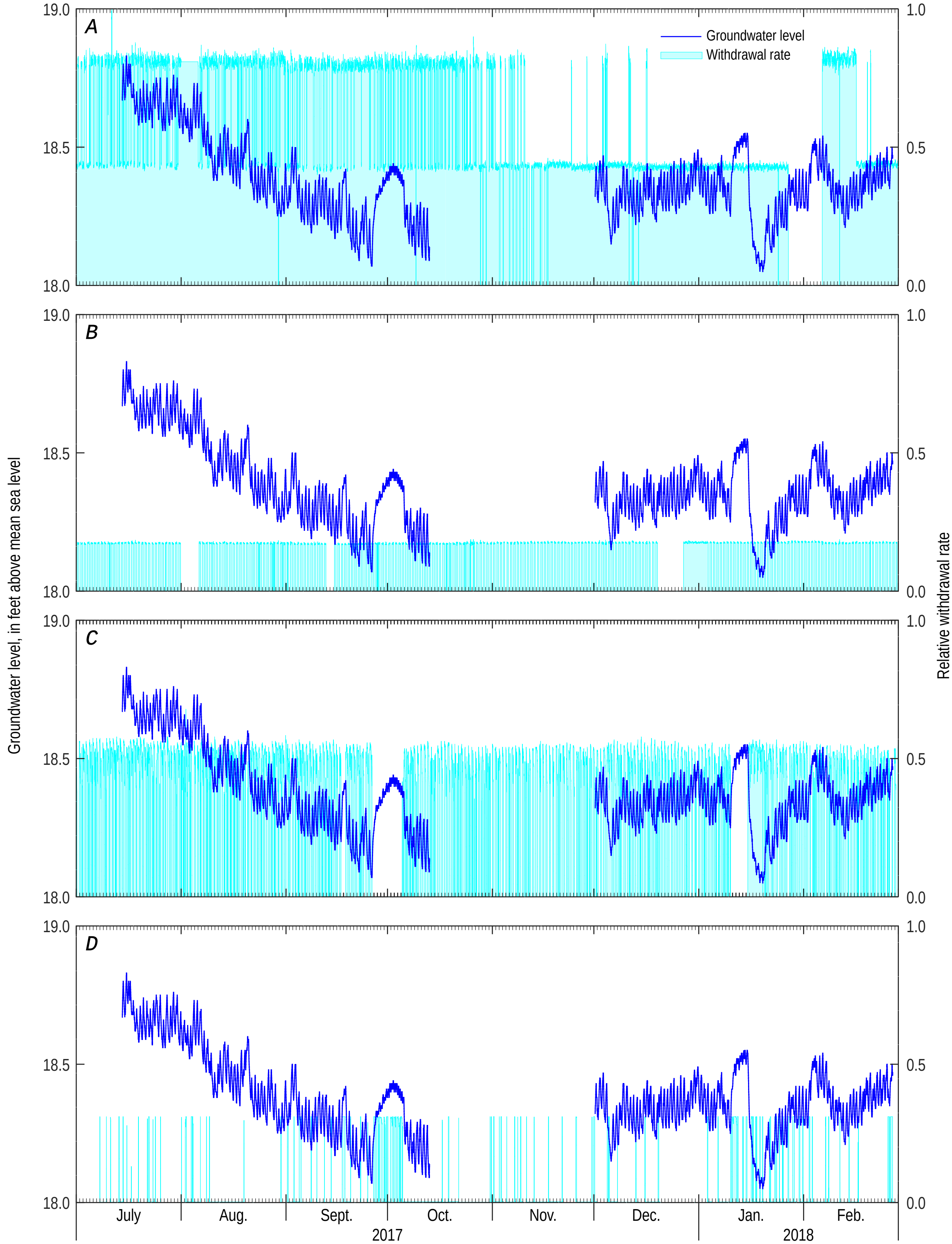

Figure 10. Measured groundwater level in well RHMW09 during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

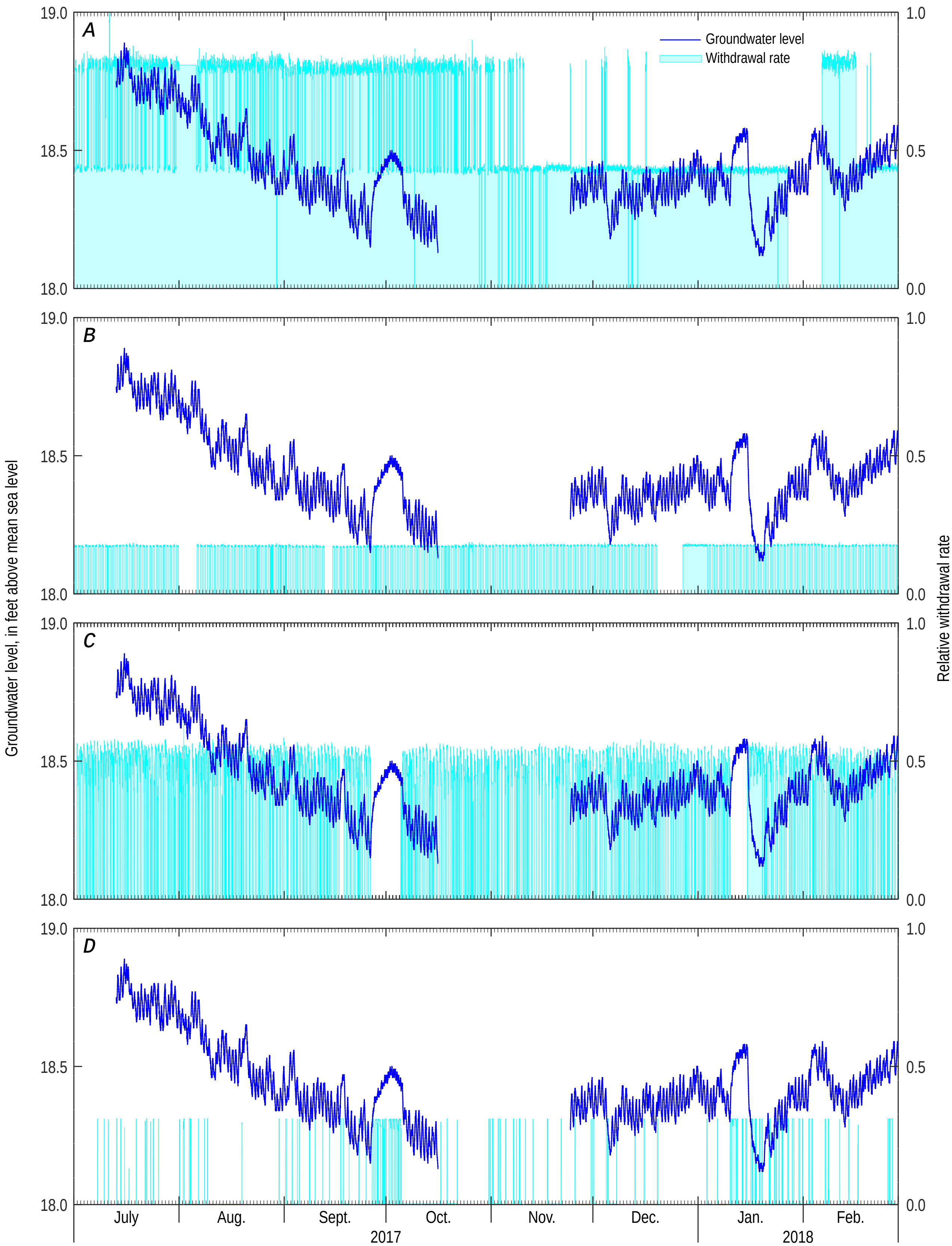

Figure 11. Measured groundwater level in well RHMW10 during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

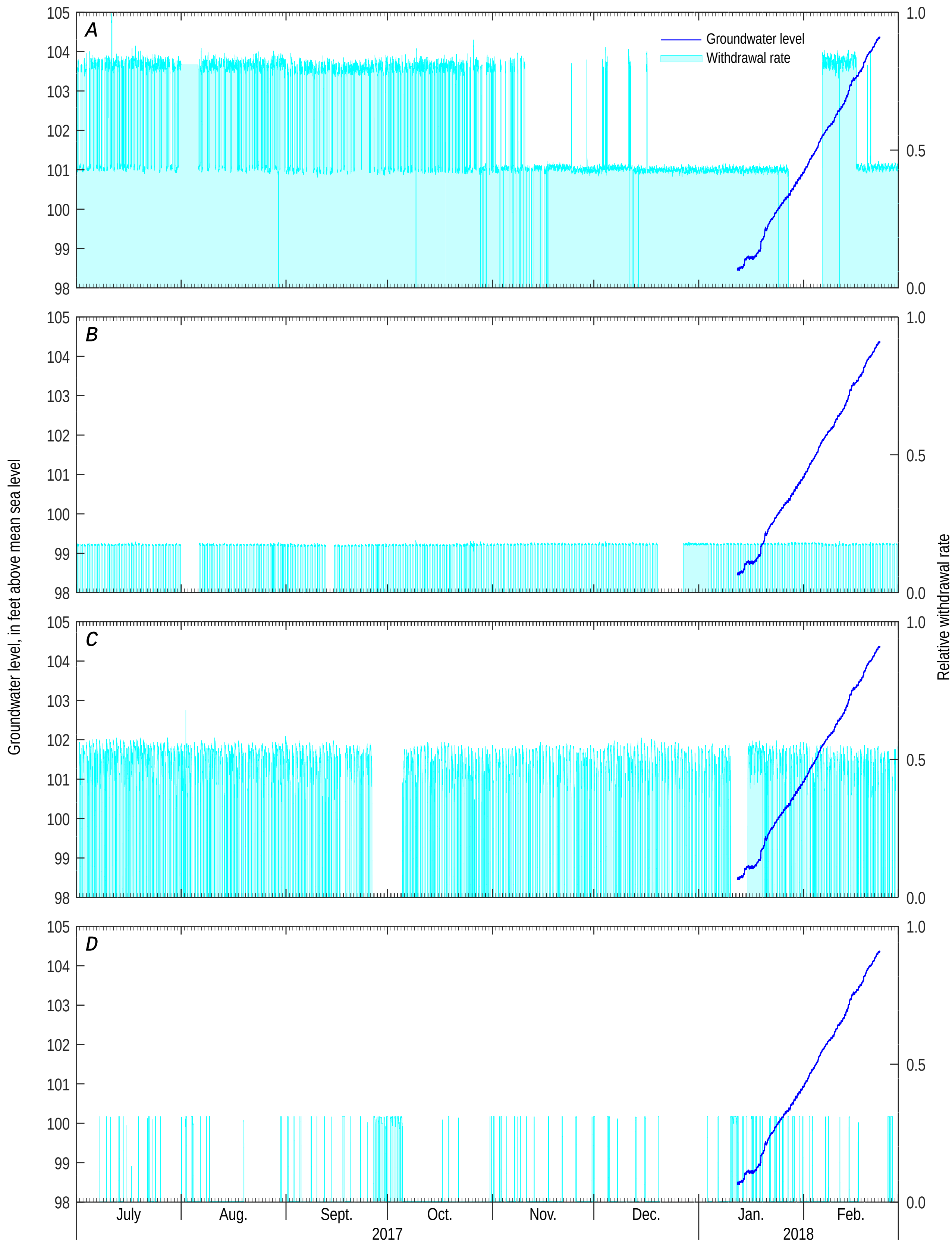

Figure 12. Measured groundwater level in well RHMW11 during July 2017–February 2018, Hālawa area, Oʻahu, Hawaiʻi, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ʻAiea Hālawa Shaft.

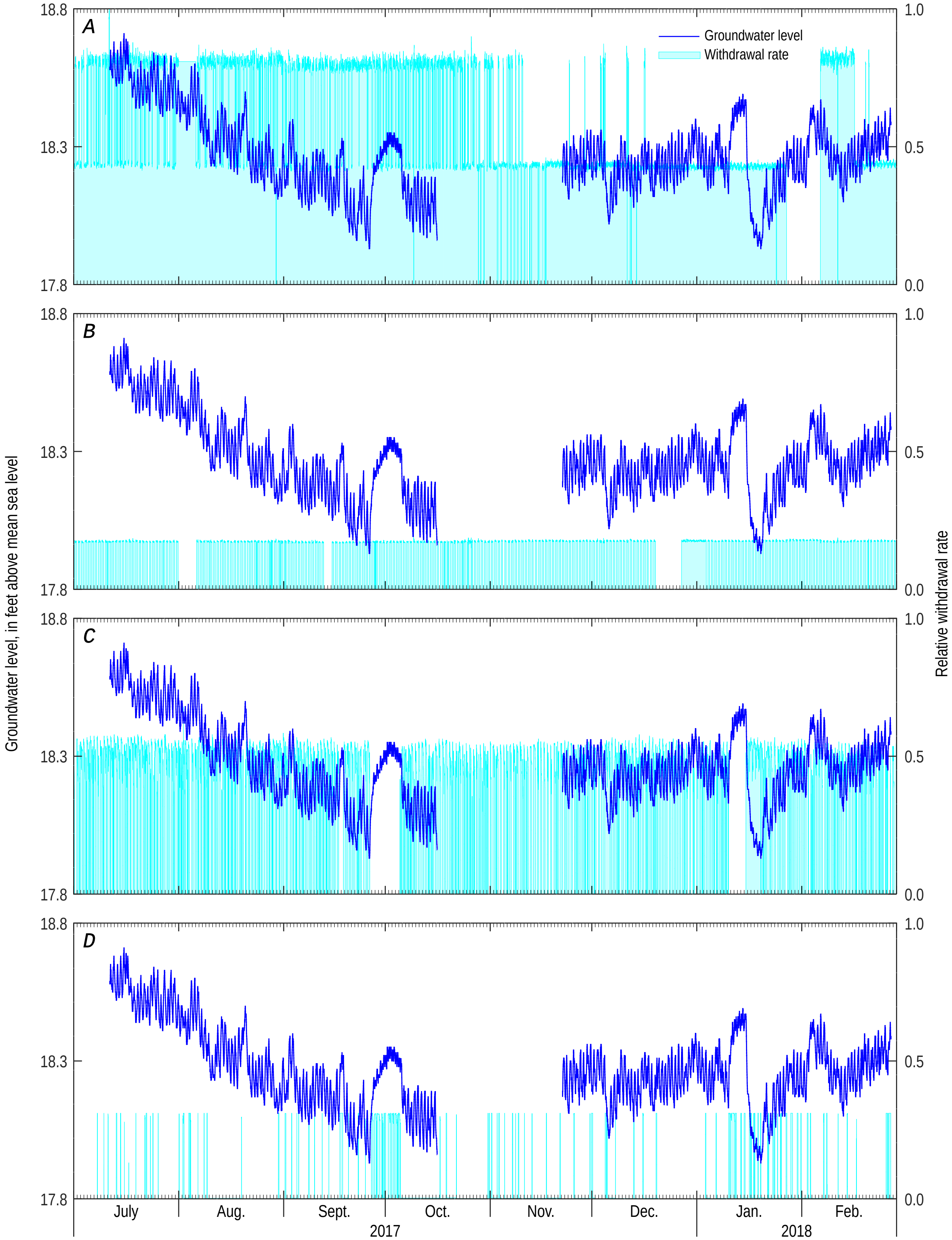

Figure 13. Measured groundwater level in well OWDFMW1 during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

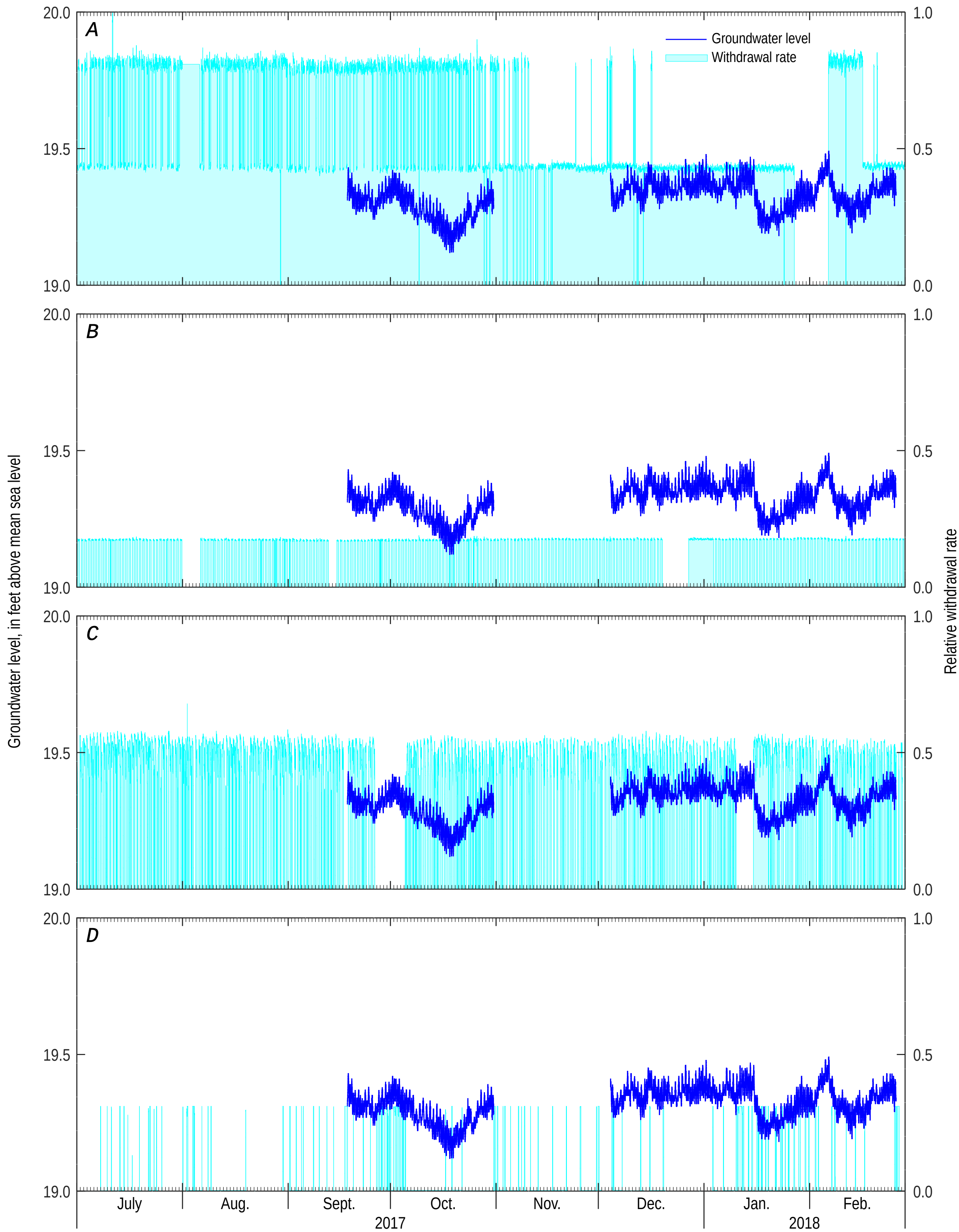

Figure 14. Measured groundwater level in well State Hālawa Deep during July 2017–February 2018, Hālawa area, Oʻahu, Hawaiʻi, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ʻAiea Hālawa Shaft.

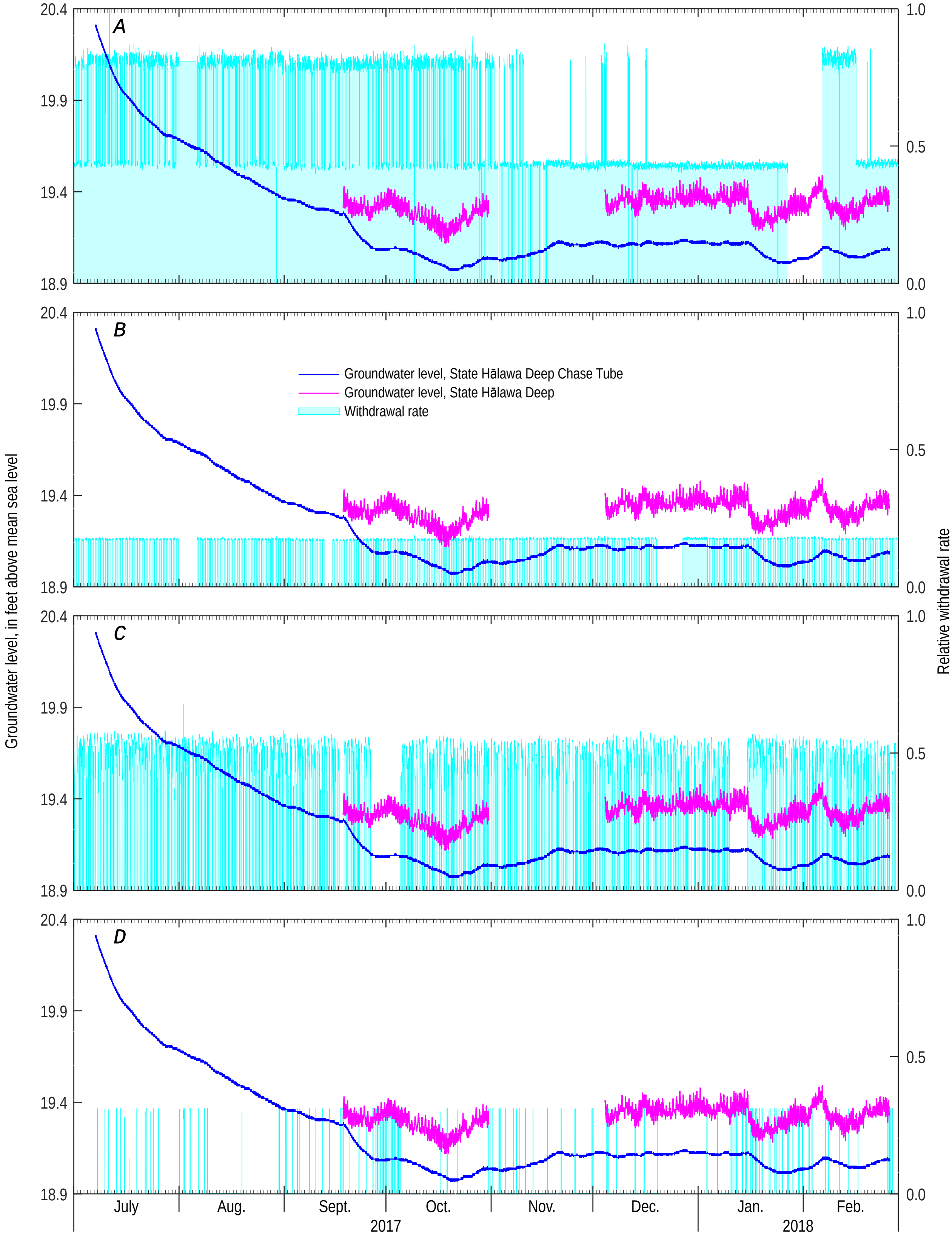

Figure 15. Measured groundwater level in wells State Hālawa Deep Chase Tube and State Hālawa Deep during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

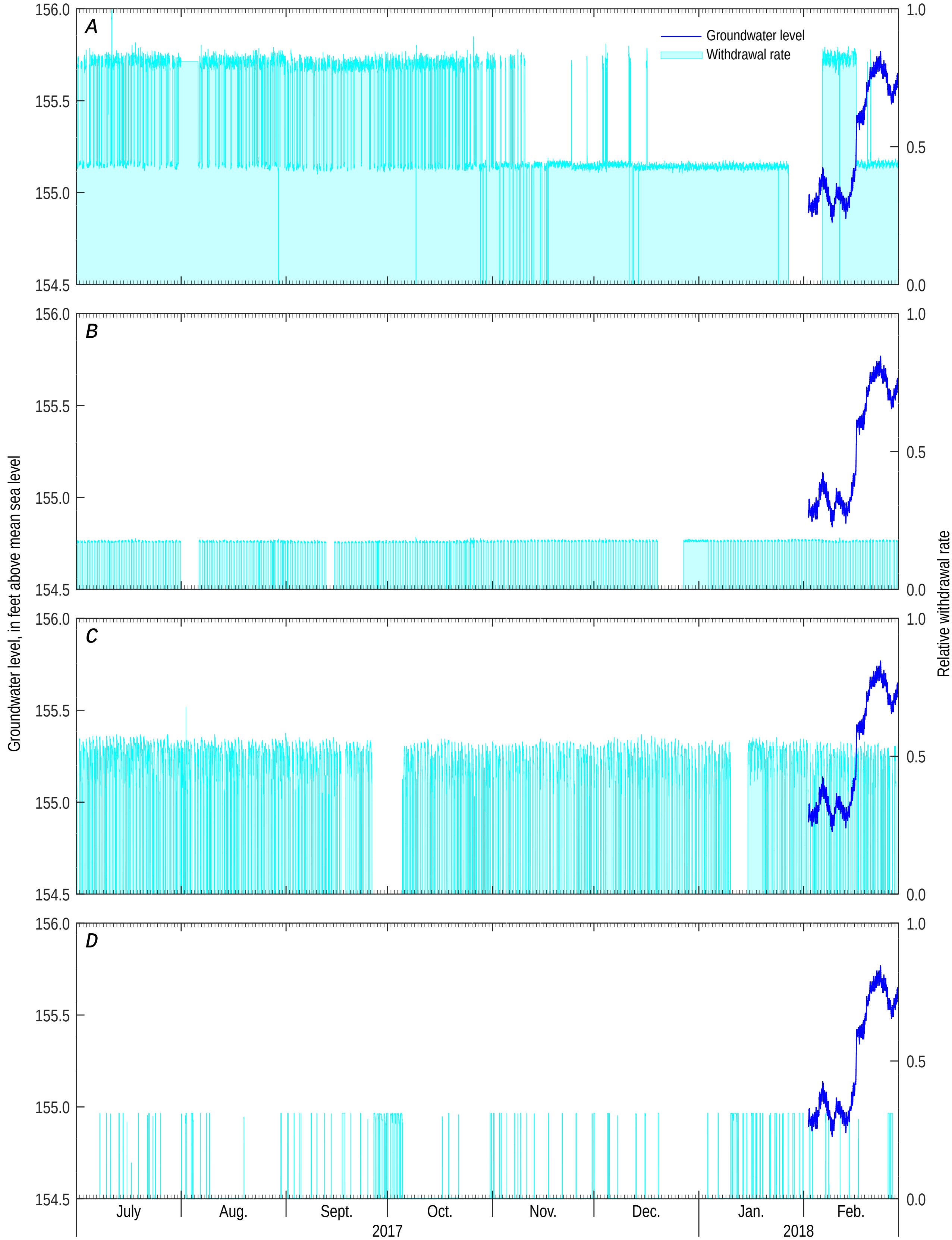

Figure 16. Measured groundwater level in well MW-1 during July 2017–February 2018, Hālawa area, Oʻahu, Hawaiʻi, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ʻAiea Hālawa Shaft.

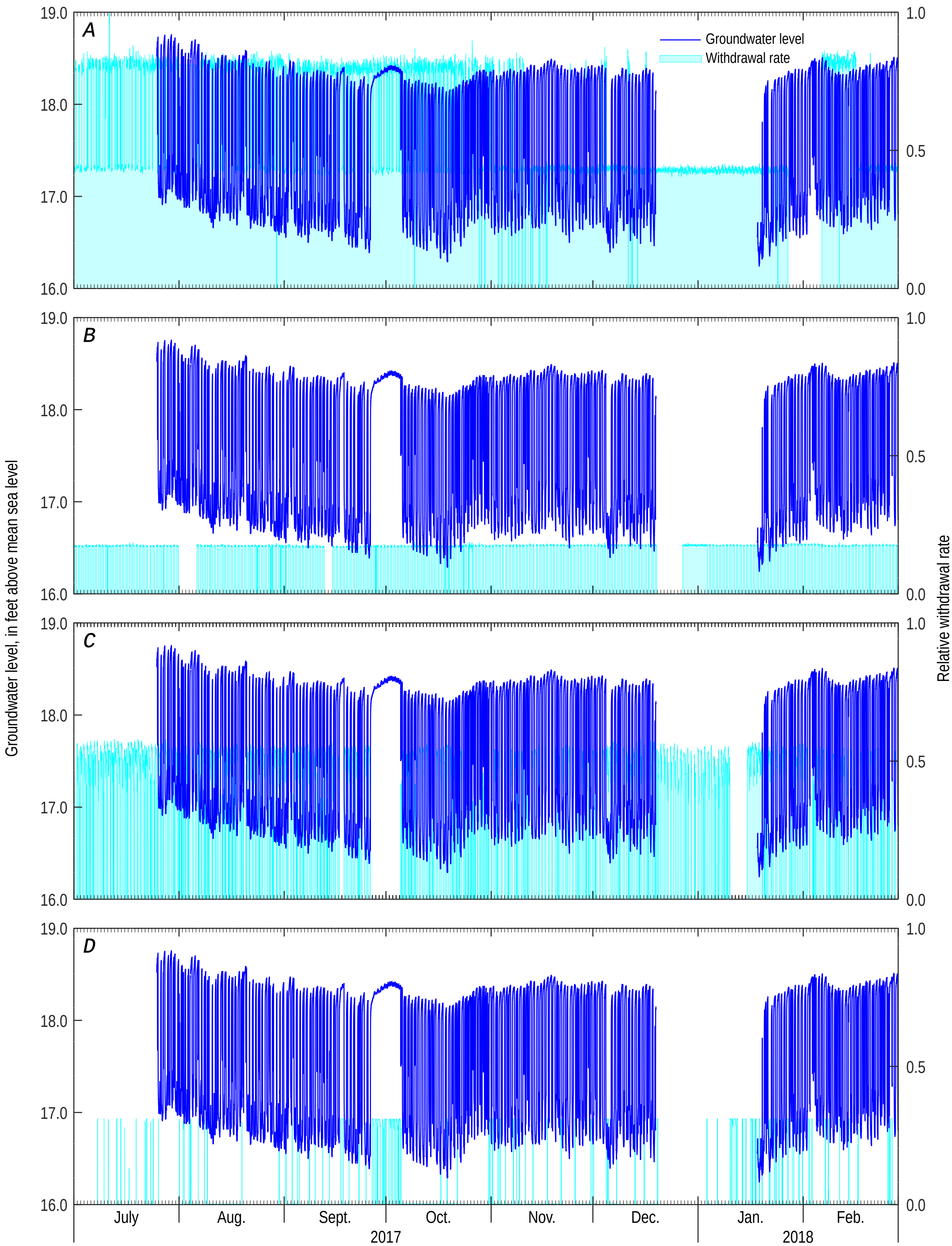

Figure 17. Measured groundwater level in Red Hill Shaft during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

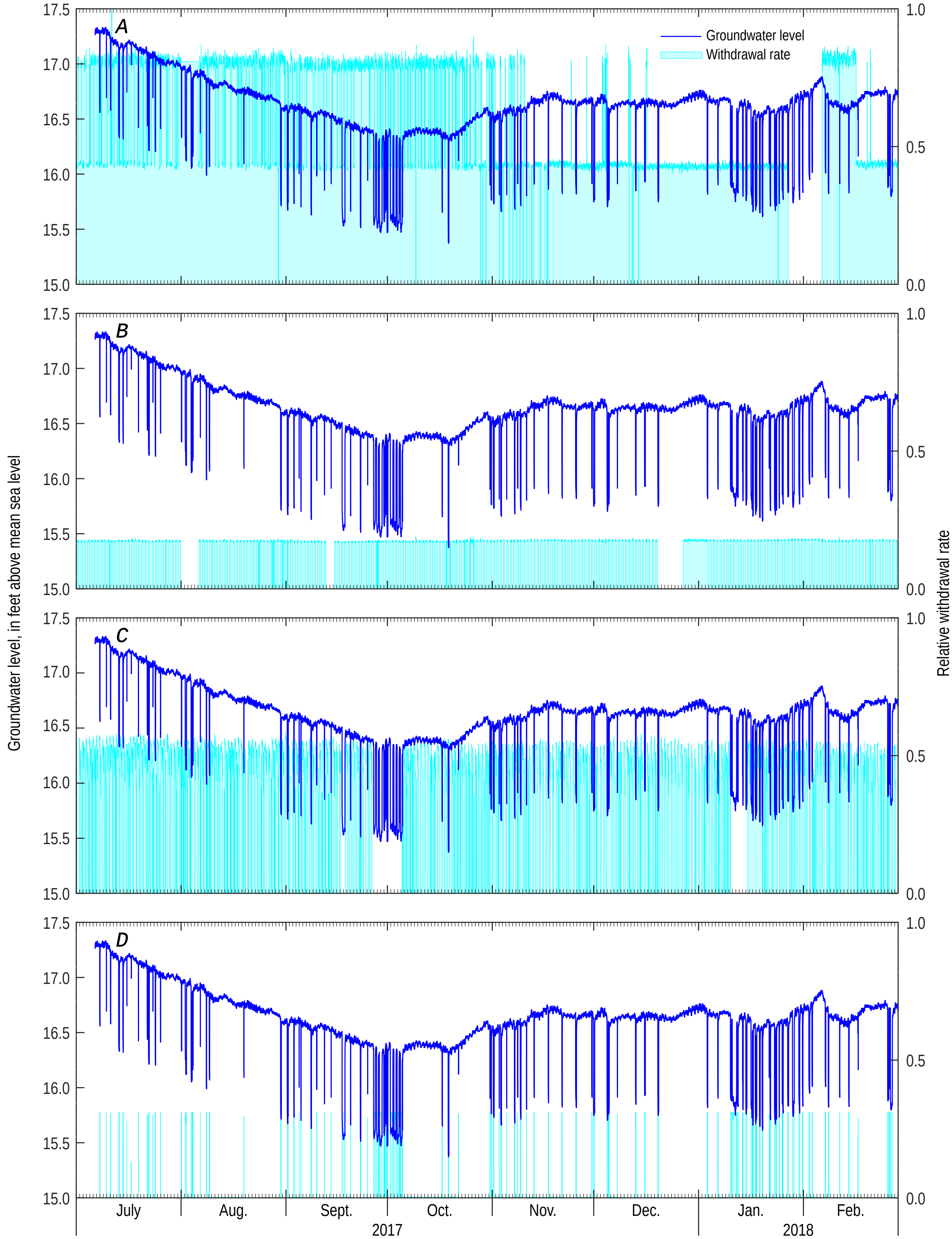

Figure 18. Measured groundwater level in ‘Aiea Hālawa Shaft during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

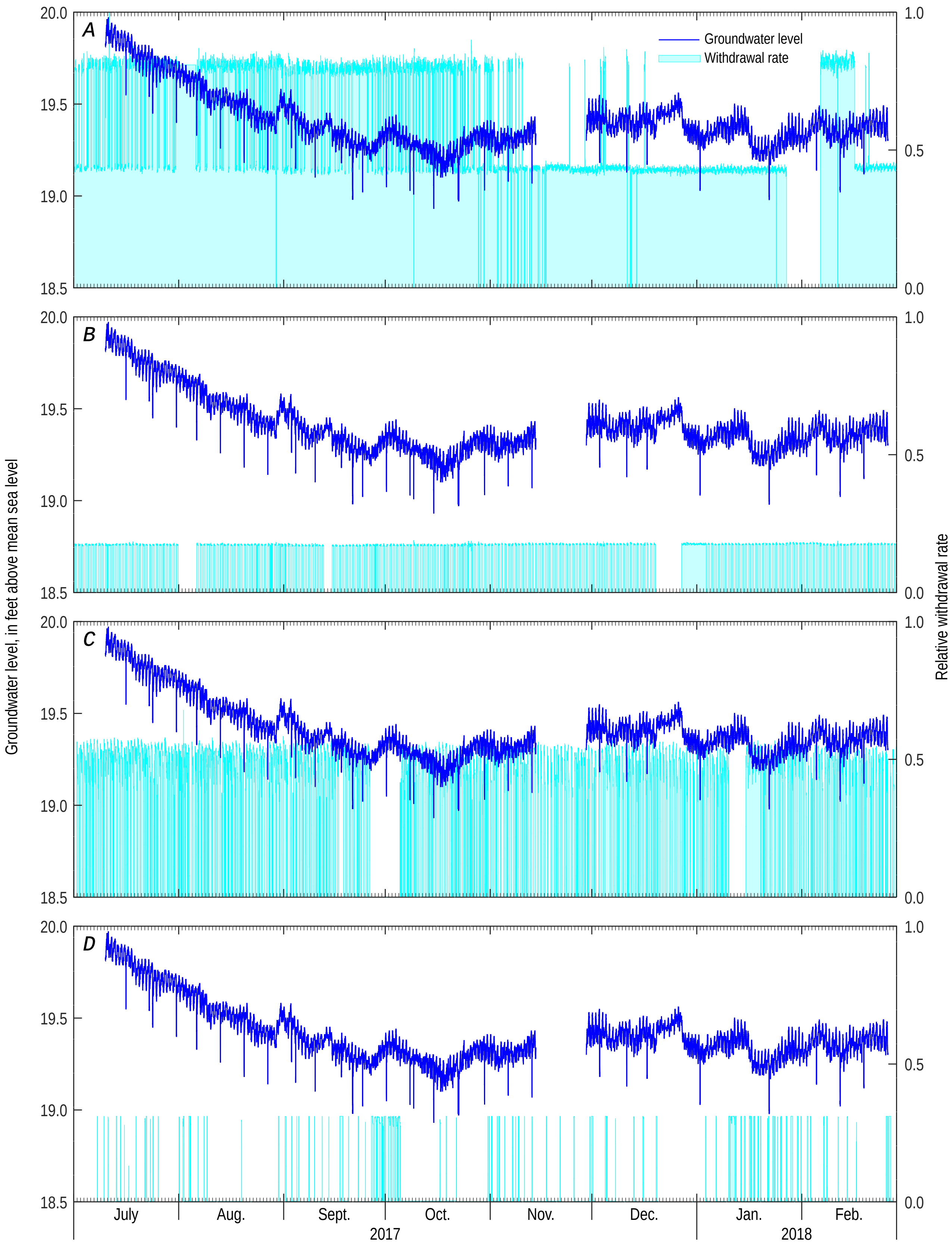

Figure 19. Measured groundwater level in well Moanalua Deep during July 2017–February 2018, Hālawa area, Oʻahu, Hawaiʻi, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ʻAiea Hālawa Shaft.

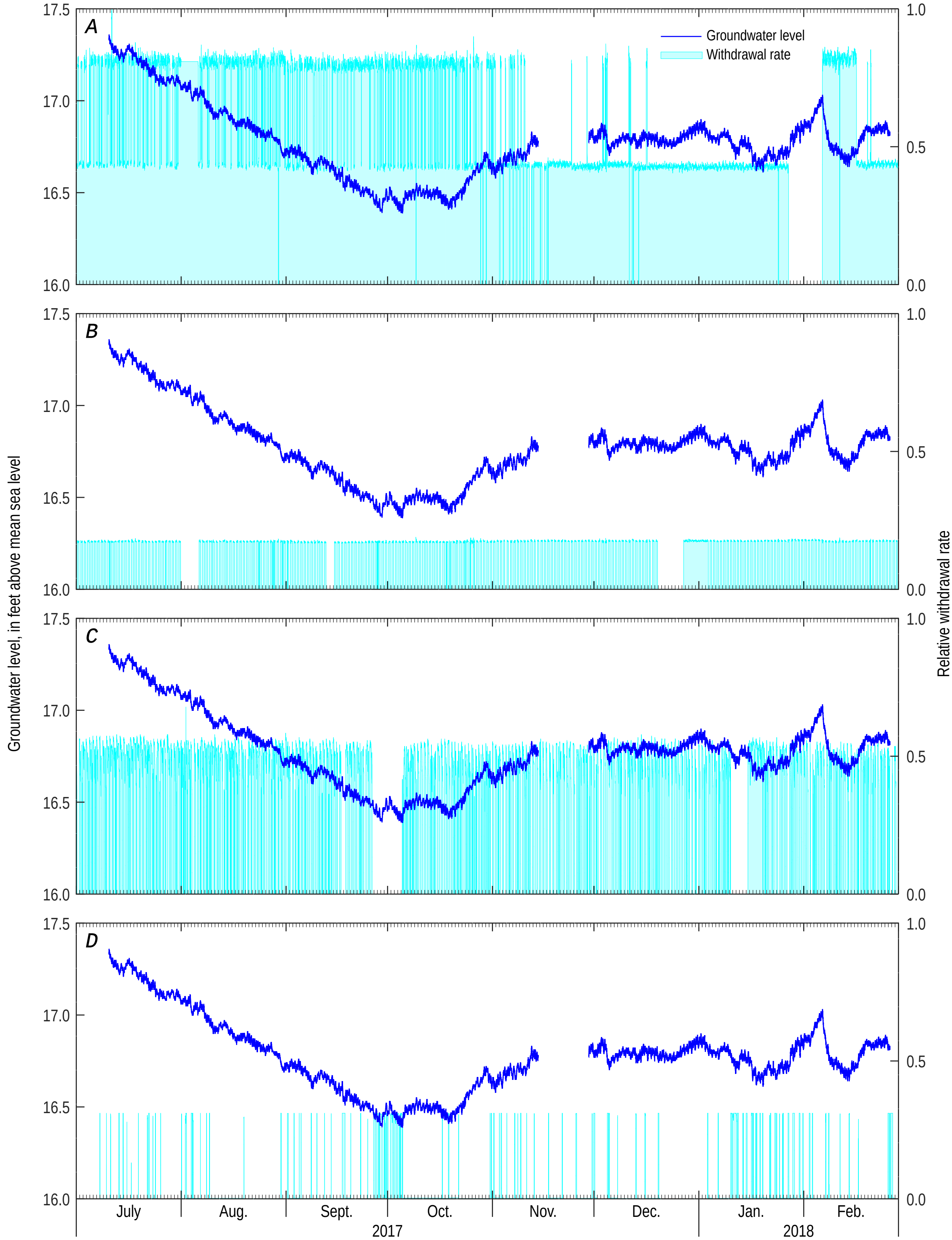

Figure 20. Measured groundwater level in well Hālawa TZ during July 2017–February 2018, Hālawa area, Oʻahu, Hawaiʻi, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ʻAiea Hālawa Shaft.

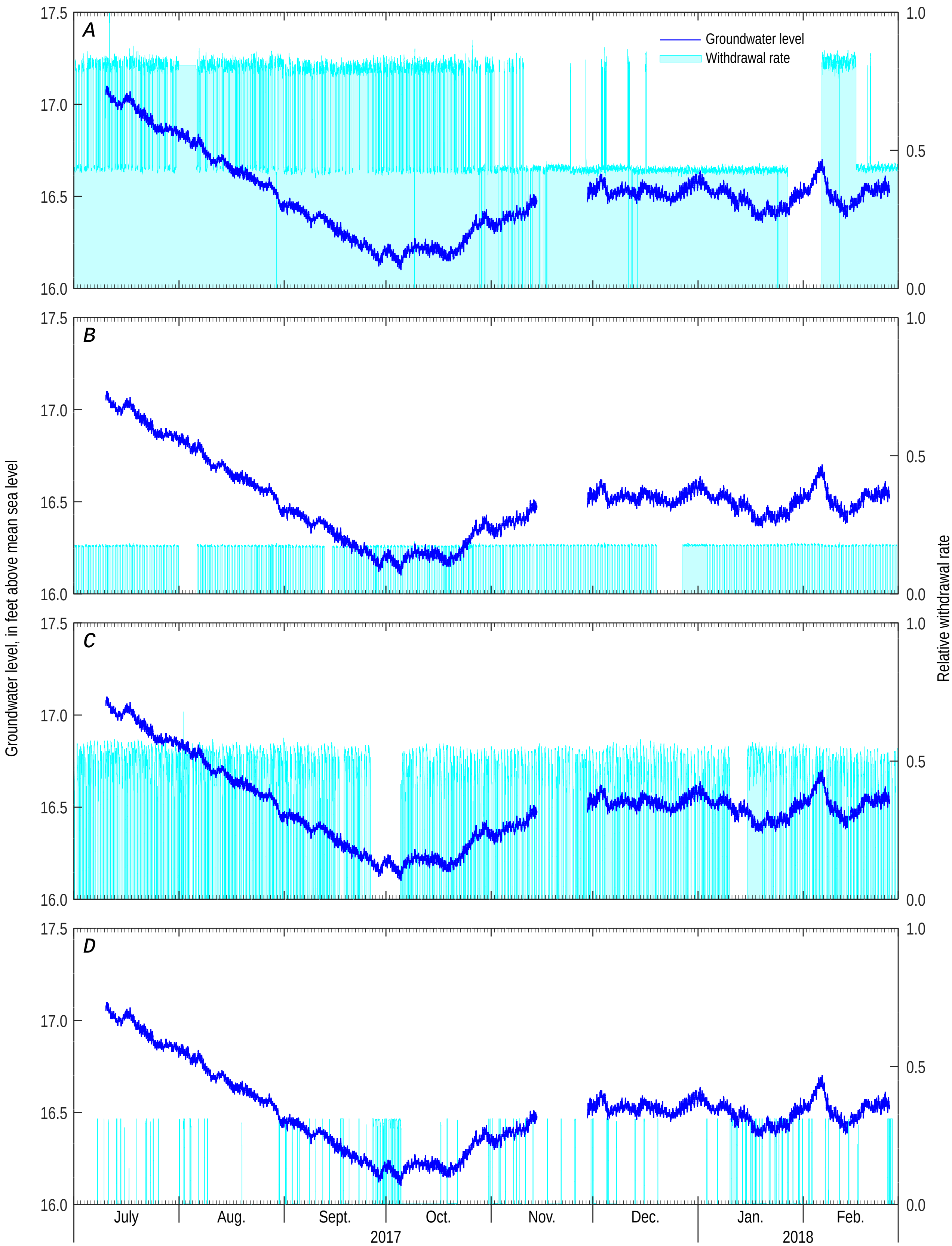

Figure 21. Measured groundwater level in well Ka‘amilo during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Ai ea Hālawa Shaft.

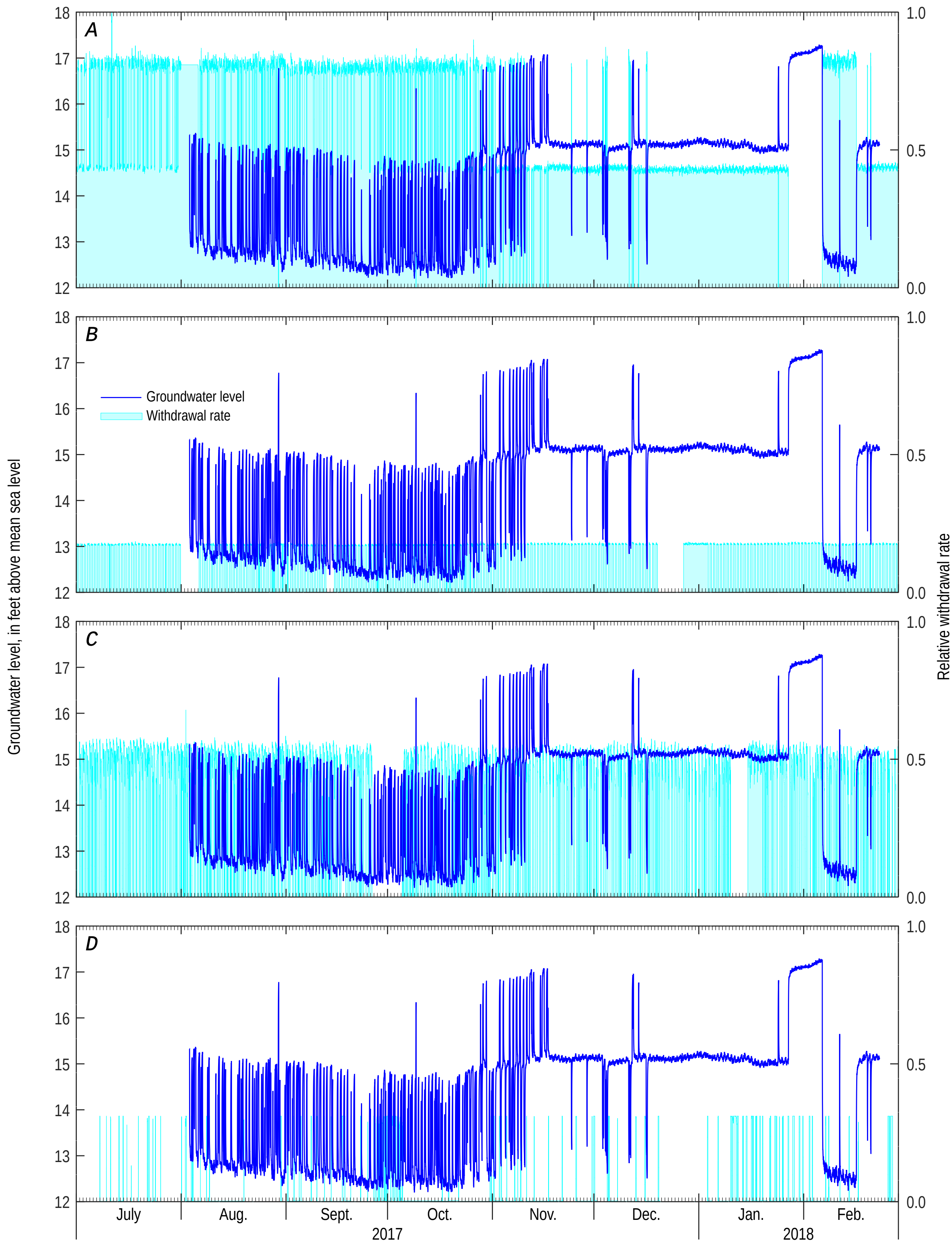

Figure 22. Measured groundwater level in Hālawa Shaft during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

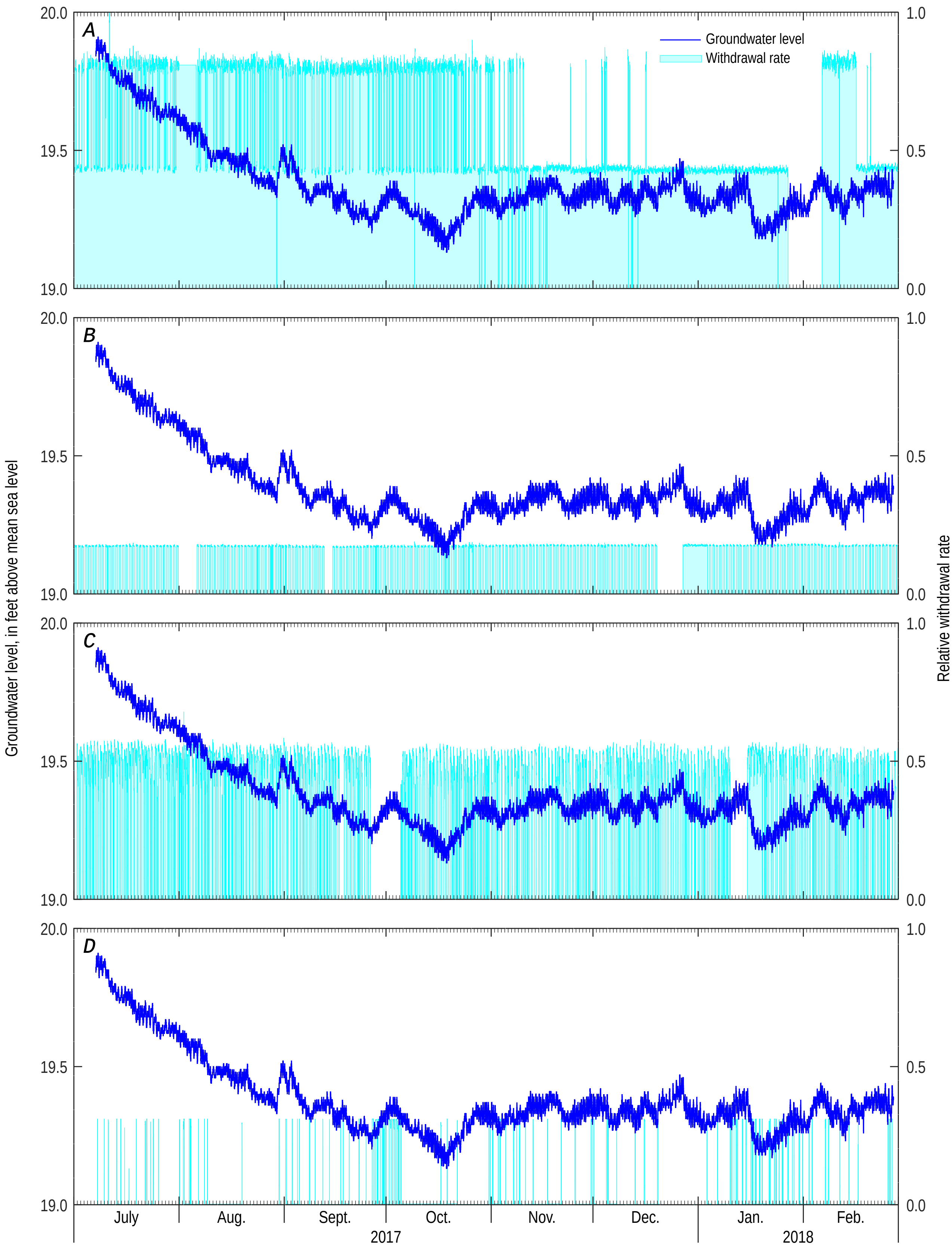

Figure 23. Measured groundwater level in well TAMC MW2 during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

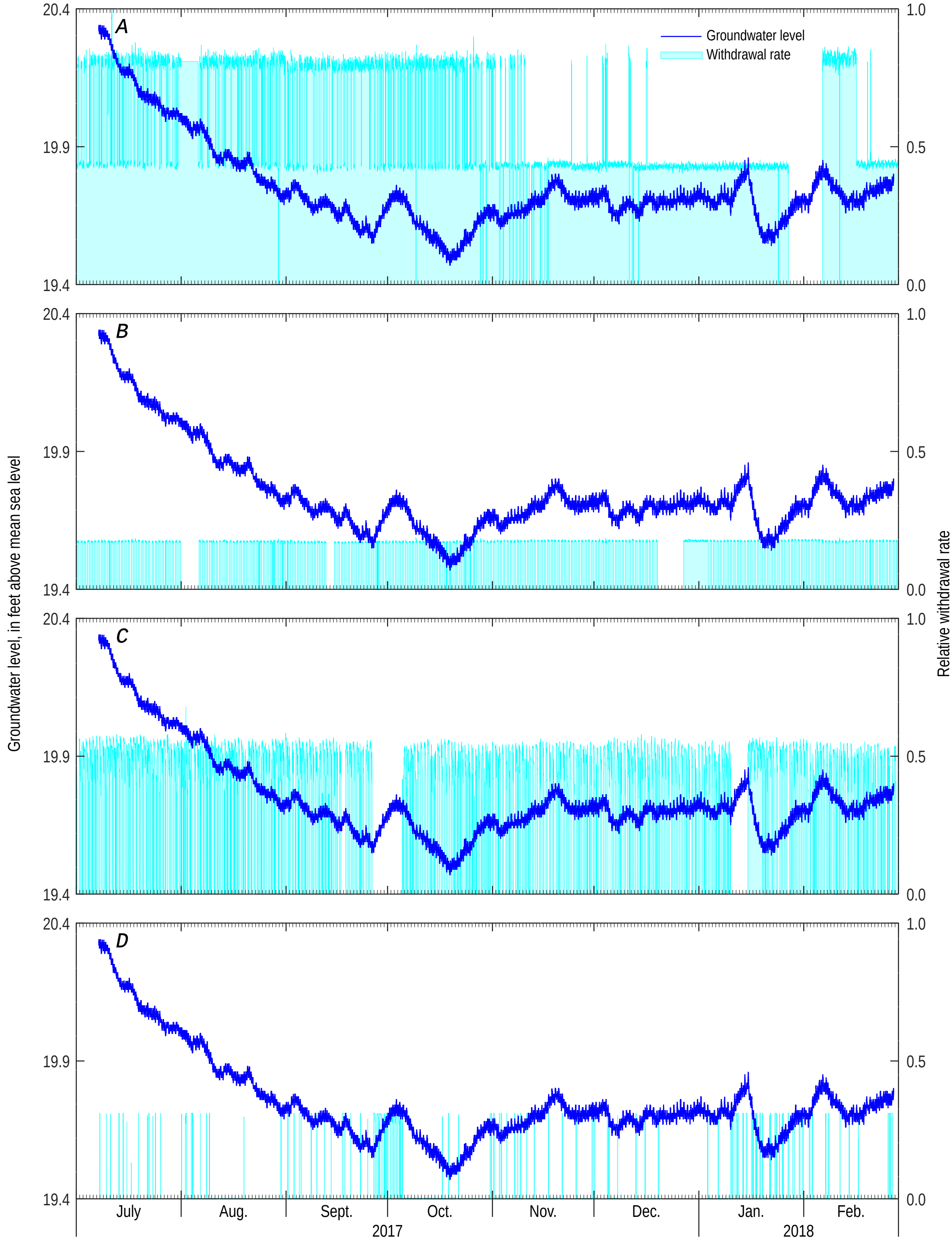

Figure 24. Measured groundwater level in well DH 43 during July 2017–February 2018, Hālawa area, Oʻahu, Hawaiʻi, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ʻAiea Hālawa Shaft.

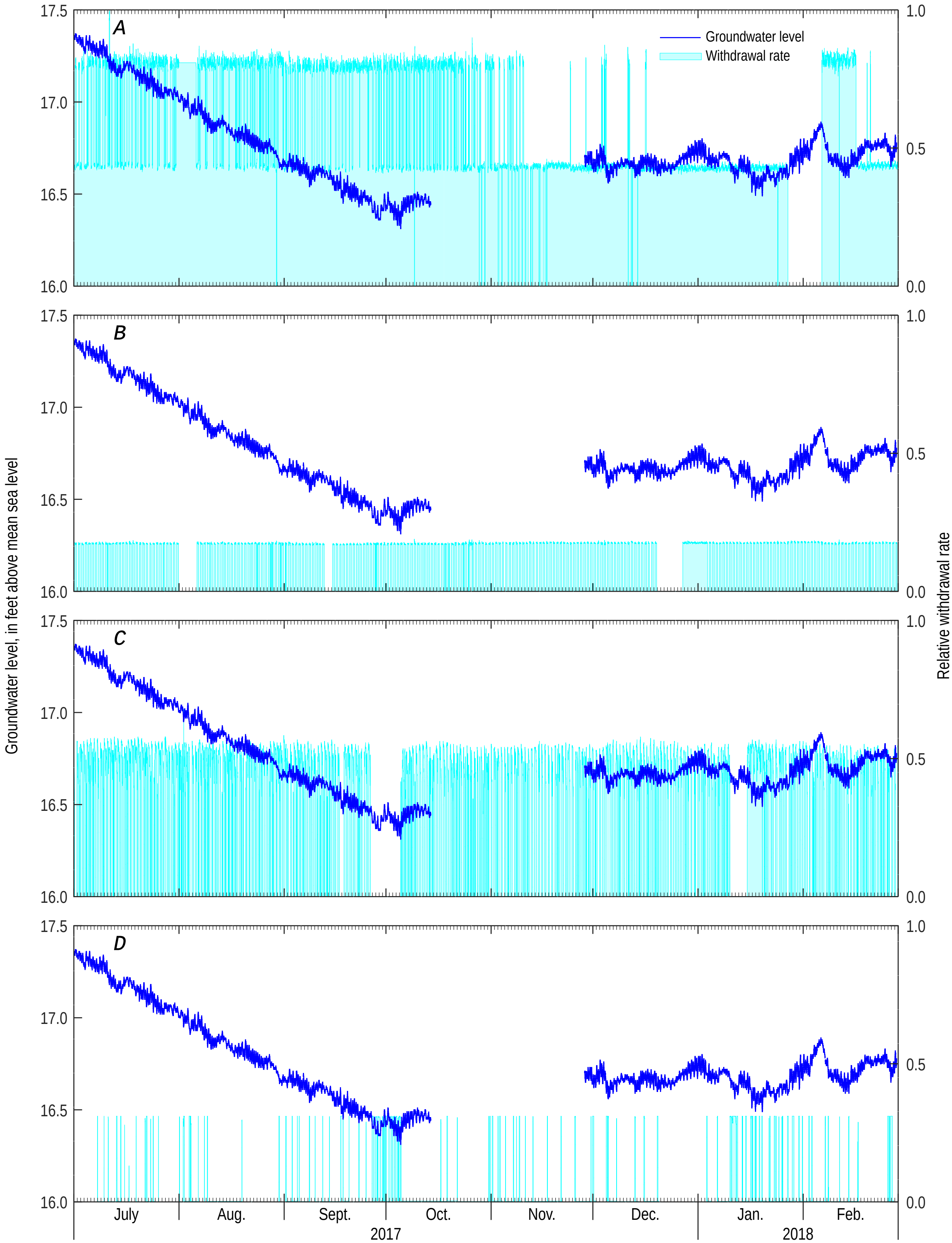

Figure 25. Measured groundwater level in well ‘Aiea Boat Harbor during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i, plotted with relative withdrawal rate (arbitrary scale from 0 to 1) from nearby wells (A) Hālawa Shaft, (B) Moanalua Wells, (C) Red Hill Shaft, and (D) ‘Aiea Hālawa Shaft.

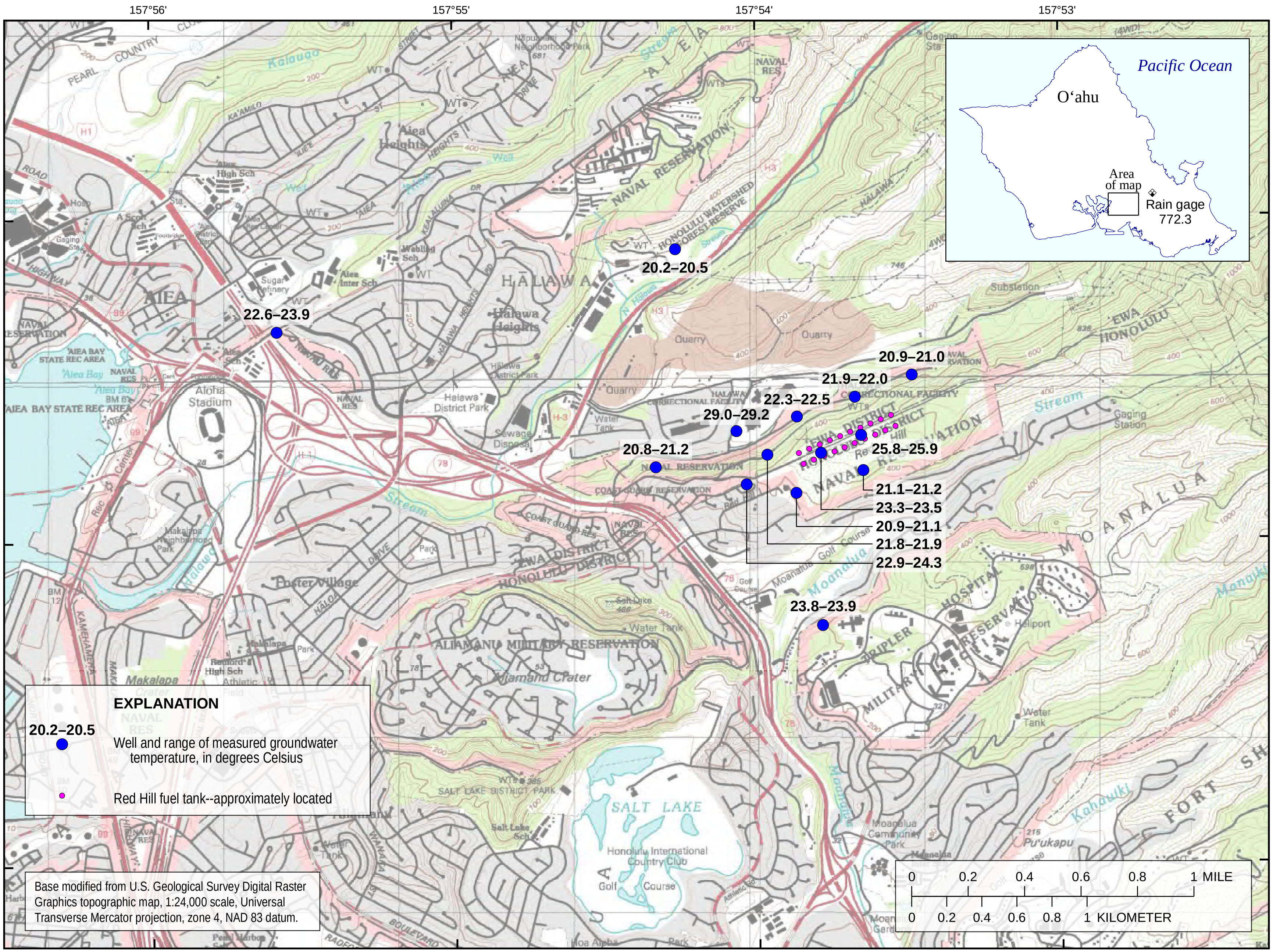

Figure 26. Measured groundwater temperature in wells monitored during July 2017–February 2018, Hālawa area, O'ahu, Hawai'i.

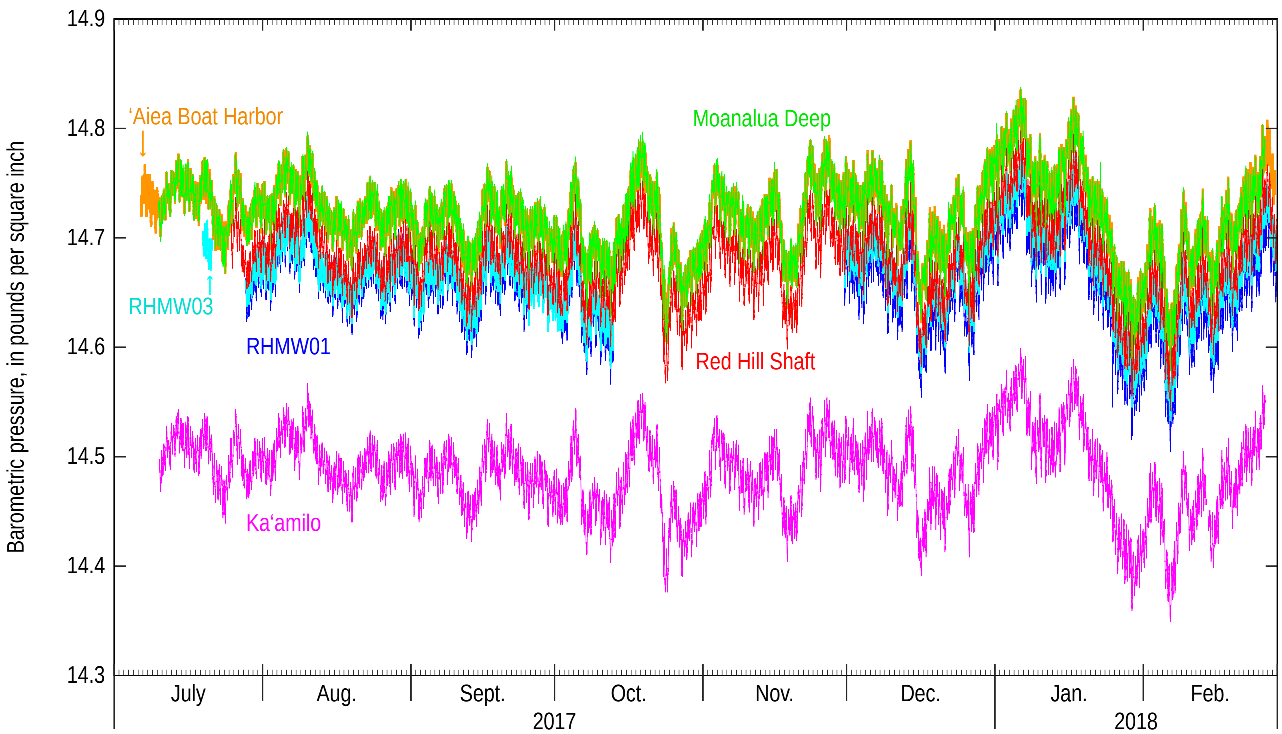

Figure 27. Measured barometric pressure at six monitoring sites during July 2017–February 2018, Hālawa area, O‘ahu, Hawai‘i.

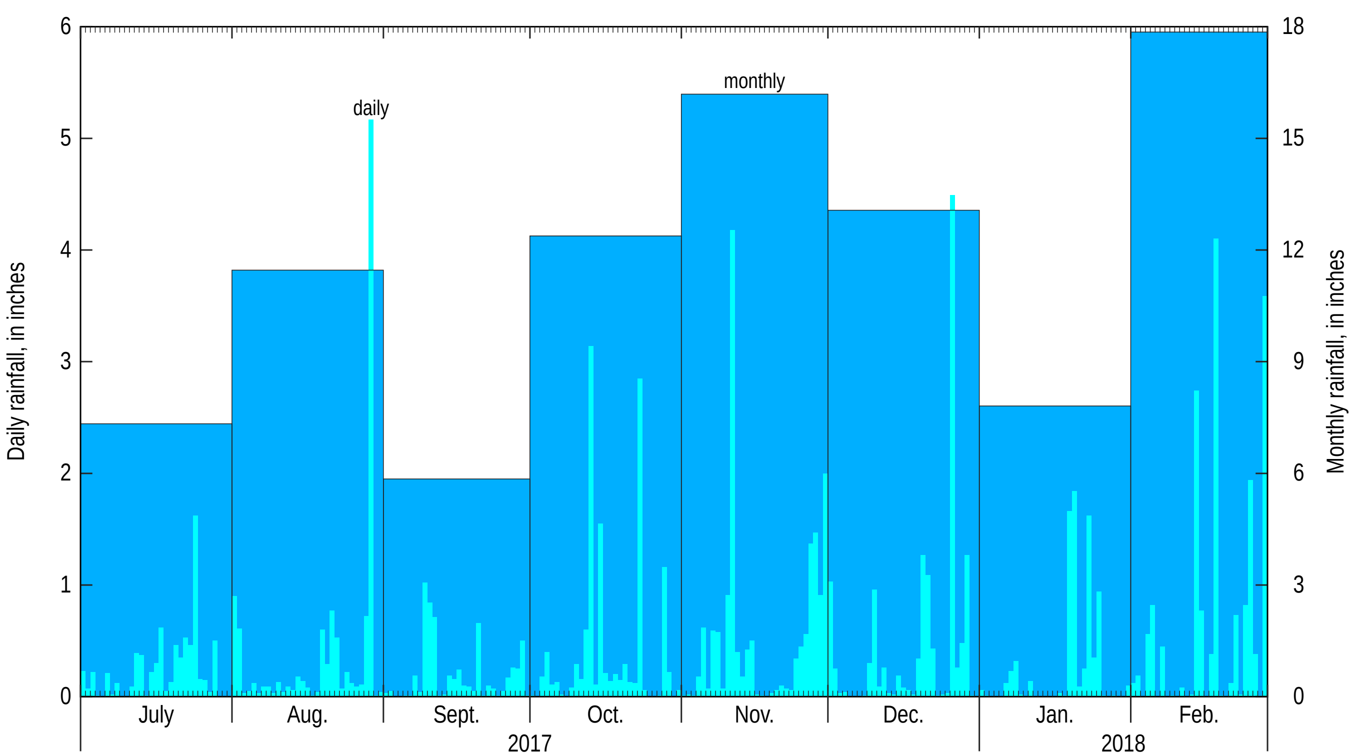

Figure 28. Measured daily and monthly rainfall during July 2017–February 2018 at U.S. Geological Survey rain-gaging station 212359157502601 (State key number 772.3, Moanalua rain gage no. 1), at altitude 1,000 feet, O‘ahu, Hawai‘i.

The semidiurnal water-level variations at RHMW04 are characterized by changes that were in the same direction as barometric-pressure changes. The transducer and vented cable at RHMW04 passed inspections before and after the study. The reason for the difference in semidiurnal water-level characteristics at RHMW04 relative to other wells remains uncertain.

The water-level and barometric-pressure data from RHMW01, RHMW03, and RHMW05, all located within the lower access tunnel of the RHSF, contain numerous brief spikes in pressure. Nearly all of the pressure spikes occurred between the hours of 07:00 and 19:00, typical working hours when human activity within the tunnel is common. The opening and closing of security doors within the tunnel can create air-pressure changes in affected sections of the tunnel, and air-pressure changes are reflected in the barometric-pressure records as well as the water-level records. The water-level data from RHMW02, located in the same tunnel, have significantly fewer spikes than the other wells in the tunnel; the reason for this is uncertain.

Semidiurnal water-level variations at State Hālawa Deep Chase Tube are attenuated relative to the semidiurnal water-level variations at State Hālawa Deep, collocated with the chase tube. The chase tube is only open at the bottom of the casing (no perforations) and lacks an open borehole below the casing, whereas State Hālawa Deep has several hundred feet of open borehole below the solid casing. The attenuated semidiurnal water-level variations at State Hālawa Deep Chase Tube could be related to either low permeability of the surrounding rock or a poor connection to the aquifer due to well characteristics.

On two occasions, brief and concurrent water-level changes, ranging from 0.03–0.06 ft, occurred in the records of at least two sites (the deep wells Hālawa TZ and Kaʻamilo). These water-level changes occurred shortly after large earthquakes with epicenters near the Aleutian Trench (USGS, 2017; USGS, 2018a). The water-level changes appear in the water-level records at approximately 14:00 HST on July 17, 2017, and 23:50 HST on January 22, 2018.

During dry periods, low rates of rainfall and groundwater recharge could affect groundwater levels. During the summer months of July through September 2017, rainfall was lower than subsequent months (fig. 28). Also during this period, groundwater levels generally declined.

The Hālawa TZ, Kaʻamilo, Moanalua Deep, and State Hālawa Deep wells are deep boreholes with long open sections. As a result, the measured water levels could reflect a vertical integration of heads and borehole flow (Rotzoll, 2012).

Data Gaps

Data gaps are present in each of the records, ranging from single data points to several weeks of continuous data. The data gaps were caused by: (1) the removal of equipment during routine site visits to retrieve data and make discrete water-level measurements; (2) the removal of equipment for several weeks to allow water samples or geophysical logs to be collected by well owners; (3) unknown personnel tampering with equipment at RHMW03, which affected the data during the period from July 21 to 28, 2017; (4) the delayed equilibration of sensors after deployments; and (5) general equipment malfunction. The temperature sensors generally took several minutes to equilibrate to ambient conditions, whereas the pressure sensors equilibrated within seconds. The State Hālawa Deep, MW-1, and RHMW11 sites were added to the study after the initiation of monitoring at the other sites.

Limitations

The water-level data, although reported to hundredths of a foot, have several components that could affect their accuracy.

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

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. Factors that could adversely affect the accuracy of the discrete water-level data include, but are not limited to: (1) the accuracy of the steel tape used to collect the measurement; (2) the accuracy of the surveyed MP altitude; (3) the accuracy of a gyroscopic-survey correction; (4) the accuracy of the wetted chalk mark on steel tapes; and (5) human error. The tape-correction values, applied to each depth-to-water measurement collected with a steel tape, reflect tape errors at specific depths and may not perfectly reflect errors at depths of each site in the study. Results of the tape calibration in September 2017 indicated that steel-tape corrections for tapes were generally zero or 0.01 ft for depths measured at the 24 sites included in the study. The discrete water-level measurements at RHMW11 may contain additional uncertainty because of the presence of an irremovable steel cable in the small-diameter well (about 1.5 inches), which could have affected how the steel tape hung in the well and, therefore, the representativeness of the gyroscopic-survey correction.

The water-level data were collected using the MP altitude as a reference; thus, any inaccuracies in the MP-altitude data are reflected in the water-level data. The personnel, procedures, and equipment used to determine the MP altitudes were not identical at each site, potentially affecting comparability and the accuracy of each reported MP altitude.

The gyroscopic-survey data, available for 12 of the 21 monitoring wells in the study, result 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 likely improved the accuracy of the water-level data collected at the 12 sites; however, the corrections also may introduce a potential bias in the data. Gyroscopic deviation surveys can only result in an increase in measured water levels because the total vertical depth cannot exceed the measured depth. Consequently, wells that were surveyed have an elevated water level compared to wells that were not surveyed, all other factors being equal.

Summary

The Red Hill Bulk Fuel Facility, operated by the U.S. Navy, includes 20 underground storage tanks that can store a combined 250 million gallons of fuel. In January 2014, a fuel release of approximately 27,000 gallons was reported by the U.S. Navy. Due to concern regarding potential groundwater contamination, the U.S. Geological Survey (USGS), in coordination with well operators, conducted a regional aquifer test in the Hālawa area, O‘ahu, Hawai‘i, to provide information for evaluating groundwater-flow directions and estimating aquifer hydraulic properties in the area. The study entailed collecting groundwater-level data at 24 sites near the Red Hill Bulk Fuel Storage Facility during July 2017–February 2018. At 14 of the 24 sites, groundwater-temperature data were also collected, and at 6 of the 24 sites, barometric-pressure data were collected. The data collected during the study are available on the USGS National Water Information System database (USGS, 2018b); the data can be found using the USGS site identifiers or hyperlinks listed in table 1. The water-level data have several limitations that may affect interpretation of the data, including, but not limited to, inaccuracies in measuring-point altitudes, tape corrections, gyroscopic corrections (if applicable), and continuous water-level recorders.

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