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Low-Flow Characteristics for Streams on the Islands of Kaua‘i, O‘ahu, Moloka‘i, Maui, and Hawai‘i, State of Hawai‘i

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U.S. Department of the Interior
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COVER PHOTOS (top to bottom)

Kaua'i—View of the mountains above river valleys of Hanalei and Wai'oli, Island of Kaua'i, Hawai'i. Photograph by Chui Ling Cheng, U.S. Geological Survey, 2012.

O'ahu—View of Maunalua Bay on the southeastern coast of O'ahu from a forested ridge on Hawai'iloa Valley, Island of O'ahu, Hawai'i. Photograph by Chui Ling Cheng, U.S. Geological Survey, 2014.

Moloka'i—Kalohi Channel between Moloka'i and Lāna'i from Kamakou Preserve access road near a Kawela Valley ridge, Island of Moloka'i, Hawai'i. Photograph by Sarah N. Rosa, U.S. Geological Survey, 2010.

Maui—View at the summit of Haleakalā, Island of Maui, Hawai'i. Photograph by Chui Ling Cheng, U.S. Geological Survey, 2013.

Hawai'i—View of Mauna Kea from Waimea, Island of Hawai'i, Hawai'i. Photograph by Vaughn E. Kunishige, U.S. Geological Survey, 2011.

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SALLY JEWELL, Secretary

U.S. Geological Survey
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This study was conducted in cooperation with the State of Hawai‘i Commission on Water Resource Management (CWRM), State of Hawai‘i Department of Hawaiian Home Lands (DHHL), and Office of Hawaiian Affairs (OHA). The study was completed with the help of several U.S. Geological Survey (USGS) personnel. Julie E. Kiang provided valuable technical support throughout the study. Sarah N. Rosa and Heather A. Jeppesen compiled over 6,000 historical streamflow measurements and entered the measurements into the National Water Information System (NWIS) database.

Datum

Vertical coordinate information is referenced relative to local mean sea level.
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).
Altitude, as used in this report, refers to distance above the vertical datum.

Conversion Factors

Inch/Pound 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)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.64636	million gallons per day (Mgal/d)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)

Abbreviations

CWRM	State of Hawai‘i Commission on Water Resource Management
DHHL	State of Hawai‘i Department of Hawaiian Home Lands
GIS	geographic information system
OHA	Office of Hawaiian Affairs
MOVE.1	Maintenance of Variance Extension Type 1
NSE	Nash-Sutcliff coefficient of efficiency
NWIS	National Water Information System
SREF	Streamflow Record Extension Facilitator
TMDL	total maximum daily load
USGS	U.S. Geological Survey

Low-Flow Characteristics for Streams on the Islands of Kaua‘i, O‘ahu, Moloka‘i, Maui, and Hawai‘i, State of Hawai‘i

By Chui Ling Cheng

Abstract

Statistical models were developed to estimate natural streamflow under low-flow conditions for streams with existing streamflow data at measurement sites on the Islands of Kaua‘i, O‘ahu, Moloka‘i, Maui, and Hawai‘i. Streamflow statistics used to describe the low-flow characteristics are flow-duration discharges that are equaled or exceeded between 50 and 95 percent of the time during the 30-year base period 1984–2013. Record-augmentation techniques were applied to develop statistical models relating concurrent streamflow data at the measurement sites and long-term data from nearby continuous-record streamflow-gaging stations that were in operation during the base period and were selected as index stations. Existing data and subsequent low-flow analyses of the available data help to identify streams in under-represented geographic areas and hydrogeologic settings where additional data collection is suggested.

Low-flow duration discharges were estimated for 107 measurement sites (including long-term and short-term continuous-record streamflow-gaging stations, and partial-record stations) and 27 index stations. The adequacy of statistical models was evaluated with correlation coefficients and modified Nash-Sutcliff coefficients of efficiency, and a majority of the low-flow duration-discharge estimates are satisfactory based on these regression statistics.

Moloka‘i and Hawai‘i have the fewest number of measurement sites (that are not located on ephemeral stream reaches) at which flow-duration discharges were estimated, which can be partially explained by the limited number of index stations available on these islands that could be used for record augmentation. At measurement sites on some tributary streams, low-flow duration discharges could not be estimated because no adequate correlations could be developed with the index stations. These measurement sites are located on streams where duration-discharge estimates are available at long-term stations at other locations on the main stream channel to provide at least some definition of low-flow characteristics on that stream. In terms of general natural streamflow data availability, data are scarce in the leeward areas for all five islands as many leeward streams are dry or have minimal flow. Other under-represented areas include central O‘ahu, central Maui, and southeastern Maui.

Introduction

Surface water in the State of Hawai‘i (fig. 1) is valued for its economic, ecologic, cultural, and aesthetic importance. Flow in many streams in Hawai‘i is currently diverted for agricultural, industrial, or municipal uses. An assessment of Hawaiian streams identified 376 perennial streams, of which 125 were diverted to some extent (Hawaii Cooperative Park Service Unit, 1990). Although streams supply only a small percentage of the drinking water statewide, surface water from streams is the main source of drinking water in some areas. Streams also provide riparian and instream habitats for many unique native species, and they support traditional and customary Hawaiian gathering rights and taro cultivation. Streams provide aesthetic enjoyment in the form of flowing water, waterfalls, and plunge pools, and they affect the physical and chemical quality of receiving waters such as estuaries, bays, and nearshore waters, which are critical to the tourism-based economy of the islands.

Allocation of the limited water resources for offstream and instream uses is a major challenge in the State of Hawai‘i. The diversion of surface water for offstream uses reduces flow in the downstream reaches, which can adversely affect traditional Hawaiian practices, stream ecology, water quality, recreational activities, and aesthetics. The Commission on Water Resource Management (CWRM) established a statewide instream-use protection program (Chapter 174C–71, Hawaii Revised Statutes) for protecting these instream uses through the use of instream-flow standards. “Each instream flow standard shall describe the flows necessary to protect the public interest in the particular stream. Flows shall be expressed in terms of variable flows of water necessary to protect adequately fishery, wildlife, recreational, aesthetic, scenic, or other beneficial instream uses in the stream in light of existing and potential water developments including the economic impact of restriction of such use” (Chapter 174C–71, Hawaii Revised Statutes). Quantitative instream-flow standards have not yet been established for most streams in the State of Hawai‘i.

Balancing between offstream and instream uses requires information on the current and future water demands, as well as the availability of water. Conflicts have led to costly litigation over rights to the water between those currently diverting the water and those desiring sufficient flow in the stream for instream uses. On O‘ahu, a contested-case hearing was initiated in 1995 to address competing uses of surface water and groundwater in the Waiāhole area of windward O‘ahu (Miike, 2004). The Waiāhole Ditch diverted large amounts of dike-impounded groundwater at high altitudes that previously fed Waiāhole (and its tributaries Waianu and Uwao), Waikāne, and Kahana Streams through seeps and springs, resulting in diminished base flows in these streams. In 2005, the Punalu‘u Watershed Alliance was formed to address community issues and coordinate efforts to establish an instream-flow standard for Punalu‘u Stream (State of Hawai‘i, 2007). On Maui, the Native Hawaiian Legal Corporation filed a petition to CWRM in 2001 for flow to be restored to 27 streams in northeast Maui that were diverted mainly by the East Maui Irrigation Company for irrigating sugarcane cultivated in central Maui (State of Hawai‘i, 2001). In 2004, Earthjustice filed a petition to amend instream-flow standards for the Nā Wai ‘Ehā streams (Waihe‘e and Wailuku[1] Rivers, and Waiehu and Waikapū Streams) in the eastern part of west Maui (State of Hawai‘i, 2004). For these cases, streamflow data under natural flow conditions for the streams involved were limited or unavailable at the time of the disputes. Consequently, the U.S. Geological Survey (USGS), in cooperation with various agencies, provided the information necessary for planning and management of the water resource (see Gingerich, 2005; Oki and others, 2006; Yeung and Fontaine, 2007; Oki and others, 2010b).

Low-Flow Characteristics

During low-flow conditions, the amount of surface water available may become insufficient to meet all the competing demands. Inadequate streamflow poses a threat to the survival of native stream animals by reducing available instream habitats and, in some streams, by eliminating continuous flow to the ocean. Water quality also may become a concern during low-flow conditions, and streamflow information is needed to determine the total maximum daily load (TMDL) that will help characterize impaired waters statewide. Documentation of low-flow conditions is important for identifying critical areas that affect both mankind and aquatic species and for developing plans to mitigate further negative effects to the resource.

Streamflow measurements under low-flow conditions can also be used to identify areas of groundwater discharge and to assess the potential effect of groundwater withdrawal. Although the State of Hawai‘i is mostly dependent on groundwater for municipal water supply, increasing groundwater withdrawals, which may result from increased urbanization, can affect streamflow in some places. The effect of groundwater withdrawal on streamflow depends on factors including the rate of withdrawal and the proximity of the pumped wells to the streams. To reduce the amount of potable groundwater used to meet nonpotable needs, alternative surface-water sources might be considered.

In the State of Hawai‘i, management of the surface-water resources for many streams is problematic because of the lack of information on natural flow during low-flow conditions. As the population of the State of Hawai‘i increases and development expands to new areas, effective management of water resources is critical to meet future needs. Surface-water resources in an area must be quantified as part of evaluating existing and potential uses. Ideally, accurate long-term streamflow data are used to provide information on the availability of streamflow. The USGS has operated hundreds of continuous-record streamflow-gaging stations in the State of Hawai‘i since the early 1900s, although information on natural (unregulated) flows for many streams is unavailable because many of the gaging stations were located downstream of surface-water diversions or were operated for only short periods (Fontaine, 1995). Reliable estimates of natural low-flow characteristics for ungaged streams represent basic information necessary for quantifying streamflow availability in the State of Hawai‘i. Because the cost of maintaining continuous-record streamflow-gaging stations at all sites of interest on all streams is prohibitive, methods for estimating low-flow characteristics of ungaged streams are needed to fill an important information need. Methods for estimating peak flows in the State of Hawai‘i currently exist (Oki and others, 2010a), although methods for estimating low-flow characteristics throughout the State of Hawai‘i are limited.

At sites where streamflow data are unavailable, regional-scale regression analysis can provide estimates of low-flow duration discharges based on data collected from gaged streams in similar hydrologic settings (for example, drainage area, slope, soil types, and rainfall). Fontaine and others (1992) developed multiple-regression equations to estimate the median discharge (the discharge that is equaled or exceeded 50 percent of the time during a specified period, or Q_{50} discharge) for undiverted perennial streams in the State of Hawai‘i. Gingerich (2005) developed regression equations to estimate the Q_{50} and Q_{95} discharges for total flow and base flow for undiverted sites in northeast Maui. (The Q_{95} discharge is the discharge that is equaled or exceeded 95 percent of the time during a specified period.) Existing regression equations are useful for estimating limited flow-duration discharges for particular geographic areas. However, a method is needed to estimate low-flow duration discharges, from Q_{50} to Q_{95} discharges, for natural-flow conditions throughout the State of Hawai‘i. These estimates will be useful for characterizing flow availability for streams where streamflow-gaging station data do not currently exist.

Not all streamflow data that USGS has gathered are easily accessible, particularly historic streamflow measurements made at locations that are not continuously gaged. As part of this study, data from continuous-record streamflow-gaging stations, partial-record stations, and miscellaneous discharge-measurement sites (such as seepage-run sites) are compiled

[1]The U.S. Board on Geographic Names approved the name change from ‘Īao Stream to Wailuku River on November 12, 2015.

from USGS files and published USGS reports and entered into the National Water Information System (NWIS) database, where the data are stored and easily accessible to anyone over the Internet. Partial-record stations offer a cost-effective way of expanding the geographic coverage of low-flow information (Curran and others, 2012) because they commonly are used to estimate low-flow characteristics at sites without a long-term continuous-record streamflow-gaging station. Partial-record stations are also useful because they provide additional data that can be used to develop regression models for estimating low-flow characteristics at ungaged sites, although the errors associated with the flow estimates are greater than those associated with continuous-record streamflow-gaging stations. Low-flow duration discharges are estimated using record-augmentation methods that relate discharge measurements at the partial-record stations and concurrent daily mean discharges at nearby continuous-record streamflow-gaging stations. Miscellaneous measurements, such as seepage-run discharge measurements, may also be available for other areas. Seepage runs are typically conducted to identify gaining and losing reaches of a stream.

Existing data and subsequent low-flow analyses of the available streamflow measurements establish the basis for identifying streams in under-represented geographic areas and hydrogeologic settings that can be considered for additional data collection. Existing measurement sites with limited numbers of discharge measurements are often ideal locations for collecting more data.

Previous Low-Flow Investigations

Previous low-flow investigations of Hawaiian streams have been largely conducted on a basin scale, with a focus on computing a selected range of low-flow duration statistics and examining the effects of surface-water diversions on low flows and habitat availability for native stream fauna. The application of record-augmentation methods for estimating low-flow characteristics at sites with either short-term record or partial-record streamflow data is well documented. A majority of the previous low-flow studies have been conducted on Maui. Fontaine (2003) quantified base-flow availability and the effects of streamflow diversions and return flows on base-flow availability in Honokōhau Stream, Maui. Gingerich (2005) assessed the effects of streamflow diversions on flow characteristics for perennial streams in northeast Maui. A subsequent study by Gingerich and Wolff (2005) examined the effects of streamflow diversions on instream temperatures and habitat availability for native stream fauna in the same study area, northeast Maui. Oki and others (2010b) assessed the effects of streamflow diversions on low flows, groundwater recharge, habitat for native stream fauna, and instream temperatures for streams in the eastern part of west Maui. Cheng (2014) characterized low-flow availability for the main streams in the western part of west Maui. A few of the previous low-flow studies have been conducted on the Islands of Kauaʻi, Oʻahu, and Hawaiʻi. Cheng and Wolff (2012) characterized availability and distribution of low flow in Anahola Stream, Kauaʻi, and assessed flow availability for agricultural use under a variety of potential instream-flow standards established for Anahola Stream. Oki and others (2006) characterized natural low-flow availability in Punaluʻu Stream, Oʻahu, and examined the effects of streamflow diversions on habitat availability for native stream fauna. Yeung and Fontaine (2007) described natural and regulated low flows for streams that were affected by the Waiāhole Ditch System in northeast Oʻahu. Fontaine (2012) quantified natural and regulated low-flow characteristics for streams in Waipiʻo Valley, Island of Hawaiʻi (herein referred to as Hawaiʻi), and evaluated implications of proposed streamflow diversion strategies on low flows. Strauch and others (2015) assessed the influence of changes in rainfall on streamflow on the northeastern part of Hawaiʻi. Documented efforts to understand low-flow characteristics on a statewide basis include, but are not limited to, studies by Yamanaga (1972) in analyzing peak-flow, mean-flow, and low-flow characteristics; Fontaine and others (1992) in estimating natural and regulated median streamflows; and Bassiouni and Oki (2013) in describing trends and shifts in streamflow and base flow.

Purpose and Scope

The purpose of this report is to present results of a study conducted in cooperation with the Commission on Water Resource Management (CWRM), Department of Hawaiian Home Lands (DHHL), and Office of Hawaiian Affairs (OHA) to aid in the proper planning and management of surface-water resources in the State of Hawaiʻi. The objectives of this study are to (1) provide estimates of selected natural low-flow duration discharges, between the 50 and 95 flow-duration percentiles, for streams with streamflow data at measurement sites and (2) identify streams in hydrologically under-represented geographic areas where additional streamflow data collection is needed. The scope of this investigation involves compiling and analyzing (1) historical and current streamflow data at continuous-record streamflow- and ditch-flow gaging stations and (2) discharge measurements at partial-record stations and miscellaneous discharge-measurement sites. Streams on the Islands of Kauaʻi, Oʻahu, Molokaʻi, Maui, and Hawaiʻi are included in the analyses.

Results of this study can be used to coordinate regional data collection and to effectively apply regional-scale regression analysis to characterize low flows on ungaged streams. Scientific information generated from this study can be used to assist with (1) determining equitable, reasonable, and beneficial instream and offstream uses of surface-water resources throughout the State of Hawaiʻi; (2) documenting water rights and uses associated with the perennial streams in the State of Hawaiʻi; (3) assessing the effects of existing uses on these streams; (4) determining quantitative and technically defensible instream-flow standards for these streams; and (5) developing effective adaptive-management strategies that help to protect and enhance water resources in the State.

StreamStats

As part of this study, low-flow duration discharges estimated at existing measurement sites are incorporated into StreamStats. StreamStats (Ries and others, 2005) is an integrated geographic information system (GIS) Web application that makes the process of computing streamflow statistics much faster, more accurate, and more consistent than previous manual methods. StreamStats incorporates (1) a map-based user interface for site selection; (2) a database (StreamStatsDB) that provides streamflow statistics and other information for stream-gaging stations; (3) a GIS program that determines boundaries of drainage basins, measures physical characteristics of the drainage basins, and solves regression equations to estimate streamflow statistics for the sites; and (4) a GIS database needed to display maps and determine the physical characteristics of the drainage basins. StreamStats has been implemented in the State of Hawai‘i for estimating the magnitude of peak discharges at ungaged sites in unregulated streams (Rosa and Oki, 2010) and is used in this study to facilitate the accessibility of selected low-flow duration discharges. Statistical models developed as part of this study will not be incorporated into StreamStats because the models are only applicable for estimating low-flow duration discharges at specific sites and the models will not be used to estimate duration discharges at other locations.

Description of the Study Area

The five main Hawaiian Islands—Kaua‘i, O‘ahu, Moloka‘i, Maui, and Hawai‘i (listed from northwest to southeast)—are situated between 19° and 22° north latitudes and between 155° and 160° west longitudes (fig. 1). The approximate sizes, in square miles, of each island are Kaua‘i, 552; O‘ahu, 597; Moloka‘i, 260; Maui, 727; and Hawai‘i, 4,028 (Juvik and Juvik, 1998). The highest altitude on Kaua‘i is 5,226 feet (ft) above sea level at Kawaikini, the summit of the island’s central shield volcano Mount Wai‘ale‘ale. O‘ahu has two parallel mountainous ridges; the western mountainous ridge—Wai‘anae Range—rises to the island’s highest altitude at 4,025 ft above sea level at Mount Ka‘ala, and O‘ahu’s eastern mountainous ridge—Ko‘olau Range—rises to an altitude of 3,100 ft above sea level at Kōnāhuanui. The highest peak on Moloka‘i is 4,960 ft above sea level at Kamakou, part of the East Moloka‘i volcano comprising the east side of the island. Maui consists of two major shield volcanoes, the older West Maui volcano (West Maui Mountain) that rises to an altitude of 5,788 ft at Pu‘u Kukui and the younger East Maui volcano (Haleakalā) that rises to an altitude of 10,025 ft at Pu‘u ‘Ula‘ula. Hawai‘i has the highest altitude in the State at 13,796 ft above sea level at Mauna Kea. Geologically, the islands are oldest in the northwest (about 4.5 to 5.5 million years) and youngest in the southeast (about 1 to 2 million years) (Langenheim and Clague, 1987).

Climate

The climate of the Hawaiian Islands is primarily governed by the North Pacific subtropical anticyclone, an area of high atmospheric pressure located northeast of the islands. The topography of the islands and the position of the anticyclone relative to the islands produce an atmosphere characterized by mild and uniform temperatures, cool and persistent trade winds, and seasonal and geographic variability in rainfall (Blumenstock and Price, 1967; Schroeder, 1993). These factors define the primary physiographic zones, windward and leeward, for each island (fig. 2). Windward areas are generally cooler and wetter, whereas leeward areas are hotter and drier. The dry season of May through September is dominated by persistent northeasterly trade winds that blow 80–95 percent of the time. During the rainy season of October to April, other migratory weather systems that affect the Hawaiian Islands cause a reduction in trade-wind frequency to 50–80 percent of the time.

Rainfall

The distribution of rainfall in the Hawaiian Islands is highly influenced by the topography of each island. Rainfall is primarily generated from the orographic ascent and cooling of moisture-laden trade winds along the windward slopes of the islands. The mountainous areas receive the highest rainfall between altitudes of 2,000 and 6,000 ft above sea level. Between these altitudes, rainfall can also occur in the form of fog drip, which is moisture from clouds that is intercepted by vegetation and eventually falls to the ground. Above an altitude of 6,000 ft, temperatures increase with altitude, and climate is influenced by the moist air below and dry air above. Microclimate occurring above this temperature-inversion zone, at altitudes above 8,000 ft, is distinguished by drier air and clearer skies. Drier air descends the leeward slopes of the mountains, resulting in decreased rainfall in those areas, which is a phenomenon known as the rain-shadow effect (Giambelluca and others, 2013). Heavy and intense rainfall can be caused by low-pressure systems from the northwest and those accompanied with southerly winds (Kona storms), cold fronts associated with mid-latitude cyclones, and tropical cyclones from the eastern Pacific Ocean (Giambelluca and Schroeder, 1998). Dry coastal areas of the Hawaiian Islands can receive most of their annual rainfall amounts from these storms.

Mean annual rainfall exceeds 340 inches near the summit of Mount Wai‘ale‘ale on Kaua‘i, 240 inches over the Ko‘olau Range and 65 inches over the Wai‘anae Range on O‘ahu, 140 inches near the eastern part Moloka‘i, 300 inches near Pu‘u Kukui of the West Maui Mountain and 340 inches over the northern slopes of Haleakalā on Maui, and 280 inches on the northeastern part of Hawai‘i (Giambelluca and others, 2013) (figs. 1 and 2). Most of the southwestern coastal areas on Kaua‘i, O‘ahu, Moloka‘i, and Maui receive less than 35 inches of rain annually. However, on Hawai‘i, some high

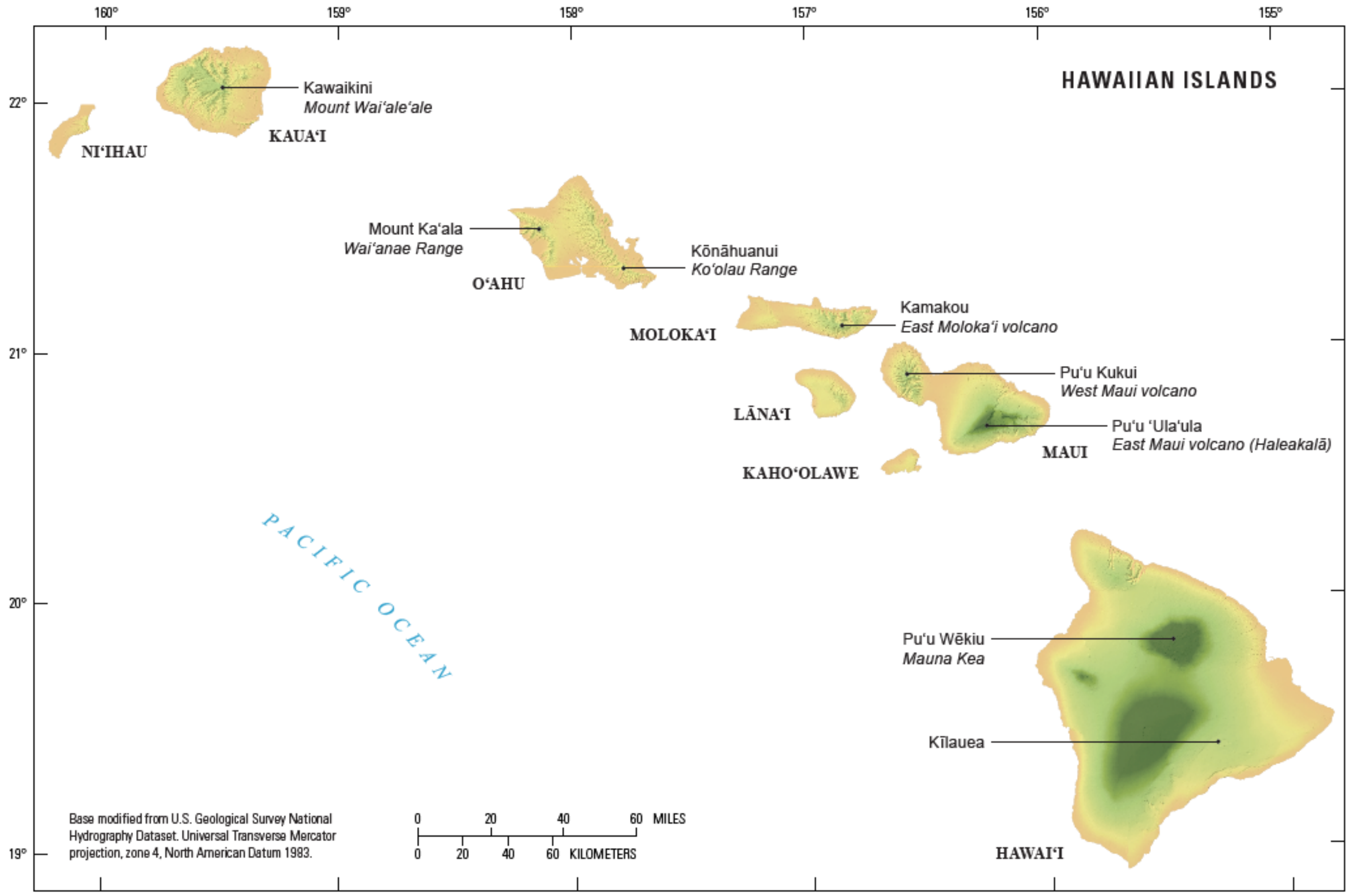


Figure 1. Map showing general topography of the main Hawaiian Islands.

altitude areas that reach above the temperature-inversion zone and the northwestern coastal areas receive less than 15 inches of rainfall annually. Rainfall in the mountainous areas is often characterized by steep spatial gradients with increasing altitude. For example, within a horizontal distance of 1 mile from Pu'u Kukui on Maui towards the ocean, mean annual rainfall can vary by more than 140 inches.

Streams

Streams play a critical role in shaping the unique landscape of the Hawaiian Islands and in supporting the lives of the islands' inhabitants. Throughout the evolution of the islands, the erosive power of the water the streams convey carved deep amphitheater-headed valleys in the geologically older islands and transported and deposited soils to various parts of the valleys and offshore waters. Hawaiian streams typically originate from mountainous interior areas, where rainfall is more abundant, and terminate at the coast. The density of stream channels increases with altitude; therefore, stream capture of rainwater is more prominent in the mountainous areas. Flow in streams is highly variable in space and time (as discussed in the following section "Hydrogeology") and is mainly controlled by rainfall and geology. Hawaiian streams are referred to as flashy because they respond quickly to rainfall during intense rainfall periods; streams can transition from base flows to flood flows in less than an hour. Streams often flow perennially in the windward areas where flow is supported by persistent rainfall and groundwater discharge. In leeward areas, streams may run dry part of the year when rainfall is low. Ephemeral streams are dry most of the time and flow only in response to heavy rainfall.

Streams in the Hawaiian Islands provide a vital source of water for mankind. Many streams are diverted for traditional, agricultural, domestic, and municipal uses. As discussed in section "Surface-Water Use," changes in surface-water use in the last century may place further stress on the resource.

Hydrogeology

The geological setting near a stream is an important control on the natural low-flow characteristics of the stream because low flows are largely derived from groundwater sources. Volcanic dikes that occur mainly near the caldera and within the rift zones of the volcano are low-permeability tabular sheets of rock that act much like a leaky dam to impede the movement of groundwater, consequently elevating the water level inland of the dikes. These dikes can impound groundwater levels to as high as 3,000 ft above sea level (Stearns and Macdonald, 1942, p. 195). Dike-impounded groundwater

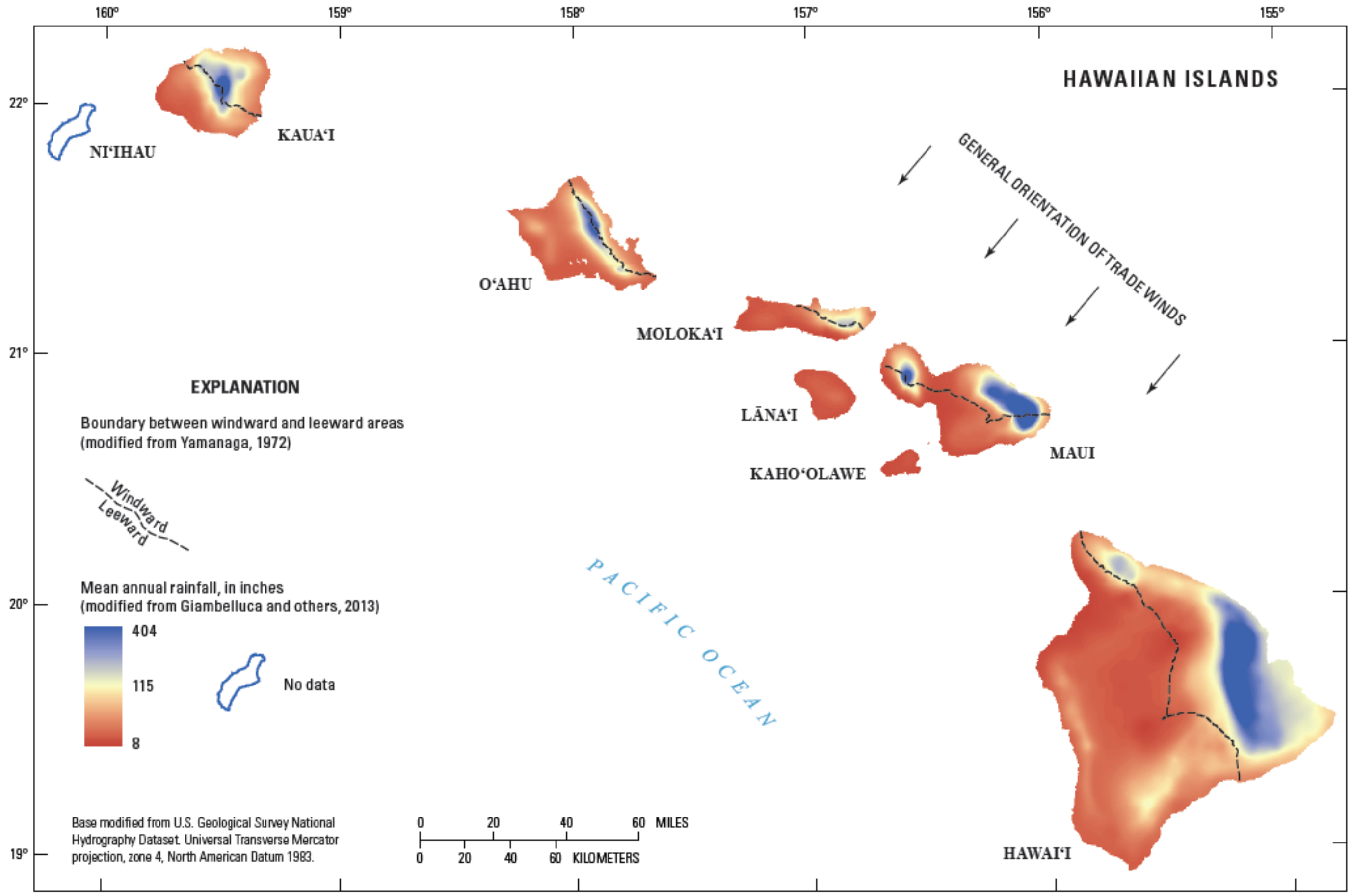


Figure 2. Map showing mean annual rainfall in the State of Hawai'i.

maintains perennial flow in some streams at the upper reaches where the streams intersect the dike-impounded water body. These stream reaches are referred to as gaining reaches because groundwater contributes to streamflow. In stream valleys where extensive erosion has exposed dike compartments, groundwater from these dike-impounded systems discharges directly to streams. Downstream from the area of dike-impounded groundwater, the water table is typically below the streambed. In many of the streams, the lower altitude reaches are referred to as losing reaches because streamflow discharges to the groundwater body. Some streams may lose all flow to the groundwater body before reaching the ocean during low-flow conditions.

Surface-Water Use

Surface-water use over the 20th century in the State of Hawai'i has generally shifted from providing irrigation water for large-scale agricultural operations to supporting diversified agriculture, urban developments, and other uses. During the latter part of the 1800s, numerous large-scale sugar plantations became established in the State of Hawai'i, and many plantations continued to operate during much of the 1900s. By 1920, over 50 sugar plantations were established, and more than 800 million gallons per day of water were regularly diverted from Hawaiian streams (Wilcox, 1996). Large engineered diversion systems were built to support the irrigation-water demand of the sugar plantations. The diversion systems typically transported water within and across drainage basins, altering drainage patterns within them. Stream reaches downstream of the diversion intakes commonly were dry because the diversions captured all of the dry-weather flow of streams. Sugarcane acreage in the State of Hawai'i decreased from 188,396 to 43,821 acres from 1984 to 2000 (State of Hawai'i, 2000). Consequently, large amounts of prime agricultural lands became available for diversified agriculture, urban developments, and other uses. As of May 2016, the last remaining large-scale plantation is the Hawaiian Commercial and Sugar Company's plantation, located in central Maui.

While plantation agriculture decreased, the State's population has continued to increase. The resident population in the State of Hawai'i increased almost sevenfold from 154,001 in 1900 to 1,211,537 in 2000 (State of Hawai'i, 2014). The 2013 projections indicate O'ahu, with a population of over 980,000, is the most populated of the main Hawaiian Islands and has over 5 times the population on Hawai'i; over 6 times the population on Moloka'i, Lāna'i, and Maui combined; and over 14 times the population on Kaua'i (State of Hawai'i, 2014). Increased urbanization may place further stress on limited water resources. To sustainably manage the State of Hawai'i's water resources and to accommodate the needs of a growing population, surface-water resources in an area must be quantified. An assessment of the surface-water resources in the State of Hawai‘i is among the goals for this study.

Data

The compilation of available streamflow data from USGS files and reports not stored in the NWIS database yielded over 6,000 additional streamflow measurements and over 1,000 additional measurement sites. Most of these streamflow data are instantaneous discharge measurements at partial-record stations and miscellaneous measurement sites. Although not all additional measurement sites had an adequate number of streamflow measurements to characterize low flows at the sites, these sites can be useful for low-flow analysis if additional measurements are made there. The compilation of data for this study has provided an updated and more complete representation of available USGS streamflow data in the State, and this is critical in identifying data needs for future research.

Trends in Streamflow Characteristics

Selection of a low-flow analysis period is constrained by the presence of trends found in streamflow and base flow for long-term continuous-record stations in the State of Hawai‘i (Bassiouni and Oki, 2013). Significant downward trends in base flow and low-streamflow characteristics were found during 1913–2008; however, the downward trends detected during 1943–2008 generally were not significant. The long-term downward trends detected during 1913–2008 are likely related to a significant downward shift in flow that occurred around 1943, which corresponded to a 22-percent decrease in median total flow and a 23-percent decrease in median base flow between periods 1913–1943 and 1943–2008. The shift in flow was greater during the drier months.

The detected downward trends and shift reflect region-wide changes in climatic and land-cover factors, such as changes in temperature and (or) trade winds, and reforestation. Decrease in base flow is most likely related to decreases in groundwater storage and recharge and therefore has important implications for low-flow analyses in the State. Because of the shift in flow that occurred around 1943, only streamflow data from water year 1944 and beyond are used in the analyses of this study.

Types of Streamflow-Measurement Sites

Four types of streamflow-measurement sites are described in this report: (1) a continuous-record streamflow-gaging station, which provides continuous record of discharge at a location in the stream; (2) a continuous-record ditch-flow gaging station, which provides continuous record of discharge at a location in the ditch; (3) a partial-record station, which commonly has 10 or more systematic streamflow measurements at a location in the stream; and (4) a miscellaneous site, which typically has less than 10 streamflow measurements that may not have been collected in a systematic manner as with a partial-record station. In this study, a long-term continuous-record streamflow-gaging station has 10 or more complete water years of record during 1944–2013, and a short-term continuous-record station has less than 10 complete water years of record during 1944–2013. A water year is a 12-month period that extends from October 1 to September 30 of the following year and is named according to the year during which the period ends. For example, the 2013 water year is the period October 1, 2012, to September 30, 2013. A seepage-run measurement site is an example of a miscellaneous site where measurements have been made for the purposes of determining seepage gains and losses along a stream.

Natural (Unregulated) Streamflow Data

Mainly natural (unregulated) streamflow data are used in the analysis of low flows in this study. Natural flow represents streamflow that is not affected by surface-water diversions, irrigation return flows, or groundwater pumping that has been known to reduce streamflow. Surface-water diversion information from Fontaine (1995), Wilcox (1996), and CWRM diversion records are used to determine whether a measurement site monitored regulated flow. Regulated-streamflow data are only used when concurrent ditch-flow records are available that are sufficient to allow reconstruction of natural streamflow at the measurement sites. Some measurement sites monitored regulated flow for part of the record. If concurrent ditch-flow records are not available at these sites, only the period of record with natural-streamflow data is used in the analysis. Information on measurement sites used in the analysis of low flows in this study is summarized in appendix 1, and the locations of the sites are illustrated in figures 3 to 7.

Measurement sites on streams affected by the Waiāhole Ditch System in the northeastern part of O‘ahu (between map areas B and C, fig. 4) are excluded from the analysis because of the complex flow diversions associated with the Waiāhole Ditch. These complex flow diversions include the following: (1) additional unknown amounts of surface water pumped into the diversion system during 1951–69, (2) flow releases from the ditch to the affected streams during 1951–69 and 1999–2004, (3) closure of surface-water diversion intakes during the mid-1980s, and (4) changes in the development tunnels for several of the affected streams (Yeung and Fontaine, 2007). On Moloka‘i, only data collected prior to November 1960 were used for stations 16405500 and 16408000 on Waikolu Stream because of the unknown effects associated with diversions by the Molokai Tunnel. In east Maui, many of the streams affected by the East Maui Irrigation diversion system are included in this study because available streamflow data are from measurements sites located upstream of diversion intakes.

Seepage Analyses

A seepage analysis is useful for characterizing the spatial distribution of flow along a stream. During a seepage analysis, same-day streamflow measurements are made at selected sites along the stream during stable-flow conditions to determine the magnitude of streamflow gains and losses and to document stream reaches that are either flowing or dry. Different reaches of the same stream can either gain water (groundwater discharge into stream) or lose water (stream discharge into groundwater body), depending on the position of the water table relative to the streambed. When coupled with low-flow duration discharge estimates at partial-record stations, results of a seepage analysis can provide natural water-availability information for stream reaches downstream from surface-water diversions and help determine whether the streams flow continuously from the mountain to the ocean.

Results of seepage analyses that have been conducted on Hawaiian streams are not examined as part of this study. However, an inventory of the available streamflow measurements made for a seepage analysis is provided in table 1 to identify under-represented areas that may need additional data collection to determine the surface water and groundwater interaction in these areas. Seepage analyses conducted in ditches are excluded from table 1.

Methods

Flow-Duration Characteristics

Low-flow characteristics, under natural streamflow conditions, are described using flow-duration discharges that are commonly displayed on a flow-duration curve. Flow-duration curves provide an informative method of displaying the complete range of flows in a stream and have been extensively used for hydrologic planning and design (Vogel and Fennessey, 1995), especially in the field of water-resource management. A flow-duration curve is a cumulative-frequency distribution that shows the percentage of time that specified discharges at a location in a stream are equaled or exceeded over a given period of record (commonly expressed in water years). Hence, the curve shows the relation between magnitude and frequency of streamflow.

Daily mean discharges are typically used to construct the flow-duration curves because they allow for more detailed examination of the duration characteristics of a stream (Smakhtin, 2001, p. 154) compared to flow-duration curves constructed from weekly, monthly, or annual streamflow data. A flow-duration curve is constructed by first ranking the daily mean discharges for a given period of record in descending order, then computing the exceedance probability of each discharge, and finally plotting the discharges against their exceedance probabilities (Ries and Friesz, 2000, p. 8). The exceedance probabilities are computed with the Weibull formula (Loaiciga, 1989, p. 82):

$$P_k = \frac{k}{(n+1)}, \; k = 1,2,3,\ldots n \qquad (1)$$

where P_k is the exceedance probability of a daily mean discharge with rank k,
k is the rank of a daily mean discharge, and
n is the total number of daily mean discharges for the given period of record.

The 50-percent flow-duration discharge, commonly referred to as median discharge or the Q_{50} discharge, is one of the most frequently computed flow-duration statistics. The median (Q_{50}) discharge is the flow that has been equaled or exceeded 50 percent of the time during a given period of record. Flow-duration discharges that describe low-flow conditions are generally considered to be those equal to or less than the Q_{50} discharge, and they are represented by the lower end of the flow-duration curve. The natural low-flow characteristics of this study are represented by flow-duration discharges between the Q_{50} and Q_{95} discharges in 5-percent increments—Q_{50}, Q_{55}, Q_{60}, Q_{65}, Q_{70}, Q_{75}, Q_{80}, Q_{85}, Q_{90}, and Q_{95} discharges.

Record-Augmentation Techniques

Record augmentation is used to determine selected low-flow duration discharges for long-term, short-term, and partial-record stations for a base period that is representative of long-term hydrologic conditions in the State of Hawai‘i. It is an index-streamgage approach in which streamflow information from a continuously gaged basin is transferred to a basin with limited streamflow data (Eng and others, 2011). This method involves correlating concurrent streamflow data points between the measurement site of interest and a nearby long-term continuous-record streamflow-gaging station (index station) to develop a statistical relation. A sample of about 10 concurrent streamflow data points is generally needed to apply record augmentation (USGS Office of Surface Water, in Technical Memorandum no. 86.02, December 16, 1985). The statistical model built from the correlation between the data points is used to compute flow-duration discharges at the measurement site of interest from corresponding flow-duration discharges at the index station for the base period. The base period is a common period during which all index stations used in the analysis are in operation with complete water years of streamflow data for computing various flow-duration discharges. See section “Index Stations and Selection of Base Period” for explanation on the selection of index stations for each island.

The Maintenance of Variance Extension Type 1 (MOVE.1) record-augmentation technique described by Hirsch (1982) and the graphical-correlation technique described by Searcy (1959, p.14) are used to extend streamflow records for this study. Both record-augmentation techniques assume that the statistical relation between concurrent

Table 1. Summary of seepage analyses conducted for streams on the Islands of Kauaʻi, Oʻahu, Molokaʻi, Maui, and Hawaiʻi.

Stream	Date of seepage analysis
	Kauaʻi
Anahola Stream	Apr., Sept. 2011
Hanalei River	Mar. 1979
Hanamāʻulu Stream	Sept. 1973; June, July 1995; Oct. 1996
Hanapēpē River	Oct. 1996
Hulēʻia Stream	Oct. 1996
Kapaʻa Stream	Sept. 1983
Kōkeʻe Stream	Aug.[1], Sept.[1] 1996
Makaleha Stream	June 1992, Dec. 1994
North Fork Wailua River	Sept. 1982
South Fork Wailua River	Mar. 1983
	Oʻahu
ʻĀhuimanu Stream	Apr. 1960
Hakipuʻu Stream	July 1959
Heʻeia Stream	June, Dec. 1963; Feb.[1] 1981
Hina Gulch	Mar., May 1965
Honouliuli Stream	Feb., May 2016
ʻIhiʻihi Gulch	Apr. 1965
Kaʻaʻawa Stream	Mar., May 1961
Kaʻalaea Stream	July 1959
Kahaluʻu Stream	July, Sept. 1959; Feb., Aug. 1961; Oct.[1], Nov.[1] 1980
Kahana Stream	Feb. 1958; Aug., Sept. 1960, Sept. 1961, Feb. 1962, Apr. 2009
Kaipapaʻu Stream	Sept. 1964
Kalalula Stream	Jan., Mar., May 1955; Mar., Aug. 1956; Jan., Aug. 1957
Kaluanui Stream	Sept. 1962; Sept. 1966, June 1982, June 1983
Kamananui Stream	Feb. 1964
Kamoʻoaliʻi Stream	June 1959
Kawa Stream	June 1959
Kīpapa Stream	Apr., June 1957
Kūmaipō Stream	June[1], Aug.[1], Sept.[1], Oct.[1] 1981; July, Nov.[1] 1985
Luluku Stream	Aug. 1960; Sept. 1961; Sept., Oct., Dec.[1] 1984

Table 1. Summary of seepage analyses conducted for streams on the Islands of Kaua‘i, O‘ahu, Moloka‘i, Maui, and Hawai‘i.—Continued

Stream	Date of seepage analysis
Ma‘akua Stream	Aug., Sept. 1962; Oct. 1964
Mākaha Stream	Jan.[1], Feb.[1], Mar.[1], Dec.[1] 1981; Sept.[1], Dec.[1] 1983; Jan.[1], Feb.[1], Mar.[1] 1984; Aug.[1], Sept.[1] 1994
Mālaekahana Stream	July 1963
Mānoa Stream	Jan. 1964; Sept. 1982; July[1], Nov.[1], Dec.[1] 1985; Jan.[1] 1986
Maunawili Stream	July 1959
North Hālawa Stream	July, Aug., Oct. 1989
Punalu‘u Stream	July, Aug. 1960; Feb. 1962; May, June 1981; Sept., Oct. 2004; June, Aug. 2005
Waiāhole Stream	July 1959; July 1960; Oct.[1] 1988; Jan.[1], Feb.[1], July[1], Aug.[1] 1989; Mar., June, Sept. 1995
Waianu Stream	July 1959; July 1960; Mar., Sept. 1961; Oct.[1] 1988; Jan.[1], Feb.[1], Aug.[1] 1989; May, June, Sept. 1995
Waihe‘e Stream	Feb., Mar. 1961
Waikāne Stream	July, Oct. 1959; Feb., May 1960; Mar. 1961; Oct.[1] 1988; Jan.[1], Feb.[1], July[1], Aug.[1] 1989; Sept. 2002; May 2003
Wailupe Gulch	Dec.[1] 1985; Jan.[1] 1986; Feb., July, Sept. 2008
Moloka‘i	
Honoulimalo‘o Stream	Jan., Mar., July, Dec. 1966; Jan. 1967
Kawela Gulch	June 2010
Pelekunu Stream	Jan., Mar., May, July, Sept., Nov. 1956; Jan., Mar., May 1957; Oct. 1971; Jan., June 1972
Waikolu Stream	Jan., Mar., July, Sept., Nov. 1956; Mar., May 1957; Aug. 1960; Jan., Mar., Apr., May, Aug. 1961; Feb., Mar., June, Oct. 1963; Aug., Oct. 1970
Wailau Stream	Jan., Mar., May, July, Sept. 1956
Maui	
Hāhālawe Gulch	May 1969
Hanawī Stream	Oct. 1974; July 1994, Feb. 1995
Honokahua Stream	May 2008
Honokōhau Stream	Aug. 1968; Sept. 1995; Aug., Oct. 1997
Honokōwai Stream	Mar. 1967, Apr. 2009, Jan. 2010, July 2012
Honolua Stream	May 2008, Dec. 2012
Honomanū Stream	June 1995
Ho‘olawa Stream	Feb. 1998
Kahakuloa Stream	Sept. 1975, Sept. 1982
Kahoma Stream	Jan. 2010, Aug. 2012
Kailua Stream	May 1969
Kanahā Stream	Jan. 2013
Kaua‘ula Stream	Sept. 2008

Table 1. Summary of seepage analyses conducted for streams on the Islands of Kauaʻi, Oʻahu, Molokaʻi, Maui, and Hawaiʻi.—Continued

Stream	Date of seepage analysis
Kaupakulua Gulch	Nov. 1997
Kuʻiaha Gulch	Oct. 1997
Launiopoko Stream	Feb. 1967
Makamakaʻole Stream	Aug. 2005
Makapipi Stream	Sept. 2010
Māliko Gulch	Sept. 1993
ʻOheʻo Gulch	May 1969; July 1978; June 1983
Olowalu Stream	Feb. 1967, Aug. 2008, Feb. 2013
Paleʻaʻahu Gulch	Jan. 2004
Pōkāhea Gulch	Sept. 2003
Ukumehame Gulch	May, Sept. 2006; Mar. 2013
Wahikuli Gulch	Jan. 2010
Waiehu Stream	Aug. 2005; July, Oct. 2006; Mar., Aug., Dec. 2007; Mar., July, Nov. 2008
Waiheʻe River	June 2004; Dec. 2006; Jan. 2007; Feb., Nov., Dec. 2008
Waikamoi Stream	Oct. 1994
Waikapū Stream	Mar., Oct. 2004; Aug., Sept., Dec. 2006; Apr., May, Aug., Nov. 2007; Apr. 2008; Jan., Mar. 2009
Wailuku River	Sept. 2004; July, Oct., Dec. 2006; Jan., Feb., Aug., Sept. 2007; Jan., Feb. 2008
Waiokamilo Stream	Aug. 1976, May 1999
West Wailuaiki Stream	Mar. 1984
Hawaiʻi	
Ālia Stream	Aug., Sept. 1982
Honoliʻi Stream	Nov. 1962
Kamaeʻe Stream	Mar. 1983
Kapehu Stream	Sept. 1983
Pololū Stream	Oct. 1996
Waikani Gulch	Sept. 2002; Aug. 2003
Wailuku River	Feb. 1948; Dec. 1963; Sept., Oct., Nov., Dec. 1965; Mar., Apr. 1966
Waimā Stream	July 1962; Sept. 1965
Waipiʻo Stream	Dec. 1962; Sept. 2000, Sept. 2001

[1]Seepage run conducted to evaluate the effect of pumping on streamflow

records at the index and measurement site is the same for any time period (Ries, 1993, p.21). Selecting the appropriate record-augmentation technique for estimating streamflow characteristics depends on the statistical relation between data points at the measurement site and the concurrent data points at the index station. The initial procedures used prior to the application of record-augmentation techniques are as follows:

1. Compute the 50-, 55-, 60-, 65-, 70-, 75-, 80-, 85-, 90-, and 95-percent flow-duration discharges for the base period at selected index stations for each island.

2. Plot the base-10 logarithms of data points at the measurement sites (long-term and short-term continuous-record stations, and partial-record stations) and concurrent data points at each selected index station to determine which index station provides the best statistical relation by comparing the correlation coefficients. Index stations with correlation coefficients greater than 0.70 are examined.

3. Assess for curvature in the plots developed in step 2. When little or no curvature is detected in a relation on a logarithmic plot, the MOVE.1 technique is used to estimate flow-duration discharges. When curvature is evident in the relation, the graphical-correlation technique is used.

MOVE.1 Technique

The statistical model developed with the MOVE.1 technique is based on the line of organic correlation regression method. Hirsch and Gilroy (1984) and Helsel and Hirsch (2002) showed that the line of organic correlation method is most appropriate in record augmentation compared with ordinary least squares and least normal squares regression methods. The general procedure for the MOVE.1 technique begins with the transformation of concurrent data points at the index station and measurement site to base-10 logarithms, and then computation of the means and standard deviations of the transformed values. The low-flow duration discharges for the base period at the index station are also computed and transformed to base-10 logarithms. Estimates of low-flow duration discharges at the measurement site are determined using the MOVE.1 formula (equation 2) and then converted to the original (nontransformed) units of measurement in cubic feet per second (ft^3/s).

$$Y_i = m_y + \frac{s_y}{s_x}(X_i - m_x) \quad (2)$$

where Y_i is the base-10 logarithm of the estimated low-flow duration discharge at the measurement site,
X_i is the base-10 logarithm of the computed low-flow duration discharge at the index station,
m_y is the mean of the base-10 logarithms of the data points at the measurement site,
m_x is the mean of the base-10 logarithms of the concurrent data points at the index station,
s_y is the standard deviation of the base-10 logarithms of the data points at the measurement site, and
s_x is the standard deviation of the base-10 logarithms of the concurrent data points at the index station.

Granato (2009) developed the Streamflow Record Extension Facilitator (SREF) program to automate the MOVE.1 technique; this program is used in this study to facilitate record augmentation. The MOVE.1 results are evaluated by analyzing several regression statistics computed by the SREF program. Those statistics include the correlation coefficient (r), coefficient of determination (r^2), residual error for each data point (e_i), the leverage of each data point (h_i), the mean square error (MSE), the root mean square error (RMSE), and a modified Nash-Sutcliff coefficient of efficiency (NSE). Definitions of the regression statistics and the equations used to compute these statistics are found in Granato (2009).

Graphical-Correlation Technique

In the graphical-correlation record-augmentation technique, a curve of relation is plotted through the data points at the measurement site and concurrent data points at the index station. The data points are plotted on an arithmetic scale when drawing the curve of relation to reduce curvature in the extreme low flows and to avoid long downward extrapolations of the data (Ries, 1993, p. 21). The selected low-flow duration discharges at the measurement site are determined by reading the discharges of the measurement site from the best fit curve of relation that correspond to the low-flow duration discharges at the index station.

Index Stations and Selection of Base Period

An index station is a continuous-record streamflow-gaging station that measures natural flow and has a sufficient length of record for estimating streamflow characteristics representative of long-term conditions. It is usually located along the same stream as the site of interest at which flow-duration discharge estimates are needed or in a nearby stream valley that is hydrologically similar to that of the site of interest. Searcy (1959, p. 14) defines hydrologic similarity between two drainage basins as having the same probability of rainfall, not necessarily the occurrence of concurrent rainfall. Proximity is a common criterion for selecting index stations, although remote index stations as far away as 50 miles have been used to estimate streamflow characteristics (Searcy, 1959, p. 14).

Selection of a base period for adjusting streamflow records is critical to obtaining comparable low-flow estimates among the measurement sites. Flow-duration discharges may vary when computed from different time periods because the distribution of streamflow is not constant with time (Ries, 1993, p. 18). When flow-duration discharges are estimated from multiple index stations with different time periods and (or) record lengths, the time-sampling errors are generally larger than those computed with similar record periods. Therefore, streamflow records at index stations are commonly limited to a common base period to minimize time-sampling errors and to ensure that differences in flow characteristics are associated with spatial differences in climate and drainage-basin characteristics (Searcy, 1959, p. 12).

The base period should also be of sufficient length that is representative of long-term streamflow conditions. Fontaine (1995) used data from five long-term continuous-record streamflow-gaging stations on the island of O‘ahu, each with more than 60 years of record, and demonstrated that estimates of streamflow characteristics are improved with increased record length (see figure 2 and table 9 in Fontaine, 1995). A minimum of 10 years of record is required to estimate certain streamflow characteristics such as the long-term median discharge. If the length of record is deemed inadequate for representing long-term conditions, record-augmentation techniques are commonly used to adjust the short-term record to a longer period (Ries, 1993, p. 18). The 30-year period 1984–2013 is selected as the base period for this study because (1) this period is representative of recent hydrologic conditions, (2) this period is of sufficient length to represent long-term hydrologic conditions, and (3) the greatest number of long-term continuous-record streamflow-gaging stations are operated within this 30-year period.

Continuous-record streamflow-gaging stations are selected as potential index stations for estimating low-flow characteristics if they monitored natural streamflow during the base period. Refer to appendix 1 for a listing of the index stations. Out of the 27 index stations, 8 are located on the leeward side of O‘ahu, 2 on the leeward side of Kaua‘i, and the remainder on the windward sides of the islands. Index stations on Maui are used in record augmentation for estimating low-flow duration discharges at measurement sites on Moloka‘i. Several of the index stations have missing data during the 1984–2013 base period—station 16208000 on South Fork Kaukonahua Stream, O‘ahu, had incomplete data during water years 2005, 2012, and 2013; station 16211600 on Mākaha Stream, O‘ahu, had missing data in water year 2006; station 16614000 on Waihe‘e River, Maui, had missing data in water year 1984; and station 16620000 on Honokōhau Stream, Maui, had incomplete data during water years 1989 and 1990. These stations had less than 10 percent missing data during 1984–2013, and the daily mean discharges for the periods of missing records are estimated using the MOVE.1 record-augmentation technique. The procedures for MOVE.1 technique in estimating missing daily mean discharges are similar to those for estimating low-flow duration discharges at the measurement sites described in an earlier section of the report, under subheading “MOVE.1 Technique.” Concurrent daily means from complete water years during 1984–2013 are used to develop the statistical model between the two stations. Instead of low-flow duration discharges, daily mean discharges at index stations without missing data are used to estimate concurrent daily mean discharges at index stations with missing data.

Analysis of Low Flows at Different Types of Measurement Sites

The data points used to develop the statistical models between the streamflow measurement site and the index station for computing low-flow duration discharges differ for different types of measurement sites, which include long-term continuous-record stations, short-term continuous-record stations, and partial-record stations. These measurement sites are defined in section “Types of Streamflow-Measurement Sites.”

Long-Term Continuous-Record Stations

For long-term continuous-record streamflow-gaging stations (with 10 or more complete years of record between water years 1944 and 2013) that do not have record for the complete base period and therefore are not selected as index stations, the procedures for estimating low-flow duration discharges are as follows:

1. Determine the complete water years of record that are concurrent between the long-term station and the index stations.

2. Compute the annual flow-duration discharges between the 50 and 95 flow-duration percentiles (annual Q_{50}, Q_{55}, Q_{60}, Q_{65}, Q_{70}, Q_{75}, Q_{80}, Q_{85}, Q_{90}, and Q_{95} discharges) for each complete water year of record at the long-term station and the index stations.

3. Using the data computed in the previous step, apply steps 2 and 3 of the initial procedures used prior to the application of record-augmentation techniques as described in section “Record-Augmentation Techniques.”

4. Develop a model, using the appropriate record-augmentation technique (MOVE.1 or graphical) determined in the previous step, between concurrent annual flow-duration discharges at the long-term station and the index station for each low-flow duration statistic. This will result in potentially 10 statistical models per long-term station.

5. Using the models developed in the previous step, compute flow-duration discharges at the long-term station from corresponding flow-duration discharges at the index station for the base period.

This method is similar to the one described in Searcy (1959, p. 14–15), except this method compares annual instead of period-of-record flow-duration discharges. In using annual statistics, flow-duration discharges are estimated with a model that is developed for the specific flow-duration statistic that is to be estimated. It also allows the use of linear models to estimate the lower flow-duration statistics (for example, Q_{90} and Q_{95}) at which curvature is oftentimes detected in a single relation developed from period-of-record statistics or daily mean discharges.

To evaluate the use of this method, an exploratory analysis was performed on data from three measurement sites that cover the range of flow characteristics: station 16103000 on Hanalei River, Kaua‘i, station 16229300 on Kalihi Stream, O‘ahu, and station 16515000 on Waiohue Gulch, Maui. This method was applied to the data at the three measurement sites to develop statistical models for each low-flow duration statistic. Flow-duration discharges at the index station for the entire period concurrent with the measurement sites were used as input to the models to estimate flow-duration discharges for the entire period at the measurement sites. These estimates were then compared to the actual flow-duration discharges computed from the concurrent period of record at the measurement sites. The differences between the modeled and actual flow-duration discharges at the measurement sites were under 5 percent, and a majority were under 2 percent. Therefore, the use of models developed from annual statistics to estimate base-period statistics is considered reasonable.

Short-Term Continuous-Record Stations

For short-term continuous-record streamflow-gaging stations (with less than 10 complete years of record between water years 1944 and 2013), the procedures for estimating low-flow duration discharges are as follows:

1. Extract daily mean discharges during stable streamflow recessions from the short-term station. A streamflow recession is the period when flows return to low-flow conditions following a period of direct runoff. On a streamflow hydrograph, the recession period is represented by the falling limb of the curve following peak discharge. A stable recession refers to the relatively flat part of the recession curve, where flow variability is minimal over time. Stable recession daily mean discharges are selected using the following criteria: (1) daily mean discharges are from streamflow recessions that continue for 4 or more consecutive days; (2) daily mean discharge on a particular day during a streamflow recession is less than or equal to the daily mean discharge on the previous day; and (3) during each qualified streamflow recession, difference between the selected daily mean discharge and the daily mean discharge from the previous day is 10 percent or less.

2. Extract stable recession daily mean discharges from the index stations using the same criteria described in the previous step, and select the stable recession daily mean discharges that are less than the base-period Q_{40} discharge (rather than the Q_{50} discharge). This allows for the statistical relation to be defined for the full range of low-flow statistics to be estimated, particularly for cases in which stable recession daily mean discharges at Q_{50} conditions are not available at the index station but stable recession daily mean discharges at higher flow conditions are available.

3. Determine all of the stable recession daily mean discharges that are concurrent between the short-term station and the index stations. Concurrent stable recession daily mean discharges from the short-term and index stations must be from at least 10 independent recessions. All of the concurrent daily mean discharges from each stable recession will be used in the following steps.

4. Using the data determined in the previous step, apply steps 2 and 3 of the initial procedures used prior to the application of record-augmentation techniques as described in section “Record-Augmentation Techniques.”

5. Develop a model, using the appropriate record-augmentation technique (MOVE.1 or graphical) determined in the previous step, between concurrent stable recession daily means at the short-term station and the index station.

6. Using the model developed in the previous step, compute flow-duration discharges at the short-term station from corresponding flow-duration discharges at the index station for the base period.

The method used for analyzing low flows at the short-term station uses only one statistical model to estimate all the low-flow duration discharges, whereas in the long-term station method, a unique statistical model is developed to estimate each low-flow duration discharge.

This short-term method is a modification of the traditional record-augmentation method for partial-record stations in which about 10 concurrent streamflow data points, each from independent recessions, are generally needed. To evaluate the use of the short-term method, an exploratory analysis was performed on data from three measurement sites that cover a range of flow characteristics: station 16228900 on Kalihi Stream, O‘ahu; station 16241600 on Mānoa Stream, O‘ahu; and station 16524000 on Honomanū Stream, Maui. The traditional method was applied to the data at the three measurement sites to develop the statistical models by randomly selecting only one set of concurrent daily mean discharges from the short-term and index stations from each stable recession to be used in the low-flow analysis (instead of using all daily mean discharges from each stable recession as stated in step 3 of the short-term method procedures). Using one set of concurrent daily mean discharges from the short-term and index stations mirrors the traditional record-augmentation method. Low-flow duration discharges were estimated with this traditional method and compared with the low-flow duration discharges estimated with the short-term method. The differences in flow-duration estimates between the traditional method and the short-term method at the measurement sites were generally less than 10 percent. Therefore, the use of models developed from the short-term method to estimate base-period statistics is considered reasonable.

Partial-Record Stations

For partial-record stations with 10 or more instantaneous streamflow measurements taken between water years 1944 and 2013, the procedures for estimating low-flow duration discharges are as follows:

1. Determine daily mean discharges at the index stations that are concurrent with the streamflow measurements at the partial-record stations, and select the daily mean discharges at the index stations that are less than the Q_{40} discharge. This allows for the statistical relation to be defined for the full range of low-flow statistics to be estimated, particularly for cases in which daily mean discharges at Q_{50} conditions are not available at the index station but daily mean discharges at higher flow conditions are available.

2. Using the data determined in the previous step, apply steps 2 and 3 of the initial procedures used prior to the application of record-augmentation techniques as described in section “Record-Augmentation Techniques.”

3. Develop a model, using the appropriate record-augmentation technique (MOVE.1 or graphical) determined in the previous step, between streamflow measurements at the partial-record station and concurrent daily mean discharges at the index station.

4. Using the model developed in the previous step, compute flow-duration discharges at the partial-record station from corresponding flow-duration discharges at the index station for the base period.

This method is similar to the method used for analyzing low flows at the short-term station in that only one statistical model is used to estimate all the low-flow duration discharges.

Sites on Ephemeral Stream Reaches

Ephemeral stream reaches flow only in response to intense rainfall and are identified in Fontaine (1995) and by analyzing the streamflow record for absence of flow. For this study, a stream reach is ephemeral if at least 50 percent of the daily mean discharges available at the measurement site indicate zero flow. Flow-duration discharges between the 50 and 95 flow-duration percentiles for the entire period of record are computed for the measurement site, and the flow-duration discharges for the concurrent period are computed for the index stations. The concurrent flow-duration discharges at the measurement site and the index station are plotted on an arithmetic scale, and a smooth curve is drawn to connect the data points (Searcy, 1959, p. 14–15). The graphical-correlation augmentation technique is used to estimate flow-duration discharges at the measurement site that are applicable to the base period for each index station. The final flow-duration discharge estimate at the measurement site is the average of all the estimates derived from the different index stations. This method is only applied at continuous-record streamflow-gaging stations.

Evaluation of Statistical and Graphical Models

Statistical Models

The correlation coefficient measures the strength of the linear relation between concurrent data points at the index station and measurement site (Vogel and Stedinger, 1985; Helsel and Hirsch, 2002). It is used to evaluate which index stations are considered for record augmentation at the measurement sites. When data points at a measurement site are highly correlated with data points at multiple index stations, the NSE value is used to select the best statistical model to use for estimating low-flow duration discharges at the measurement site. With values ranging from minus infinity to 1, the NSE determines the accuracy to which the statistical model predicts low-flow duration discharges at the measurements sites from the low-flow duration discharges at the index station. An NSE value of zero indicates that the mean of the data points at the measurement site is as accurate for predicting flow-duration discharges as the regression model. A positive NSE value indicates that the regression model is relatively accurate for predicting flow-duration discharges compared to using the mean of the data points. A negative NSE value occurs when the mean of data points at the measurement site is a better predictor than the regression model. The NSE is recommended for use by the American Society of Civil Engineers (1993), Moriasi and others (2007), and Sevat and Dezetter (1991) because it is more sensitive to additive and proportional differences between model predictions and measured data than the correlation coefficient and coefficient of determination. Legates and McCabe (1999) suggested using a modified NSE that is less sensitive to extreme values, and this modified NSE is used in the SREF program to evaluate MOVE.1 results for this study.

Moriasi and others (2007) developed a rating system based on the NSE for evaluating performance of watershed models. The ranges of NSE values for each rating category were determined from the model calibration and validation results of various studies. A modified performance rating is implemented in this study for evaluating the MOVE.1 results (table 2). This modified rating has an additional ranking category referred to as poor, and the results with a ranking are considered acceptable based on Motovilov and others (1999). For this study, for cases in which the data points at a measurement site correlate with the data points at multiple index stations with correlation coefficients of 0.70 and higher, the low-flow duration-discharge estimates from the statistical model with the highest NSE value are selected as the best estimates at the measurement site. However, an estimate with an NSE value less than 0.36 is not presented in the results.

Graphical Models

The graphical models are evaluated statistically based on the correlation coefficient and qualitatively by assessing how closely the curve of relation fits the data points. The curve of relation must be drawn to reduce curvature in the extreme low flows and to avoid long downward extrapolations of the data. It must also be drawn to minimize the spread of data relative to the curve.

Table 2. Performance rating for the Nash-Sutcliff coefficient of efficiency (NSE) modified from Moriasi and others (2007).

[>, greater than; ≥, greater than or equal to; ≤, less than or equal to]

NSE value	Rating
>0.65 and ≤1.00	Good
>0.50 and ≤0.65	Satisfactory
≥0.36 and ≤0.50	Poor

Results and Discussion

Natural Low-Flow Characteristics

Natural low-flow characteristics for the 1984–2013 base period are quantified for 107 measurement sites and 27 index stations (tables 3–7). About 93 percent of the statistical models have correlation coefficients 0.80 and higher and about 58 percent of them 0.90 and higher. For duration discharges estimated with the MOVE.1 technique, about 86 percent of the MOVE.1 models have NSE values greater than 0.50 and about 40 percent of them greater than 0.65, corresponding to satisfactory and good ratings. Duration discharges estimated from MOVE.1 models with NSE values below 0.36 are not presented in the study. A few of the duration discharges estimated from MOVE.1 models that have correlation coefficients between 0.74 and 0.80 are presented because the NSE values are 0.36 or higher. About 22 percent of the graphical models have correlation coefficients between 0.75 and 0.80, and the associated duration-discharge estimates are presented because the curves of relation are clearly and reasonably defined with the available data.

Kaua‘i

Low flows are characterized for 6 index stations and 13 measurement sites on Kaua‘i, and a majority of the estimates are satisfactory based on the regression statistics (table 3, fig. 3, appendix 2). Excluding one measurement site—station 16130000 on Nahomalu Stream—where flow is ephemeral, the Q_{50} discharges range from 0.71 to 137 ft^3/s, and the Q_{95} discharges range from 0.34 to 73 ft^3/s. The highest flow estimates are at station 16103000 on Hanalei River. Four partial-record stations have nine data points concurrent with data from the index stations available for record augmentation, and despite the limited data, the MOVE.1 models for these stations yielded satisfactory low-flow duration-discharge estimates with NSE values between 0.51 and 0.70. Data at two short-term stations (16115000 and 16116000) with 9 complete water years of data are analyzed using two methods, the method described for long-term stations (comparing annual flow-duration statistics) and the method described for short-term stations (comparing stable recession daily means). The MOVE.1 models developed from the long-term station method with nine annual flow-duration statistics concurrent with the index station yielded higher overall NSE values than the MOVE.1 model developed from the short-term station method. Therefore, low-flow duration statistics estimated with the MOVE.1 models developed from the long-term method are selected. Station 16130000 on Nahomalu Stream is identified to be ephemeral (Fontaine, 1995) and is dry at least 50 percent of the time.

Measurements at partial-record station 220754159371901 on a tributary of Kawaikōī Stream did not correlate well with concurrent daily mean discharges at the index stations; however, index station 16010000 on the main stream channel of Kawaikōī Stream is available to provide at least some definition of low-flow characteristics on that stream. Streamflow data at stations 16029500 on Mokihana Stream, 16117000 on Kalalau Stream, and two partial-record stations on the same stream did not correlate well with concurrent discharges at the index stations on Kaua‘i; therefore, low-flow estimates for these stations are not presented in this study.

O‘ahu

On O‘ahu, natural low flows are characterized for 11 index stations and 31 measurement sites, and a majority of the estimates are satisfactory based on the regression statistics (table 4, fig. 4, appendix 2). Excluding the measurement sites where flow is ephemeral, the Q_{50} discharges range from 0.23 to 18 ft^3/s, and the Q_{95} discharges range from 0 to 11 ft^3/s. Three measurement sites—stations 16242500, 16256000, and 213726158004901—have less than 10 concurrent data points with the index stations available for record augmentation. Despite the limited data, the statistical models for these stations yielded satisfactory low-flow duration-discharge estimates with correlation coefficients between 0.88 and 0.98. Records at the measurement sites on Makaleha (16211300), North Hālawa (16226400), Moanalua (16227500, 16228000, and 16228200), Kanahā (16237600), Kaiwiko‘ele (16329000), and north fork of ‘Elehāhā (213801158011201) Streams indicate that these sites are dry at least 50 percent of the time.

Streamflow data at several measurement sites, mostly short-term and partial-record stations on tributary streams, did not correlate well with concurrent discharges at the available index stations on the island; however, flow-duration discharge estimates are available at long-term stations on the main stream channel of the tributaries to provide at least some definition of low-flow characteristics on those main streams. These streams with available long-term stations where low flows are characterized include Waiawa (16216000), North Hālawa (16226200), and Kaluanui (16304200) Streams; Waihe‘e Stream and tributaries (16284000); and Punalu‘u Stream and tributaries (16301050). The two partial-record stations—16261000 and 16263000—on Kahanaiki Stream did not have an adequate number of streamflow measurements that span the Q_{50}–Q_{95} range of flows at the available index stations; therefore, flow-duration discharges could not be estimated for those stations. Low flows at many of the leeward partial-record stations (see map area A, fig. 4) with streamflow data in 1947–57 could not be characterized because these stations have concurrent measurements with only 4 out of the 11 index stations that operated prior to 1957. No adequate correlations could be developed for any of these four index stations.

Moloka‘i

Low flows are characterized for 1 index station and 10 measurement sites on Moloka‘i, and a majority of the estimates are satisfactory based on the regression statistics of 43 models that are developed (table 5, fig. 5, appendix 2). Excluding the measurement sites where flow is ephemeral, the Q_{50} discharges range from 0.03 to 17 ft^3/s, and the Q_{95} discharges range from 0.02 to 6.2 ft^3/s. Long-term station 16403000 on Waiakeakua Stream has statistical models that are developed excluding one data point (appendix 2) that deviated from the relations established by the remainder of the data points. Although estimates at station 16416000 on Puna‘ula Gulch are based on eight concurrent data points, the estimates are

Table 3. Selected natural low-flow duration estimates at continuous-record streamflow-gaging stations and partial-record stations on the Island of Kaua'i for base period 1984–2013.

[ft^3/s, cubic feet per second; ID, identifier; --, no estimates; >, greater than; <, less than; ≥, greater than or equal to; ≤, less than or equal to; font color of discharge value reflects the accuracy of the discharge estimate as represented by a performance rating for the Nash-Sutcliff coefficient of efficiency (NSE, values listed in appendix 2) modified from Moriasi and others (2007) and this performance rating does not apply to discharge estimated using the graphical-correlation record-augmentation method; discharge in blue indicates an estimate rated as good with an NSE >0.65 and ≤1; discharge in black indicates an estimate rated as satisfactory with an NSE >0.50 and ≤0.65; discharge in red indicates an estimate rated as poor with an NSE ≥0.36 and ≤0.50; estimate with an NSE <0.36 is not presented and is indicated with --; discharge estimated using the graphical-correlation record-augmentation method is italicized]

Station ID	Discharge, in ft^3/s, that was equaled or exceeded for the selected percentages of time (from 50 to 95)									
	50	55	60	65	70	75	80	85	90	95
Index stations										
16010000	11	9.5	8.4	7.5	6.7	6.0	5.2	4.6	3.9	3.1
16019000	6.0	5.2	4.7	4.2	3.7	3.4	3.0	2.8	2.5	2.2
16068000	27	25	24	22	21	19	18	16	15	13
16071500	1.3	1.2	1.1	0.98	0.89	0.81	0.74	0.66	0.58	0.49
16097500	6.8	6.4	6.1	5.8	5.5	5.2	4.9	4.6	4.3	3.9
16108000	76	70	66	63	59	56	53	50	47	43
Stations for which record augmentation was used to estimate duration discharges										
16013000	2.6	2.2	2.0	1.7	1.5	--	--	0.93	--	--
16017000	7.4	6.3	5.6	5.1	4.3	3.9	3.3	2.9	2.6	2.2
[1]16063000	43	39	38	35	34	30	29	26	25	*22*
16081500	0.71	0.67	0.63	0.58	0.54	0.50	0.47	0.43	0.39	0.34
16085500	3.8	3.4	3.1	2.8	2.5	2.3	2.0	1.8	1.6	1.3
16088300	6.0	5.4	5.0	4.6	4.2	3.9	3.5	3.2	2.9	2.5
16088500	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2
[2]16097000	*7.1*	*6.7*	*6.5*	*6.0*	*5.7*	*5.4*	*5.2*	*4.7*	*4.6*	*4.3*
[3]16101003	63	58	56	52	51	46	45	41	40	37
16103000	137	127	119	113	105	98	92	88	81	73
16115000	7.4	6.8	6.2	5.9	5.6	5.4	5.3	4.9	4.5	4.1
16116000	1.5	1.4	1.2	1.1	0.97	0.89	0.80	0.73	0.65	0.56
16130000	Dry at least 50 percent of the time									

[1]Natural-flow record based on combined concurrent records at stations 16061000, 16062000, and 16063000, and subtracting concurrent flow record at station 16100000.

[2]Natural-flow record based on combined concurrent records at stations 16095900 and 16097000, and the combined record consisted of less than 10 complete water years".

[3]Natural-flow record based on combined concurrent records at stations 16100000 and 16101000.

acceptable because the graphical fit is very well defined with correlation coefficient of 0.92. Stations 16411400 on Kaka'ako Gulch and 16414000 on Kaunakakai Gulch are ephemeral (Fontaine, 1995), and they are dry at least 50 percent of the time. Streamflow data at measurement sites on the tributaries of Pelekunu Stream—Kapuhi, Kawailena, Kawainui, and Pilipililau Streams (see map inset, fig. 5)—did not correlate well with concurrent discharges at the index stations. However, flow-duration estimates at station 16404000 on Pelekunu Stream reflect the combined flow contributions from these tributaries.

Maui

Maui has the greatest number of measurement sites at which flow-duration discharges are estimated. Low flows are characterized for 7 index stations and 41 measurement sites, and a majority of the estimates are rated satisfactory or good based on the regression statistics (table 6, fig. 6, appendix 2). Excluding the measurement sites where flow is ephemeral, the Q_{50} discharges range from 0.12 to 50 ft^3/s, and the Q_{95} discharges range from 0 to 32 ft^3/s. Flow-duration discharge estimates at partial-record stations located in the western part

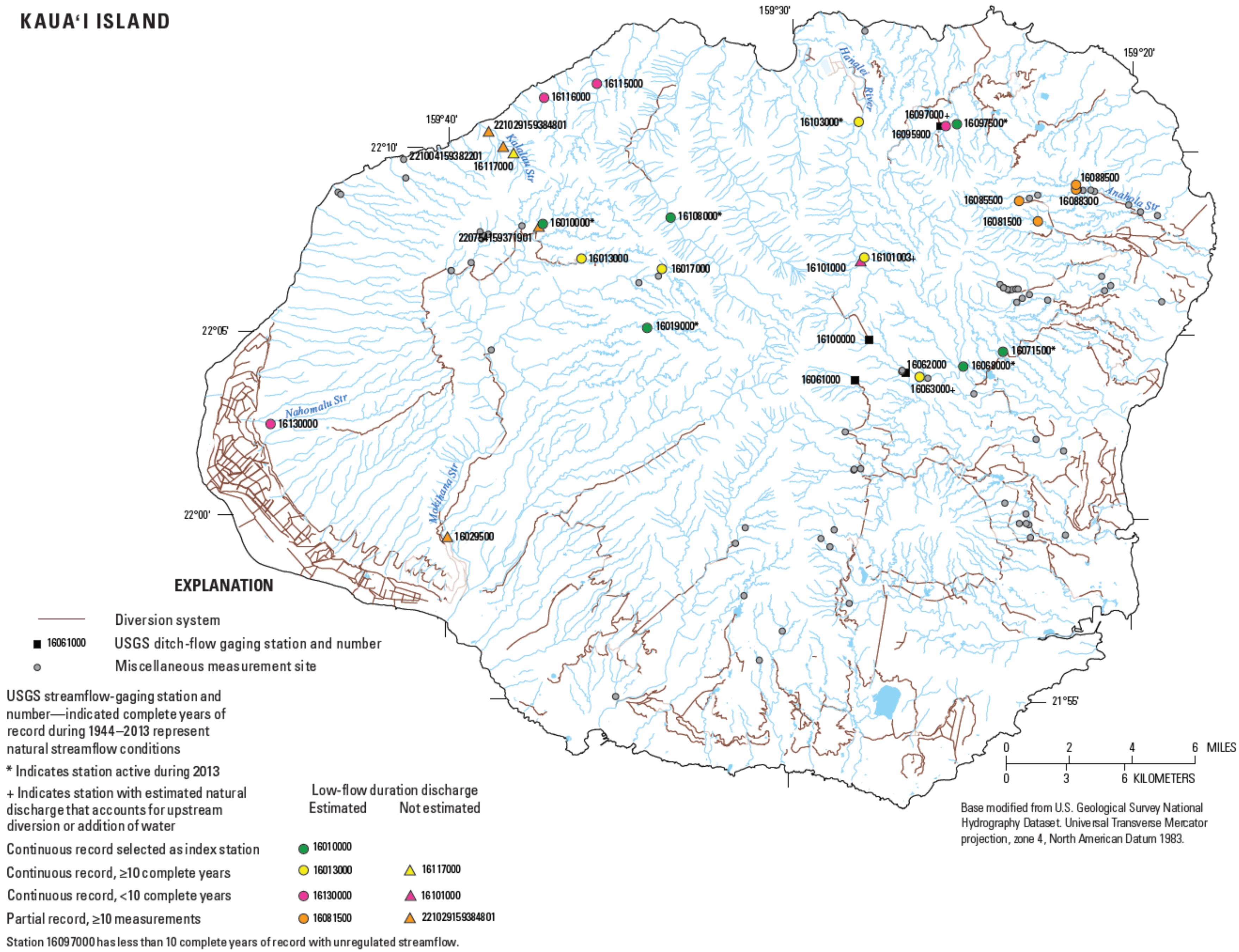


Figure 3. Map showing U.S. Geological Survey (USGS) continuous-record and partial-record stations with streamflow data between water years 1944 and 2013, Island of Kaua‘i.

Table 4. Selected natural low-flow duration estimates at continuous-record streamflow-gaging stations and partial-record stations on the Island of O‘ahu for base period 1984–2013.

[ft^3/s, cubic feet per second; ID, identifier; --, no estimates; >, greater than; <, less than; ≥, greater than or equal to; ≤, less than or equal to; font color of discharge value reflects the accuracy of the discharge estimate as represented by a performance rating for the Nash-Sutcliff coefficient of efficiency (NSE, values listed in appendix 2) modified from Moriasi and others (2007) and this performance rating does not apply to discharge estimated using the graphical-correlation record-augmentation method; discharge in blue indicates an estimate rated as good with an NSE >0.65 and ≤1; discharge in black indicates an estimate rated as satisfactory with an NSE >0.50 and ≤0.65; discharge in red indicates an estimate rated as poor with an NSE ≥0.36 and ≤0.50; estimate with an NSE <0.36 is not presented and is indicated with --; discharge estimated using the graphical-correlation record-augmentation method is italicized]

Station ID	Discharge, in ft^3/s, that was equaled or exceeded for the selected percentages of time (from 50 to 95)									
	50	55	60	65	70	75	80	85	90	95
Index stations										
16200000	6.3	5.5	4.9	4.3	3.7	3.2	2.7	2.2	1.7	1.0
16208000	8.2	7.1	6.2	5.4	4.6	3.9	3.2	2.5	1.8	0.95
16211600	0.23	0.15	0.08	0.03	0	0	0	0	0	0
16226200	0.26	0.16	0.10	0.06	0.04	0.02	0.02	0.01	0	0
16229000	2.4	2.1	1.9	1.7	1.5	1.3	1.2	1.0	0.88	0.70
16240500	3.1	2.9	2.7	2.6	2.4	2.2	2.1	1.9	1.7	1.5
16275000	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2
16301050	18	18	17	16	16	15	14	14	13	11
16304200	1.3	1.1	0.95	0.82	0.69	0.56	0.45	0.34	0.24	0.13
16330000	3.4	2.9	2.4	2.0	1.6	1.2	0.87	0.53	0.20	0.04
16345000	4.2	3.7	3.1	2.7	2.3	1.9	1.6	1.3	0.93	0.54
Stations for which record augmentation was used to estimate duration discharges										
[1]16201000	4.0	3.6	3.2	2.9	2.6	2.3	2.0	1.6	1.3	0.84
16206000	5.0	4.2	3.6	3.1	2.6	2.2	1.8	1.4	1.0	0.51
[2]16211003	*2.8*	2.5	2.2	1.9	1.6	1.3	1.1	0.95	0.65	--
16211300				Dry at least 50 percent of the time						
16212800	2.8	2.2	1.8	1.5	1.2	0.84	0.81	*0.60*	*0.40*	*0.20*
16216000	*2.7*	*2.4*	*2.3*	*2.0*	*1.8*	*1.7*	*1.6*	*1.6*	--	--
16226000	0.25	0.15	0.10	0.06	0.04	0.02	0.02	0	--	--
16226400				Dry at least 50 percent of the time						
16227500				Dry at least 50 percent of the time						
16228000				Dry at least 50 percent of the time						
16228200				Dry at least 50 percent of the time						
16228900	0.70	0.64	0.57	0.51	0.46	0.40	0.35	0.30	0.24	0.16
16229300	3.6	3.2	2.9	2.6	2.3	2.1	1.9	1.6	1.4	1.1
16237600				Dry at least 50 percent of the time						
16238500	1.9	1.6	1.4	1.2	1.1	0.90	0.74	0.59	0.44	0.24
16241600	5.4	5.1	4.9	4.6	4.4	4.1	3.8	3.5	3.2	2.6
16242500	5.8	5.0	4.7	4.4	4.0	3.8	3.4	3.2	2.9	2.4
16244000	0.70	0.62	0.56	0.52	0.49	0.45	0.42	--	0.26	--
16256000	0.98	0.77	0.60	0.53	0.40	0.29	0.25	0.18	0.12	0.077
16265600	*0.65*	*0.52*	*0.47*	*0.40*	*0.40*	*0.34*	*0.33*	*0.22*	*0.21*	*0.14*
16278000	*0.52*	*0.42*	*0.40*	*0.40*	*0.38*	*0.36*	*0.35*	--	--	--
16284000	*7.9*	*7.8*	7.7	7.6	7.3	7.0	6.9	6.7	6.3	5.9
16308990	*0.25*	*0.23*	*0.2*	*0.17*	*0.15*	*0.11*	*0.07*	*0.05*	*0.02*	*0*
16325000	2.9	2.6	2.3	2.0	1.7	1.5	1.2	0.95	*0.60*	*0.21*
16329000				Dry at least 50 percent of the time						
212639157515901	*1.8*	*1.7*	*1.7*	*1.6*	*1.6*	*1.6*	*1.5*	*1.5*	*1.5*	*1.5*

Table 4. Selected natural low-flow duration estimates at continuous-record streamflow-gaging stations and partial-record stations on the Island of O‘ahu for base period 1984–2013.—Continued

Station ID	Discharge, in ft³/s, that was equaled or exceeded for the selected percentages of time (from 50 to 95)									
	50	55	60	65	70	75	80	85	90	95
212644157514801	*4.4*	*4.0*	*3.8*	*3.8*	*3.7*	*3.6*	*3.3*	*2.6*	--	--
213439157545001	1.1	0.99	0.88	0.78	0.67	0.56	0.47	0.37	0.28	0.17
213503157543201	1.3	1.1	0.94	0.82	0.70	0.57	0.46	0.35	0.25	0.14
213726158004901	*1.0*	*0.94*	*0.72*	*0.50*	*0.31*	*0.19*	*0.12*	*0.10*	*0.09*	--
213801158011201	Dry at least 50 percent of the time									

[1]Station operated as a continuous-record and partial-record station; continuous-record data were used in the low-flow analysis of this study.

[2]Natural-flow record based on combined concurrent records at stations 16210900 and 16211000.

of west Maui are taken from Cheng (2014) because the base period selected for that study is the same as for this study.

On east Maui, streamflow data at stations on Kukui‘ula (16500800) and Hāhālawe (16502000) Gulches did not correlate well with any index stations, most likely owing to the lack of available index stations on the leeward side of the island. Although data at station 16501000 on Palikea Stream did not correlate well with the index stations on the island, its flow contribution is reflected in the flow-duration discharge estimates at station 16501200 on ‘Ohe‘o Gulch. On west Maui, data at partial-record stations on Waikapū (205121156321501), North Waiehu (205434156315701), and Huluhulupueo (205627156323401) Streams did not correlate well with concurrent discharges at any index stations on the island.

Hawai‘i

Low-flow characteristics are characterized for 2 index stations and 12 measurement sites on Hawai‘i. For 7 of the measurement sites, a majority of the estimates are satisfactory based on regression statistics from 34 models that are developed (table 7, fig. 7, appendix 2). Excluding the measurement sites where flow is ephemeral, the Q_{50} discharges range from 1.1 to 76 ft³/s, and the Q_{95} discharges range from 0.30 to 36 ft³/s. Models for long-term station 16720300 on Kawaiki Stream are developed, excluding two data points (appendix 2) that deviated from the relations established by the remainder of the data points. Streams at five of the measurement sites are dry at least 50 percent of the time—Wailuku River (16701700), Wai‘aha Stream (16759600), and Hīlea (16765000), Nīnole (16767000), and Pā‘au‘au (16770500) Gulches.

Hawai‘i has the greatest number of measurement sites at which low flows could not be characterized, most likely owing to the lack of index stations on the island. Data at measurement sites on Ālia (16717600), Waimā (200351155372801), and Waihīlau (200657155395301) Streams, and streams in the area west of Waihīlau Stream, did not correlate well with the concurrent discharges at index stations. Analysis of stations 16701750 and 16701800 on Wailuku River did not correlate well with the index stations; however, long-term station 16704000 on Wailuku River is available to provide at least some definition of low-flow characteristics on that stream. Data at short-term station 16700600 on Waiākea Stream at Hoaka Road also did not correlate well with the index stations; however, long-term station 16700000 on the Waiākea Stream near Mountain View is available to provide at least some definition of low-flow characteristics on that stream.

Limitations of Approach

Flow-duration discharges are estimated with the MOVE.1 and graphical-correlation record-augmentation techniques. Ability of the techniques to produce accurate estimates could be limited by (1) availability of index stations on each island, (2) the strength of the correlation between concurrent data points at the index stations and measurement sites, (3) the accuracy of the streamflow record, and (4) the representativeness of the selected base period relative to long-term conditions.

Limited Index Stations

Low-flow characterization using record augmentation is dependent on the correlation of streamflow data between the measurement site and a nearby index station. Therefore, presence of index stations in proximity to measurement sites where low-flow data are available for record augmentation is critical for developing statistical or graphical models that can be used to estimate low-flow duration discharges. The presence of an adequate number of index stations that are distributed throughout various parts of the island is also important for building a broader geographic coverage of low-flow information throughout the island to be used in regional low-flow analysis.

Generally, low-flow characterization of streams on all islands can greatly benefit from additional continuous-record streamflow-gaging stations that can be used as index stations. Since Moloka‘i has only one index station on the island, index stations on Maui are also used to estimate low-flow duration discharges at the Moloka‘i measurement sites. Some of the

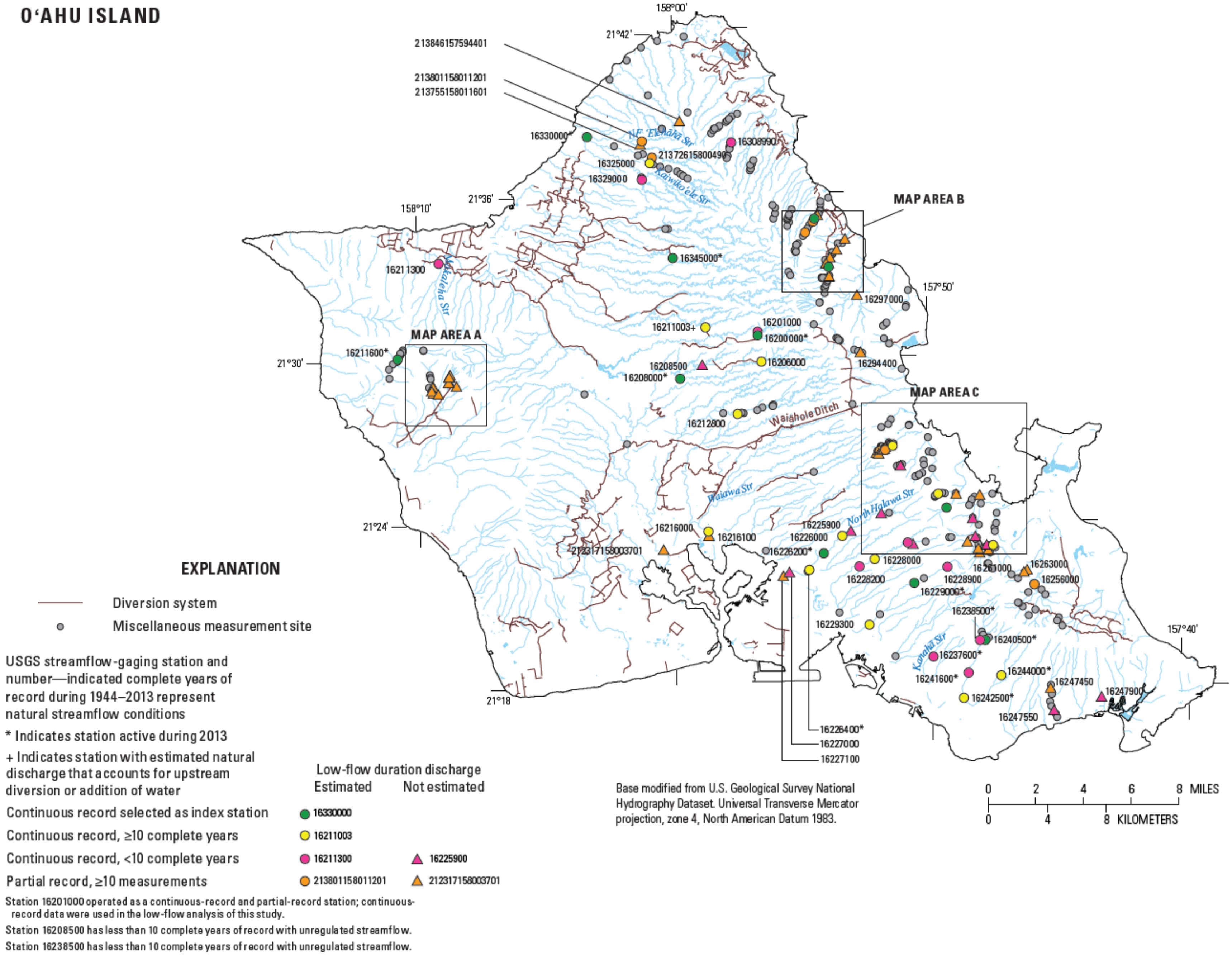


Figure 4. Map showing U.S. Geological Survey (USGS) continuous-record and partial-record stations with streamflow data between water years 1944 and 2013, Island of O'ahu.

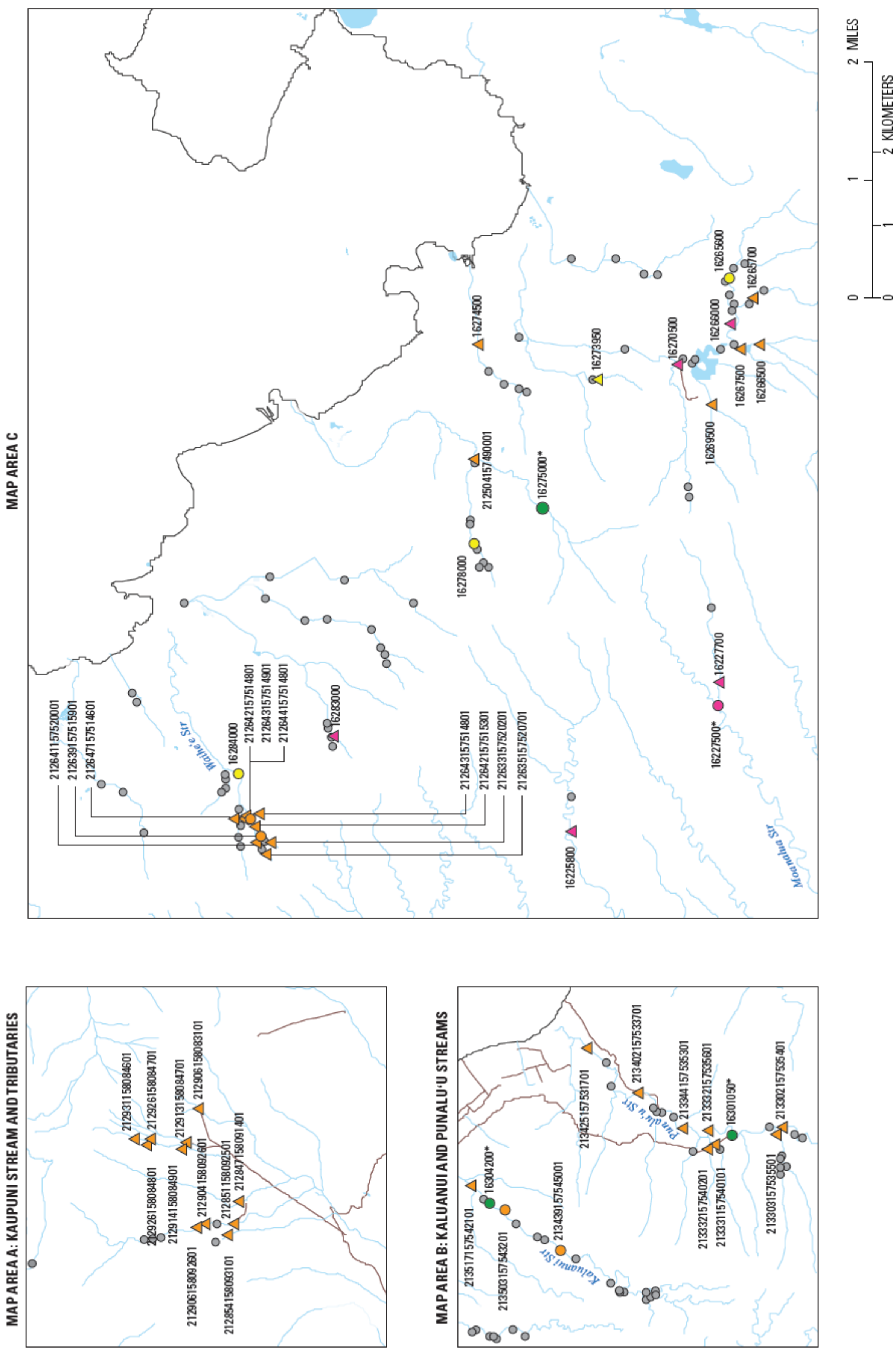


Figure 4.—Continued

Table 5. Selected natural low-flow duration estimates at continuous-record streamflow-gaging stations and partial-record stations on the Island of Molokaʻi for base period 1984–2013.

[ft^3/s, cubic feet per second; ID, identifier; --, no estimates; >, greater than; <, less than; ≥, greater than or equal to; ≤, less than or equal to; font color of discharge value reflects the accuracy of the discharge estimate as represented by a performance rating for the Nash-Sutcliff coefficient of efficiency (NSE, values listed in appendix 2) modified from Moriasi and others (2007) and this performance rating does not apply to discharge estimated using the graphical-correlation record-augmentation method; discharge in blue indicates an estimate rated as good with an NSE >0.65 and ≤1; discharge in black indicates an estimate rated as satisfactory with an NSE >0.50 and ≤0.65; discharge in red indicates an estimate rated as poor with an NSE ≥0.36 and ≤0.50; estimate with an NSE <0.36 is not presented and is indicated with --; discharge estimated using the graphical-correlation record-augmentation method is italicized]

Station ID	Discharge, in ft^3/s, that was equaled or exceeded for the selected percentages of time (from 50 to 95)									
	50	55	60	65	70	75	80	85	90	95
Index stations										
16400000	11	10	9.0	8.0	7.1	6.4	5.7	5.0	4.3	3.5
Stations for which record augmentation was used to estimate duration discharges										
16402000	17	16	15	13	12	10	9.1	8.3	7.2	6.2
16403000	6.3	5.9	5.6	5.3	5.1	*4.9*	--	--	--	--
[1]16404000	*8.5*	*8.2*	*6.9*	*6.2*	*6.1*	*5.5*	*5.1*	*4.6*	*4.2*	--
16404200	*0.95*	*0.90*	*0.87*	*0.80*	--	--	--	--	--	--
16405000	*7.4*	*7.0*	*6.4*	*6.2*	*5.5*	*4.9*	--	--	--	--
16408000	9.2	--	--	9.0	8.6	7.4	7.4	7.2	6.5	--
16411400	Dry at least 50 percent of the time									
16413000	*0.03*	*0.02*	*0.02*	*0.02*	*0.02*	*0.02*	*0.02*	*0.02*	*0.02*	*0.02*
16414000	Dry at least 50 percent of the time									
[2]16416000	--	--	*0.70*	*0.53*	*0.33*	*0.24*	*0.16*	*0.12*	*0.10*	*0.08*

[1]Station operated as a continuous-record and partial-record station; continuous-record data were used in the low-flow analysis of this study.

[2]Station operated as a continuous-record and partial-record station; partial-record data were used in the low-flow analysis of this study.

models developed with Maui index stations had correlation coefficients less than 0.80 and an NSE rating of poor. Low flows at many measurement sites on Hawaiʻi could not be characterized because only two index stations are available on the island. Although Maui lacks leeward index stations, low-flow duration discharges at many of the leeward partial-record stations, especially on the west part of west Maui, are estimated using models developed from data available at windward index stations. However, the accuracy of the estimates could probably be improved by using data at leeward index stations on the island if available. On Oʻahu, low flows at many of the leeward partial-record stations with streamflow data in 1947–57 could not be characterized because these stations have concurrent measurements with only 4 out of the 11 index stations that operated prior to 1957, and no adequate correlations could be developed for any of these 4 index stations. The lack of leeward index stations on southeastern Kauaʻi, southwestern Oʻahu, Molokaʻi, Maui, and Hawaiʻi makes it problematic to accurately characterize low flows there.

Strength of Correlations

The MOVE.1 models provide relatively accurate flow-duration estimates as indicated by the occurrence of NSE values greater than 0.50 in about 86 percent of the models for all islands. The NSE values computed as part of this study also indicate that the predictive ability of the models tends to decrease from the Q_{50} to Q_{95} statistic for long-term continuous-record stations with 10 or more complete years of record during water years 1944–2013. The same comparison could not be made at short-term and partial-record stations because only one model was developed for the entire range of low-flow statistics. Correlation coefficients of the graphical models show a similar decreasing trend. The graphical-correlation technique is mostly applied to estimate lower flow statistics (below the Q_{80} discharge), which implies that the relations for the lower flow statistics in the Q_{50} to Q_{95} range exhibit curvature and that the relations for the higher flow statistics in the Q_{50} to Q_{95} range are linear.

The statistical models used to estimate low-flow duration discharges are generally developed based on 10 or more concurrent data points at the index stations and measurement sites. Models that are developed based on eight or nine concurrent data points yielded satisfactory low-flow duration-discharge estimates with a majority of NSE values greater than 0.80. Only 4 measurement sites out of 107 have extreme outliers that are not used in record augmentation (appendix 2).

Accuracy of Streamflow Record

Regulated-streamflow data at a measurement site are used when a concurrent ditch-flow record is available to reconstruct the natural-streamflow record at the measurement

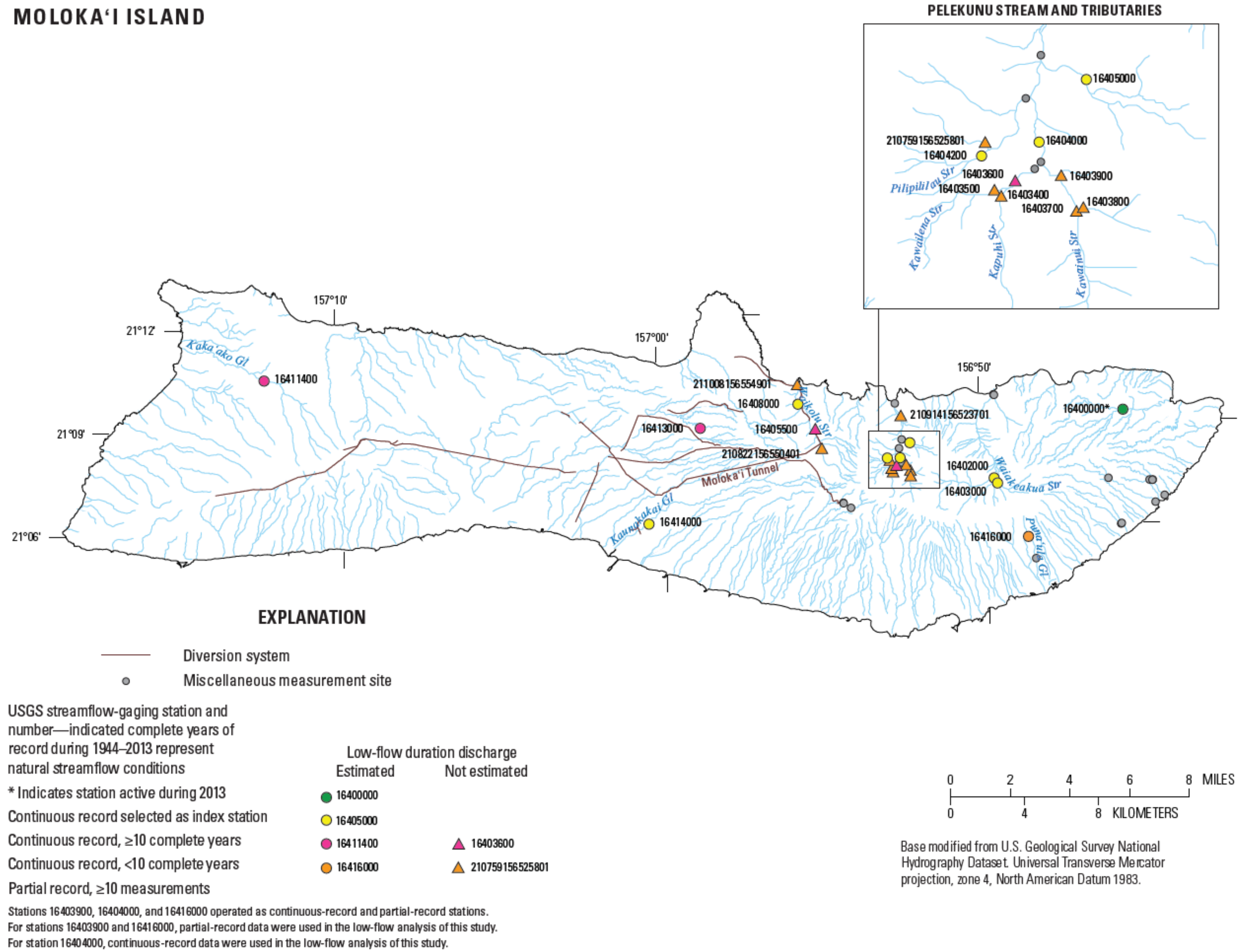


Figure 5. Map showing U.S. Geological Survey (USGS) continuous-record and partial-record stations with streamflow data between water years 1944 and 2013, Island of Moloka‘i.

Table 6. Selected natural low-flow duration estimates at continuous-record streamflow-gaging stations and partial-record stations on the Island of Maui for base period 1984–2013.

[ft^3/s, cubic feet per second; ID, identifier; --, no estimates; >, greater than; <, less than; ≥, greater than or equal to; ≤, less than or equal to; font color of discharge value reflects the accuracy of the discharge estimate as represented by a performance rating for the Nash-Sutcliff coefficient of efficiency (NSE, values listed in appendix 2) modified from Moriasi and others (2007) and this performance rating does not apply to discharge estimated using the graphical-correlation record-augmentation method; discharge in blue indicates an estimate rated as good with an NSE >0.65 and ≤1; discharge in black indicates an estimate rated as satisfactory with an NSE >0.50 and ≤0.65; discharge in red indicates an estimate rated as poor with an NSE ≥0.36 and ≤0.50; estimate with an NSE <0.36 is not presented and is indicated with --; discharge estimated using the graphical-correlation record-augmentation method is italicized]

Station ID	Discharge, in ft^3/s, that was equaled or exceeded for the selected percentages of time (from 50 to 95)									
	50	55	60	65	70	75	80	85	90	95
Index stations										
16508000	6.2	5.4	4.8	4.3	3.9	3.6	3.2	2.9	2.6	2.2
16518000	8.9	7.8	6.9	6.0	5.2	4.5	3.9	3.4	2.8	2.2
16587000	2.0	1.8	1.6	1.3	1.2	1.0	0.86	0.72	0.60	0.47
16604500	36	33	30	28	26	24	22	20	18	16
16614000	50	48	46	44	42	40	39	37	35	32
16618000	8.0	7.4	6.9	6.4	6.0	5.6	5.2	4.9	4.4	3.9
16620000	21	20	19	17	16	15	14	13	12	11
Stations for which record augmentation was used to estimate duration discharges										
16500100	Dry at least 50 percent of the time									
16501200	*5.7*	*4.5*	*3.3*	*2.8*	*2.4*	*1.7*	*1.5*	*1.2*	--	--
16510000	4.3	3.6	3.1	2.7	2.3	2.3	1.7	1.5	1.3	0.98
16513000	*0.80*	*0.77*	*0.75*	*0.70*	*0.68*	*0.65*	*0.62*	*0.58*	*0.54*	*0.50*
16515000	5.2	4.7	4.4	4.2	3.9	3.7	3.4	3.2	2.9	2.5
16516000	6.6	5.5	5.0	*4.2*	*3.8*	*3.4*	*3.0*	*2.7*	*2.4*	*2.1*
16517000	7.7	6.9	5.9	5.3	4.6	4.2	3.6	3.2	2.8	2.1
16519000	3.8	3.3	3.0	2.5	2.2	1.9	1.6	1.4	1.1	0.75
16520000	3.1	2.7	2.4	2.0	1.7	1.5	1.3	1.1	0.91	0.65
16524000	1.6	1.3	1.1	0.92	0.76	0.62	0.50	0.42	0.32	0.23
16527000	4.9	4.3	3.8	3.1	2.6	2.2	1.8	1.4	1.1	0.73
[1]16531100	0.43	--	--	--	--	0.12	--	0.06	--	--
16542000	*0.41*	*0.32*	*0.29*	*0.27*	*0.25*	*0.24*	*0.22*	*0.21*	*0.19*	*0.16*
16552600	Dry at least 50 percent of the time									
16552800	0.12	0.09	0.07	0.06	*0.05*	0.04	0.03	*0.03*	0.02	--
16557000	2.5	2.1	1.7	1.5	1.3	1.2	0.96	0.82	0.69	0.53
16565000	2.4	2.1	1.9	1.6	1.3	1.1	0.94	0.82	0.69	0.52
16566000	0.95	0.79	0.69	0.54	0.50	0.42	0.36	*0.33*	*0.26*	0.18
16569700	0.73	0.52	0.39	0.29	0.23	0.19	0.14	0.11	0.08	0.06

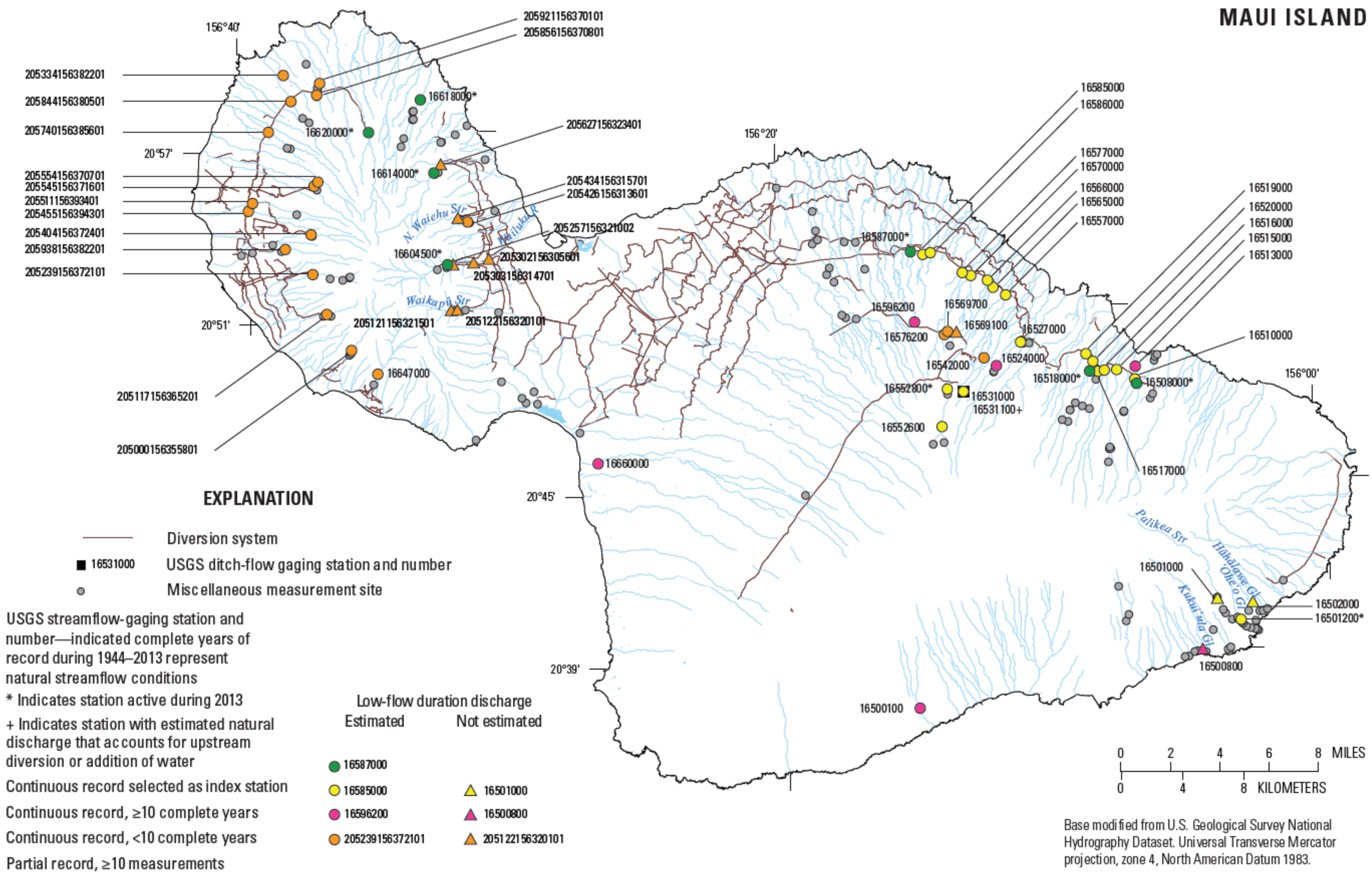
Table 6. Selected natural low-flow duration estimates at continuous-record streamflow-gaging stations and partial-record stations on the Island of Maui for base period 1984–2013.—Continued

Station ID	Discharge, in ft³/s, that was equaled or exceeded for the selected percentages of time (from 50 to 95)									
	50	55	60	65	70	75	80	85	90	95
16570000	14	13	12	9.8	8.6	8.0	7.0	5.6	4.6	3.6
16576200	0.67	0.55	0.47	0.41	0.36	0.32	0.27	0.24	0.20	0.16
16577000	7.8	6.8	5.9	4.9	4.2	3.8	3.2	2.5	2.0	1.4
16585000	4.4	3.9	3.5	2.9	2.6	2.2	1.9	1.6	1.4	1.0
16586000	3.6	3.4	3.1	2.8	2.7	2.4	2.2	1.9	1.7	1.4
16596200	0.87	0.69	0.56	0.44	0.34	0.27	0.21	0.17	0.12	0.08
[2]16647000	5.0	4.7	4.5	4.2	4.0	3.8	3.6	3.4	3.2	3.0
16660000	Dry at least 50 percent of the time									
[2]205000156355801	6.1	5.6	5.2	4.8	4.5	4.2	4.0	3.7	3.4	3.1
[2]205117156365201	0.47	0.45	0.44	0.42	0.41	0.39	0.38	0.37	0.35	0.34
[2]205239156372101	9.5	8.6	8.1	7.6	7.1	6.6	6.2	5.7	5.2	4.8
[2]205334156382201	4.9	4.8	4.7	4.6	4.5	4.4	4.3	4.2	4.1	4.0
[2]205404156372401	*5.8*	*5.7*	*5.6*	*5.6*	*5.4*	*5.2*	*4.9*	*4.3*	*2.9*	*2.0*
205426156313601	*2.5*	*2.5*	*2.5*	*2.5*	*2.4*	*2.4*	*2.4*	*2.3*	*2.1*	*2.0*
[2]205455156394301	Dry at least 50 percent of the time									
[2]205511156393401	Dry at least 50 percent of the time									
[3]205545156371601 +205554156370701	5.4	5.1	4.9	4.7	4.5	4.2	4.0	3.8	3.6	3.4
[2]205740156385601	Dry at least 50 percent of the time									
[2]205844156380501	Dry at least 50 percent of the time									
[2]205856156370801	*3.8*	*2.8*	*2.3*	*1.7*	*1.2*	*0.75*	*0.40*	*0*	*0*	*0*
[2]205921156370101	Dry at least 50 percent of the time									
[2]205938156382201	Dry at least 50 percent of the time									

[1]Natural-flow record based on combined concurrent records at stations 16531000 and 16531100.

[2]Discharge estimates from Cheng (2014).

[3]Discharge estimates apply to the confluence of Amalu and Kapaloa Streams.



Station 16502000 operated as a continuous-record and partial-record station; continuous-record data were used in the low-flow analysis of this study.
Station 16647000 operated as a continuous-record and partial-record station; partial-record data were used in the low-flow analysis of this study.
Data at stations 205545156371601 and 205554156370701 were summed in estimating low-flow duration statistics at the confluence of Amalu and Kapaloa Streams.

Figure 6. Map showing U.S. Geological Survey (USGS) continuous-record and partial-record stations with streamflow data between water years 1944 and 2013, Island of Maui.

Table 7. Selected natural low-flow duration estimates at continuous-record streamflow-gaging stations and partial-record stations on the Island of Hawai‘i for base period 1984–2013.

[ft^3/s, cubic feet per second; ID, identifier; --, no estimates; >, greater than; <, less than; ≥, greater than or equal to; ≤, less than or equal to; font color of discharge value reflects the accuracy of the discharge estimate as represented by a performance rating for the Nash-Sutcliff coefficient of efficiency (NSE, values listed in appendix 2) modified from Moriasi and others (2007) and this performance rating does not apply to discharge estimated using the graphical-correlation record-augmentation method; discharge in blue indicates an estimate rated as good with an NSE >0.65 and ≤1; discharge in black indicates an estimate rated as satisfactory with an NSE >0.50 and ≤0.65; discharge in red indicates an estimate rated as poor with an NSE ≥0.36 and ≤0.50; estimate with an NSE <0.36 is not presented and is indicated with --; discharge estimated using the graphical-correlation record-augmentation method is italicized]

Station ID	Discharge, in ft^3/s, that was equaled or exceeded for the selected percentages of time (from 50 to 95)									
	50	55	60	65	70	75	80	85	90	95
Index stations										
16717000	40	35	30	26	22	19	16	14	11	8.5
16720000	4.2	3.2	2.5	2.0	1.6	1.2	0.97	0.71	0.51	0.30
Stations for which record augmentation was used to estimate duration discharges										
16700000	*8.4*	*7.1*	*6.0*	*5.4*	*4.5*	*3.5*	*2.8*	*2.5*	--	--
16701700	Dry at least 50 percent of the time									
16704000	76	63	49	38	30	23	17	*14*	*9.0*	--
16717800	8.6	7.4	6.0	5.1	4.0	--	--	--	--	--
16720300	*1.1*	*0.90*	*0.68*	*0.60*	*0.50*	*0.40*	--	--	--	--
16725000	*2.2*	*1.7*	*1.3*	*1.2*	--	--	--	--	--	--
16737500	*72*	*49*	*44*	*44*	*43*	*42*	*42*	*41*	*39*	*36*
16759600	Dry at least 50 percent of the time									
16765000	Dry at least 50 percent of the time									
16767000	Dry at least 50 percent of the time									
16770500	Dry at least 50 percent of the time									
200505155383801	34	32	29	26	24	22	20	18	16	13

site. This technique is applicable only for cases in which the ditch-flow record reflects diverted flow at the diversion intake. Documented averages of diverted flow published in other studies are not used in this study to avoid additional errors in the reconstructed record that could affect the accuracy of the flow-duration discharge estimates. Streamflow records for five continuous-record stations reflect regulated flow—stations 16063000, 16097000, and 16101003 on Kaua‘i, station 16211003 on O‘ahu, and station 16531100 on Maui. The natural-streamflow records at these stations are reconstructed by combining with the concurrent daily means from ditch-flow stations. Flow-duration estimates at stations 16063000, 16101003, and 16211003 are satisfactory with most of the NSE values greater than 0.50. However, the flow-duration estimates at stations 16097000 and 16531100 are poor because the reconstructed natural-flow records may not accurately reflect the actual natural flows in the streams. This could occur when the ditch-flow record is not representative of the actual amount of flow diverted, which could result from (1) unreported pumpage of water from another stream that was added to the ditch or (2) ditch flow released downstream from the gaged location.

Continuous records of discharge at gaging stations are determined by applying a stage-discharge relation to records of stage (height of water surface). A stage-discharge relation is a plot of periodic streamflow measurements and concurrent stage measurements. Streamflow measurements should cover the interested range of stage to avoid extrapolation of the data. Two important attributes of a gaging-station control—permanence and sensitivity—govern the stage-discharge relation and consequently affect the accuracy of the streamflow record. A stable control is one that is structurally permanent and does not alter during changing flow conditions. If a control is unstable, the stage-discharge relation is subject to change, and frequent measurements of streamflow and stage are needed to continually recalibrate the stage-discharge relation, which may affect the accuracy of the streamflow record.

Factors that could contribute to streamflow-measurement errors include, but are not limited to, the condition of the measuring instrument and instrument error, characteristics of the measurement cross section, spacing and number of observation verticals in a cross section, changing stage during the measurement, flow depth and velocity, and environment (Rantz and others, 1982, p. 179–180). A rating of excellent, good, fair, or poor is assigned to each discharge measurement by the field technician based on these factors that could potentially affect the accuracy of the measurement. Some of the historic streamflow measurements used in this study are not rated because the rating system was not yet developed. For streamflow measurements that are rated and are used in this study, they were generally rated good or fair.

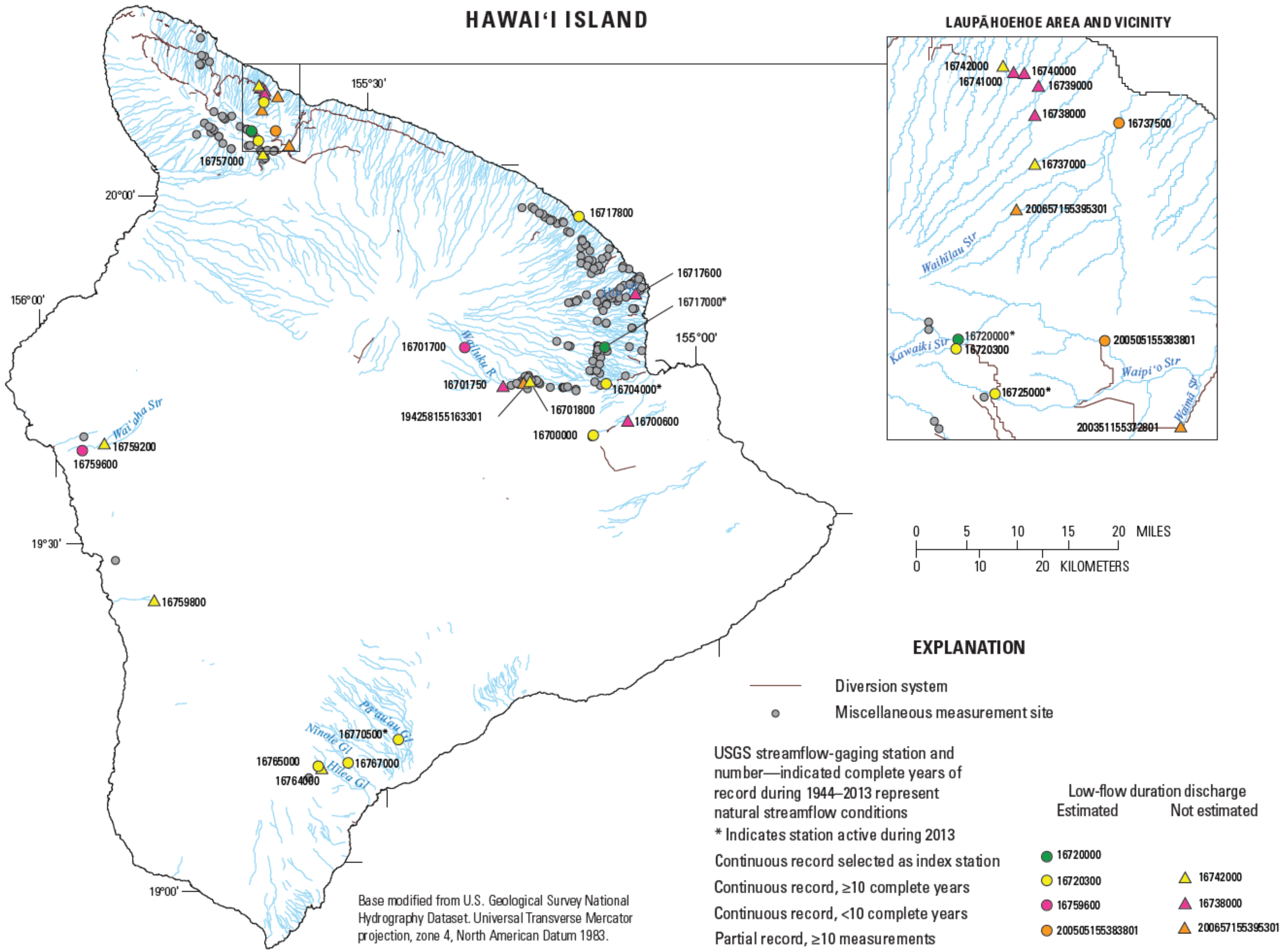


Figure 7. Map showing U.S. Geological Survey (USGS) continuous-record and partial-record stations with streamflow data between water years 1944 and 2013, Island of Hawai‘i.

Representation of Long-Term Flow Conditions

Flow-duration statistics at the index station and the measurement sites are applicable to the base period, 30-year period 1984–2013, over which they have been computed. To assess whether flow-duration statistics at the index stations provide estimates of streamflow characteristics at the measurement sites that are representative of long-term flow conditions, the Q_{50} to Q_{95} discharges for the base period are compared to those calculated using all the data available during the period 1944–2013 (table 8). This comparison could not be done using data from index stations 16226200, 16604500, and 16614000 because a longer period of record was not available. Duration discharges at all except the index stations on Heʻeia Stream (16275000) and Mākaha Stream (16211600), Oʻahu, averaged less than 10-percent difference for the Q_{50} to Q_{95} discharges between the 30-year base period and the long term periods, and duration discharges at 15 of the stations averaged less than 5-percent difference. Duration discharges at the following seven index stations averaged between 5- and 10-percent difference: stations 16010000, 16019000, and 16071500 on Kauaʻi; stations 16240500 and 16330000 on Oʻahu; station 16400000 on Molokaʻi; and station 16618000 on Maui. Whether the statistics at the index stations with differences averaging over 5 percent provide estimates of streamflow characteristics at the measurement sites that are representative of long-term streamflow conditions is less certain. Extrapolation of flow-duration statistics to future conditions assumes that the hydrologic condition that occurred during the base period will be representative of those in the future.

Additional Data Collection

Streamflow data are scarce in the leeward areas for all five islands probably because many leeward streams are dry or have minimal flow. Additional measurements are needed to determine which streams in these leeward areas are ephemeral; the data can be used in conjunction with logistic regression methods (Helsel and Hirsch, 2002) to determine the probability that these streams are dry during low-flow periods. Additional streamflow measurements at miscellaneous sites with less than 10 streamflow measurements, located in southeastern Kauaʻi, in streams affected by the Waiāhole Ditch, and in northeastern Hawaiʻi, would allow for record augmentation to be applied at these sites for estimating flow-duration discharges. Other under-represented areas include central Oʻahu, central Maui, and southeastern Maui. Both Molokaʻi and Hawaiʻi would greatly benefit from additional partial-record stations and continuous-record stations for monitoring natural streamflow. Low-flow characterization of streams on all islands can also greatly benefit from additional continuous-record streamflow-gaging stations that can be used as index stations.

Summary

Land-use and water-diversion changes have significantly altered the hydrology of the Hawaiian Islands. Over the 20th century, surface-water use in the State of Hawaiʻi has generally shifted from providing irrigation water for large-scale agricultural operations to supporting diversified agriculture, urban developments, and other uses. Today, the use of stream water for agriculture, protection of traditional and customary Hawaiian rights, maintenance of ecologic balance, aesthetic qualities of streams, and recreational use of the streams are factors that play a role in planning and management decisions by many agencies. During low-flow conditions, the amount of surface water available may be insufficient to support all these different surface-water uses. Therefore, documentation of water availability during low-flow conditions is important for identifying critical areas that affect both mankind and aquatic species, and for developing plans to mitigate negative impacts to the resource.

The purposes of this study are to (1) characterize natural streamflow under low-flow conditions for streams with existing streamflow data at gaged sites and (2) to identify streams in under-represented geographical areas for additional data collection. As part of this study, estimates of low-flow duration discharges will be incorporated into StreamStats. Statistical and graphical models are developed to estimate natural streamflow under low-flow conditions for streams with existing streamflow data at measurement sites on the main Hawaiian Islands. Measurement sites include continuous-record gaging stations with 10 or more complete years of data during water years 1944–2013, continuous-record gaging stations with less than 10 complete years of data during water years 1944–2013, and partial-record stations with streamflow measurement data during water years 1944–2013. Streamflow statistics used to describe low flows are flow-duration discharges that are equaled or exceeded between 50 and 95 percent of the time (between Q_{50} and Q_{95} discharges) during a 30-year base period 1984–2013. Two record-augmentation techniques, MOVE.1 and graphical-correlation techniques, are used to develop statistical and graphical models between concurrent streamflow data at the measurement sites and nearby long-term continuous-record streamflow-gaging stations that were in operation during essentially all the study period (index station). Existing data, subsequent low-flow analyses of the available data, as well as an inventory of the available seepage analyses help to identify streams in under-represented geographic areas and hydrogeologic settings that will be considered for additional data collection.

Low-flow duration discharges are estimated for 107 measurement sites and 27 index stations. The numbers of measurement sites with duration-discharge estimates for each island are Kauaʻi, 13; Oʻahu, 31; Molokaʻi, 10; Maui, 41; and Hawaiʻi, 12. A majority of the flow-duration estimates are satisfactory based on correlation coefficients and modified

Table 8. Selected flow-duration discharges for selected periods at index stations, State of Hawai‘i.

[ft^3/s, cubic feet per second; abv, above; alt, altutide; E, East; EB, East Branch; ft, feet; N, North; NF, North Fork; nr, near; RB, Right Bank; SF, South Fork; Str, Stream; a water year is a 12-month period that extends from October 1 to September 30 of the following year and is named according to the year during which the period ends; database limitations preclude the use of Hawaiian diacritical marks in USGS station names]

Water years used to compute selected flow-duration discharges	Length of record, in years	Discharge, in ft^3/s, that was equaled or exceeded for the selected percentages of time (from 50 to 95)									
		50	55	60	65	70	75	80	85	90	95
16010000 Kawaikoi Stream nr Waimea, Kauai, HI											
1944–2013	70	12	11	9.3	8.2	7.3	6.5	5.6	4.9	4.1	3.2
1984–2013	30	11	9.5	8.4	7.5	6.7	6.0	5.2	4.6	3.9	3.1
16019000 Waialae Str at alt 3,820 ft nr Waimea, Kauai, HI											
1953–2013	61	6.5	5.8	5.1	4.5	4.0	3.6	3.3	2.9	2.6	2.2
1984–2013	30	6.0	5.2	4.7	4.2	3.7	3.4	3.0	2.8	2.5	2.2
16068000 EB of NF Wailua River nr Lihue, Kauai, HI											
1944–2013	70	29	27	25	23	22	20	18	17	15	13
1984–2013	30	27	25	24	22	21	19	18	16	15	13
16071500 Left Branch Opaekaa Str nr Kapaa, Kauai, HI											
1961–2013	53	1.6	1.4	1.3	1.1	1.0	0.88	0.79	0.70	0.60	0.49
1984–2013	30	1.3	1.2	1.1	0.98	0.89	0.81	0.74	0.66	0.58	0.49
16097500 Halaulani Str at alt 400 ft nr Kilauea, Kauai, HI											
1959–2013	51	7.1	6.7	6.4	6.0	5.7	5.4	5.1	4.8	4.4	4.0
1984–2013	30	6.8	6.4	6.1	5.8	5.5	5.2	4.9	4.6	4.3	3.9
16108000 Wainiha River nr Hanalei, Kauai, HI											
1953–55, 1959–2013	51	77	72	68	64	60	57	54	51	48	44
1984–2013	30	76	70	66	63	59	56	53	50	47	43
16200000 NF Kaukonahua Str abv RB, nr Wahiawa, Oahu, HI											
1944–52, 1961–2013	62	6.3	5.5	4.8	4.2	3.6	3.1	2.6	2.1	1.6	0.92
1984–2013	30	6.3	5.5	4.9	4.3	3.7	3.2	2.7	2.2	1.7	1.0
16208000 SF Kaukonahua Str at E pump, nr Wahiawa, Oahu, HI											
1958-62, 1965-2013[1]	45	8.4	7.3	6.3	5.5	4.7	4.0	3.3	2.6	1.9	1.1
1984–2013[1]	30	8.2	7.1	6.2	5.4	4.6	3.9	3.2	2.5	1.8	0.95
16211600 Makaha Str nr Makaha, Oahu, HI											
1960-2013	54	0.40	0.31	0.24	0.18	0.12	0.06	0.02	0	0	0
1984–2013	30	0.23	0.15	0.08	0.03	0	0	0	0	0	0
16226200 N. Halawa Str nr Honolulu, Oahu, HI											
1984–2013	30	0.26	0.16	0.10	0.06	0.04	0.02	0.02	0.01	0	0

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Table 8. Selected flow-duration discharges for selected periods at index stations, State of Hawai‘i.—Continued

Water years used to compute selected flow-duration discharges	Length of record, in years	Discharge, in ft³/s, that was equaled or exceeded for the selected percentages of time (from 50 to 95)									
		50	55	60	65	70	75	80	85	90	95
16229000 Kalihi Str nr Honolulu, Oahu, HI											
1944–2013	70	2.4	2.2	1.9	1.7	1.5	1.3	1.2	1.0	0.82	0.60
1984–2013	30	2.4	2.1	1.9	1.7	1.5	1.3	1.2	1.0	0.88	0.70
16240500 Waiakeakua Str at Honolulu, Oahu, HI											
1944–2013	70	3.3	3.1	2.9	2.8	2.6	2.4	2.2	2.0	1.8	1.5
1984–2013	30	3.1	2.9	2.7	2.6	2.4	2.2	2.1	1.9	1.7	1.5
16275000 Heeia Stream at Haiku Valley nr Kaneohe, Oahu, HI											
1944–77, 1983–2013	69	1.6	1.5	1.4	1.4	1.3	1.3	1.2	1.1	0.99	0.67
1984–2013	30	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2
16301050 Punaluu Str abv Punaluu Ditch Intake, Oahu, HI											
1954–2013	59	19	18	18	17	16	15	15	14	13	12
1984–2013	30	18	18	17	16	16	15	14	14	13	11
16304200 Kaluanui Stream nr Punaluu, Oahu, HI											
1968–2013	46	1.3	1.1	0.96	0.83	0.69	0.57	0.45	0.35	0.25	0.13
1984–2013	30	1.3	1.1	0.95	0.82	0.69	0.56	0.45	0.34	0.24	0.13
16330000 Kamananui Str at Maunawai, Oahu, HI											
1959–2013	55	3.6	3.0	2.5	2.1	1.6	1.3	0.91	0.58	0.25	0.040
1984–2013	30	3.4	2.9	2.4	2.0	1.6	1.2	0.87	0.53	0.20	0.040
16345000 Opaeula Str nr Wahiawa, Oahu, HI											
1960–2013	54	4.3	3.7	3.2	2.7	2.3	1.9	1.6	1.3	0.92	0.55
1984–2013	30	4.2	3.7	3.1	2.7	2.3	1.9	1.6	1.3	0.93	0.54
16400000 Halawa Stream near Halawa, Molokai, HI											
1944–2013	70	12	11	9.6	8.6	7.7	6.8	6.1	5.3	4.4	3.5
1984–2013	30	11	10	9.0	8.0	7.1	6.4	5.7	5.0	4.3	3.5
16508000 Hanawi Stream near Nahiku, Maui, HI											
1944–2013	70	6.2	5.5	5.0	4.4	4.0	3.7	3.3	2.9	2.6	2.2
1984–2013	30	6.2	5.4	4.8	4.3	3.9	3.6	3.2	2.9	2.6	2.2
16518000 West Wailuaiki Stream near Keanae, Maui, HI											
1944–2013	70	9.0	8.0	7.1	6.3	5.6	4.9	4.2	3.6	3.0	2.3
1984–2013	30	8.9	7.8	6.9	6.0	5.2	4.5	3.9	3.4	2.8	2.2
16587000 Honopou Stream near Huelo, Maui, HI											
1944–2013	70	2.1	1.9	1.6	1.4	1.2	1.1	0.90	0.74	0.63	0.47
1984–2013	30	2.0	1.8	1.6	1.3	1.2	1.0	0.86	0.72	0.60	0.47

Table 8. Selected flow-duration discharges for selected periods at index stations, State of Hawai‘i.—Continued

Water years used to compute selected flow-duration discharges	Length of record, in years	Discharge, in ft^3/s, that was equaled or exceeded for the selected percentages of time (from 50 to 95)									
		50	55	60	65	70	75	80	85	90	95
16604500 Wailuku River at Kepaniwai Park nr Wailuku, Maui, HI											
1984–2013	30	36	33	30	28	26	24	22	20	18	16
16614000 Waihee River at Dam near Waihee, Maui, Hawaii											
1984–2013[1]	30	50	48	46	44	42	40	39	37	35	32
16618000 Kahakuloa Stream near Honokohau, Maui, HI											
1948–70, 1976–2013	61	8.4	7.8	7.3	6.8	6.4	6.0	5.7	5.3	4.8	4.2
1984–2013	30	8.0	7.4	6.9	6.4	6.0	5.6	5.2	4.9	4.4	3.9
16620000 Honokohau Stream near Honokohau, Maui, HI											
1944–2013[1]	70	21	20	19	18	17	16	15	14	13	11
1984–2013[1]	30	21	20	19	17	16	15	14	13	12	11
16717000 Honolii Stream nr Papaikou, HI											
1968–2013	46	39	34	30	26	22	19	16	13	11	8.0
1984–2013	30	40	35	30	26	22	19	16	14	11	8.5
16720000 Kawainui Stream nr Kamuela, HI											
1965–2013	49	4.2	3.2	2.5	2.0	1.6	1.2	0.96	0.71	0.50	0.30
1984–2013	30	4.2	3.2	2.5	2.0	1.6	1.2	0.97	0.71	0.51	0.30

[1]Selected flow-duration discharges computed from index station streamflow records that have been extended.

Nash-Sutcliff coefficients of efficiency used to evaluate the statistical models. About 93 percent of the models have correlation coefficients 0.80 and higher and about 58 percent of them 0.90 and higher.

Low-flow characterization of streams on all islands can greatly benefit from additional continuous-record streamflow-gaging stations that can be used as index stations. The Islands of Moloka‘i and Hawai‘i have the fewest number of measurement sites (that are not located on ephemeral stream reaches) at which flow-duration discharges are estimated, which is probably related to the limited number of index stations available on these islands. Low flows at many of the leeward partial-record stations on O‘ahu with streamflow data during 1947–57 could not be characterized because these stations have concurrent measurements with only 4 out of the 11 index stations that operated prior to 1957 and no adequate correlations could be developed for any of these 4 index stations. Index stations are scarce in the leeward areas for all five islands and this presents a difficulty in applying record-augmentation for characterizing low flows for non-ephemeral streams in the leeward areas when more streamflow data become available. Other under-represented areas include central O‘ahu, central Maui, and southeastern Maui.

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Appendix 1. Station Numbers, Names, Station Type, Period of Record, and Record Length of Measurement Sites Used in this Study, State of Hawai‘i.

[Index stations are in green font; ab, above; abv, above; alt, altitude; Bdry, Boundary; bl, below; blw, below; Br, Branch; conf, confluence; confl, confluence; div, diversion; Dr, Drive; DS, downstream; E, East; EB, East Branch; fr, from; ft, feet; HI, Hawai‘i; ID, identification; L, left; L., Lower; LB, Left Branch; mi, mile; Mil, Military; N, North; na, not applicable; NF, North Fork; No, number; nr, near; P, present (2013); PL, pipeline; Quar, Quarantine; R, Right; RB, Right Branch; Rd, Road; SF, South Fork; stn, station; Str, Stream; Trib, Tributary; tun, tunnel; US, upstream; w, with; W, West; WF, West Fork; CT-A, continuous-record streamflow-gaging station in operation during 2013; CT-I, discontinued continuous-record streamflow-gaging station; Ditch, discontinued ditch-flow gaging station; PR, partial-record station; Period of record includes all calendar years with discharge data in the U.S. Geological Survey National Water Information System database, regardless of completeness of record during each of those calendar years; Years of record is the number of water years of complete continuous record as of the end of 2013 water year; database limitations preclude the use of Hawaiian diacritical marks in USGS station names]

Station ID	Station name	Station type	Aspect	Period of record	Years of record	Flow classification
			Kaua‘i			
16010000	Kawaikoi Stream nr Waimea, Kauai, HI	CT-A	Leeward	1909–16, 1919–P	96	Natural
16013000	Mohihi Stream at alt 3420 ft nr Waimea, Kauai, HI	CT-I	Leeward	1920–26, 1936–71	40	Regulated since 7/1970
16017000	Koaie Stream at alt 3770 ft near Waimea, Kauai, HI	CT-I	Leeward	1919–32, 1954–68	26	Natural
16019000	Waialae Str at alt 3,820 ft nr Waimea, Kauai, HI	CT-A	Leeward	1920–32, 1952–P	72	Natural
16029500	Mokihana Stream nr Waimea, Kauai, HI	PR	Leeward	1962, 1964–67, 1969–83	na	Natural
16061000	North Wailua Ditch nr Lihue, Kauai, HI	Ditch	Windward	1932–85	53	Regulated
16062000	Stable Storm Ditch nr Lihue, Kauai, HI	Ditch	Windward	1937–2002	65	Regulated
[1]16063000	NF Wailua River at alt 650 ft nr Lihue, Kauai, HI	CT-I	Windward	1914–85	69	Regulated
16068000	EB of NF Wailua River nr Lihue, Kauai, HI	CT-A	Windward	1912–P	98	Natural
16071500	Left Branch Opaekaa Str nr Kapaa, Kauai, HI	CT-A	Windward	1960–P	53	Natural
16081500	Unnamed Tributary abv Kaneha Reservoir, Kauai, HI	PR	Windward	2011–12	na	Natural
16085500	Anahola Str abv upper ditch intake, Kauai, HI	PR	Windward	2011–12	na	Natural
16088300	Anahola Str nr Keaoopu Trib confl., Kauai, HI	PR	Windward	2011–12	na	Natural
16088500	Keaoopu Trib nr Anahola Str conf., Kauai, HI	PR	Windward	2011–12	na	Natural
16095900	Kalihiwai Ditch ab wasteway, nr Kilauea, Kauai, HI	Ditch	Windward	1960–68	8	Regulated
[2]16097000	Pohakuhonu Stream nr Kilauea, Kauai, HI	CT-I	Windward	1957–72	14	Regulated
16097500	Halaulani Str at alt 400 ft nr Kilauea, Kauai, HI	CT-A	Windward	1957–P	55	Natural
16100000	Hanalei Tunnel outlet nr Lihue, Kauai, HI	Ditch	Windward	1932–85	53	Regulated
16101000	Hanalei River at alt 625 ft nr Hanalei, Kauai, HI	CT-I	Windward	1914–55	39	Regulated
16101003	Sum of stations 16100000 and 16101000	CT-I	Windward	1932–55	21	Natural
16103000	Hanalei River nr Hanalei, Kauai, HI	CT-A	Windward	1912–19, 1963–P	57	Regulated prior to 1995
16108000	Wainiha River nr Hanalei, Kauai, HI	CT-A	Windward	1952–P	58	Natural
16115000	Hanakapiai Stream near Hanalei, Kauai, HI	CT-I	Windward	1932–52	20	Natural
16116000	Hanakoa Stream near Hanalei, Kauai, HI	CT-I	Windward	1932–52	20	Natural
16117000	Kalalau Stream near Hanalei, Kauai, HI	CT-I	Leeward	1931–55	22	Natural
16130000	Nahomalu Valley nr Mana, Kauai, HI	CT-I	Leeward	1963–71	8	Natural
220754159371901	Kawaikoi Str Trib nr Kawaikoi camp, Kauai, HI	PR	Leeward	1963, 1965–68	na	Natural
221004159382201	RB Kalalau Str blw Twin Falls at conf, Kauai, HI	PR	Leeward	1944–48, 1954–55	na	Natural

221029159384801	L Trib Kalalau .45mi fr mouth, at conf, Kauai, HI	PR	Leeward	1946–48, 1956–62	na	Natural
			O‘ahu			
16200000	NF Kaukonahua Str abv RB, nr Wahiawa, Oahu, HI	CT-A	Leeward	1913–53, 1960–P	90	Natural
[3]16201000	RB of NF Kaukonahua Str nr Wahiawa, Oahu, HI	CT-I	Leeward	1913–53	35	Natural
[3]16201000	RB of NF Kaukonahua Str nr Wahiawa, Oahu, HI	PR	Leeward	1960–62, 1966, 1968–86	na	Natural
16206000	S F Kaukonahua Stream near Wahiawa, Oahu, HI	CT-I	Leeward	1911, 1913–17, 1944–57	14	Natural
16208000	SF Kaukonahua Str at E pump, nr Wahiawa, Oahu, HI	CT-A	Leeward	1957–2011, P	51	Natural
16208500	R Br of S F Kaukonahua Str nr Wahiawa, Oahu, HI	CT-I	Leeward	1957–72	15	Regulated prior to 9/1971
16211003	Combined records of stations 16210900, 16211000	CT-I	Leeward	1958–74	15	Natural
16211300	Makaleha Str nr Waialua, Oahu, HI	CT-I	Leeward	1964	0	Natural
16211600	Makaha Str nr Makaha, Oahu, HI	CT-A	Leeward	1959–P	53	Natural
16212800	Kipapa Str nr Wahiawa, Oahu, HI	CT-I	Leeward	1957–2004, 2007–2011	51	Natural
16216000	Waiawa Stream nr Pearl City, Oahu, HI	CT-I	Leeward	1952–2004	52	Natural
16216100	Waiawa Stream below H-1 near Pearl City, Oahu, HI	PR	Leeward	1967–70, 1972–2012	na	Natural
16225800	N. Halawa Str nr Kaneohe, Oahu, HI	CT-I	Leeward	1991–99	8	Natural
16225900	N. Halawa Str at Bridge 8 nr Halawa, Oahu, HI	CT-I	Leeward	2009	0	Natural
16226000	N. Halawa Str nr Aiea, Oahu, HI	CT-I	Leeward	1929–33, 1953–2006	56	Natural
16226200	N. Halawa Str nr Honolulu, Oahu, HI	CT-A	Leeward	1983–P	30	Natural
16226400	N. Halawa Str nr Quar. Stn. at Halawa, Oahu, HI	CT-A	Leeward	2001–03, 2005–P	10	Natural
16227000	Halawa Stream at Aiea, Oahu, HI	CT-I	Leeward	1953–62	8	Natural
16227100	Halawa Stream below H-1, Oahu, HI	PR	Leeward	1990–94, 2001–07	na	Natural
16227500	Moanalua Stream nr Kaneohe, Oahu, HI	CT-A	Leeward	1968–78, P	9	Natural
16227700	Moanalua Stream Trib nr Kaneohe, Oahu, HI	CT-I	Leeward	1968–78	9	Natural
16228000	Moanalua Str nr Honolulu, Oahu, HI	CT-I	Leeward	1926–78	52	Natural
16228200	Moanalua Str nr Aiea, Oahu, HI	CT-I	Leeward	1968–77	9	Natural
16228900	Kalihi Str nr Kaneohe, Oahu, HI	CT-I	Leeward	1966–71	4	Natural
16229000	Kalihi Str nr Honolulu, Oahu, HI	CT-A	Leeward	1913–P	99	Natural
16229300	Kalihi Str at Kalihi, Oahu, HI	CT-I	Leeward	1962–2005	42	Natural
16237600	Kanaha Str at Tantalus Drive nr Honolulu, Oahu, HI	CT-A	Leeward	2011–P	1	Natural
16238500	Waihi Stream at Honolulu, Oahu, HI	CT-A	Leeward	1913–20, 1925–83, 2011–P	67	Regulated prior to 1983
16240500	Waiakeakua Str at Honolulu, Oahu, HI	CT-A	Leeward	1913–20, 1925–P	95	Natural
16241600	Manoa Stream at Woodlawn Drive, Oahu, HI	CT-A	Leeward	2011–P	2	Natural
16242500	Manoa Str at Kanewai Field, Honolulu, Oahu, HI	CT-A	Leeward	1999–2005, 2007–P	11	Natural
16244000	Pukele Stream near Honolulu, Oahu, HI	CT-A	Leeward	1926–82, 2002–05, 2010–P	62	Natural
16247450	Wailupe Gulch at debris dam, Oahu, HI	PR	Leeward	1985–86, 2008–10	na	Natural
16247550	Wailupe Gulch at E. Hind Dr. Bridge, Oahu, HI	CT-I	Leeward	2008–10	2	Natural
16247900	Kuliouou Valley at Kuliouou, Oahu, HI	CT-I	Leeward	2009–10	1	Natural
16256000	Kamakalepo Stream nr Kailua, Oahu, HI	PR	Windward	1956–57, 1959–61, 1988–90	na	Natural
16261000	North Br Kahanaiki Stream nr Kailua, Oahu, HI	PR	Windward	1956–57, 1959, 1988–90	na	Natural

16263000	Kahanaiki Stream nr Kailua, Oahu, HI	PR	Windward	1956–57, 1959, 1988–90	na	Natural
16265600	RB of Kamooalii Str nr Kaneohe, Oahu, HI	CT-I	Windward	1983–97	14	Natural
16265700	Kamooalii Str at alt 200 ft nr Kaneohe, Oahu, HI	PR	Windward	1959, 1983, 1985–98, 2006	na	Natural
16266000	Kamooalii Stream nr Kaneohe, Oahu, HI	CT-I	Windward	1980–81	1	Natural
16266500	Hooleinaiwa Str at alt 220 ft nr Kaneohe, Oahu, HI	PR	Windward	1983–84, 1988–97	na	Natural
16267500	Hooleinaiwa Str abv conf w Kamooalii Str, Oahu, HI	PR	Windward	1983–86, 1988–98	na	Natural
16269500	Kuou Str at alt 220 ft nr Kaneohe, Oahu, HI	PR	Windward	1959, 1983–86, 1988–98	na	Natural
16270500	Kamooalii Stream bl Kuou Str nr Kaneohe, Oahu, HI	CT-I	Windward	1967–70, 1972–76	7	Natural
16273950	SF Kapunahala Str at Kaneohe, Oahu, HI	CT-I	Windward	1987–98	10	Natural
16274500	Keaahala Stream at Kaneohe, Oahu, HI	PR	Windward	1953–55	na	Natural
16275000	Heeia Stream at Haiku Valley nr Kaneohe, Oahu, HI	CT-A	Windward	1914–19, 1939–77, 1982–P	74	Natural
16278000	Iolekaa Stream mauka near Heeia, Oahu, HI	CT-I	Windward	1940–70	28	Regulated since 7/1966
16283000	Kahaluu Stream near Heeia, Oahu, HI	CT-I	Windward	1935–71	35	Regulated since 1947
16284000	Waihee Stream nr Heeia, Oahu, HI	CT-I	Windward	1936–82	46	Regulated since 2/1955
16294400	NF Waikane Stream at alt 220 ft, Oahu, HI	PR	Windward	1988–90, 2002–03	na	Natural
16297000	Kawa Stream near Kahana, Oahu, HI	PR	Windward	1914–16, 1958, 1960–61, 1966, 1971–72, 1974–81, 1983–85, 1988–90, 2002–03	na	Natural
16301050	Punaluu Str abv Punaluu Ditch Intake, Oahu, HI	CT-A	Windward	1953–P	60	Natural
16304200	Kaluanui Stream nr Punaluu, Oahu, HI	CT-A	Windward	1967–P	46	Natural
16308990	Malaekahana Stream nr Laie, Oahu, HI	CT-I	Windward	1963–71	8	Natural
16325000	Kamananui Str at Pupukea Mil Rd, Oahu, HI	CT-I	Leeward	1963–2001	38	Natural
16329000	Kaiwikoele Stream Trib nr Maunawai, Oahu, HI	CT-I	Leeward	1967–71	2	Natural
16330000	Kamananui Str at Maunawai, Oahu, HI	CT-A	Leeward	1958–P	55	Natural
16345000	Opaeula Str nr Wahiawa, Oahu, HI	CT-A	Leeward	1959–P	54	Natural
212317158003701	Kapakahi Stream above Farrington Highway, Oahu, HI	PR	Leeward	1967–70, 1972–2012	na	Natural
212504157490001	NB Heeia Str at Hololio St nr Iolekaa, Oahu, HI	PR	Windward	1959–63, 1981	na	Natural
212633157520201	SF Waihee Stream 75 ft blw upper falls, Oahu, HI	PR	Windward	1955–57, 1959, 1961–62	na	Natural
212635157520701	NF Waihee Stream nr upper falls, Oahu, HI	PR	Windward	1955–57, 1959, 1961	na	Natural
212639157515901	SF Waihee Str at alt 500 ft, Oahu, HI	PR	Windward	1955, 1961–64, 1967	na	Natural
212641157520001	NF Waihee Str .1 mi US SF conf, Oahu, HI	PR	Windward	1954–55, 1961–64, 1967	na	Natural
212642157514801	Right trib Waihee Str at alt 350ft, Oahu, HI	PR	Windward	1955–57, 1959, 1961	na	Natural
212642157515301	Waihee Str 100 ft blw upper fork, Oahu, HI	PR	Windward	1961–64	na	Natural
212643157514801	Right trib Waihee Str at alt 330 ft, Oahu, HI	PR	Windward	1954, 1961–63, 1967	na	Natural
212643157514901	Waihee Str 540 ft DS upper fork, Oahu, HI	PR	Windward	1961–64	na	Natural
212644157514801	Waihee Str 640 ft blw fork and trib, Oahu, HI	PR	Windward	1961–62	na	Natural
212647157514601	Upper LB Waihee 300 ft abv conf, Oahu, HI	PR	Windward	1955–57, 1959, 1961	na	Natural
212847158091401	Hiu Str abv flume outlet fr Kumaipo Str, Oahu, HI	PR	Leeward	1947–57	na	Natural
212851158092501	Kumaipo Str US div to Hiu Str, Oahu, HI	PR	Leeward	1947–57	na	Natural
212854158093101	Punanaula Str .2 mi blw Tunnel 17, Oahu, HI	PR	Leeward	1948–57	na	Natural

212904158092601	Kumaipo Stream below tunnel 16, Oahu, HI	PR	Leeward	1948–57, 1981	na	Natural
212906158083101	Kanewai Str abv flume entrance, Oahu, HI	PR	Leeward	1947–57	na	Natural
212906158092601	Kumaipo Stream above tunnel 16, Oahu, HI	PR	Leeward	1981, 1985	na	Natural
212913158084701	East Fork Kalalalu .2mi US fork, Oahu, HI	PR	Leeward	1948–57	na	Natural
212914158084901	WF Kalalula .15mi US fork blw Tun15, Oahu, HI	PR	Leeward	1947–57	na	Natural
212926158084701	LB of WF Kalalula abv conf, blw Tun11, Oahu, HI	PR	Leeward	1948–57	na	Natural
212926158084801	RB of WF Kalalula Stream abv fork, Oahu, HI	PR	Leeward	1947–57	na	Natural
212931158084601	RB of WF Kalalula Stream abv Tunnel 14, Oahu, HI	PR	Leeward	1947–57	na	Natural
213302157535401	Punaluu Str 300 ft abv spring inflow, Oahu, HI	PR	Windward	1960, 1988–90	na	Natural
213303157535501	Waihoi Str 80 ft US Punaluu Str, Oahu, HI	PR	Windward	1988–90	na	Natural
213331157540101	RB of left trib Punaluu Str blw ditch, Oahu, HI	PR	Windward	1958–60, 1998	na	Natural
213332157535601	Punaluu Stream at altitude 140 feet, Oahu, HI	PR	Windward	2004–05	na	Regulated
213332157540201	LB of left trib Punaluu Str blw ditch, Oahu, HI	PR	Windward	1958–62	na	Natural
213344157535301	Punaluu Stream at altitude 100 feet, Oahu, HI	PR	Windward	2004–05	na	Regulated
213402157533701	Punaluu Stream at altitude 35 feet, Oahu, HI	PR	Windward	1960, 1962, 2004–05	na	Regulated
213425157531701	Punaluu Stream at altitude 10 feet, Oahu, HI	PR	Windward	2004–05	na	Regulated
213439157545001	Kaluanui Str 100 ft blw Sacred Falls, Oahu, HI	PR	Windward	1958–59, 1961–62, 1965, 1988–90	na	Natural
213503157543201	Kaluanui Str at lower trail crossing, Oahu, HI	PR	Windward	1965, 1983, 1988–90	na	Natural
213517157542101	Kaluanui Str .2mi DS stn16304200, Oahu, HI	PR	Windward	1958–61	na	Natural
213726158004901	NF Kamananui Str on Pupukea Mil Rd, Oahu, HI	PR	Leeward	1945, 1965–66	na	Natural
213755158011601	SF Elehaha Stream at Pupukea Mil Road, Oahu, HI	PR	Leeward	1965–66	na	Natural
213801158011201	NF Elehaha Str at Pupukea Mil Rd, Oahu, HI	PR	Leeward	1965–66	na	Natural
213846157594401	Oio Str at Drum Rd lower crossing, Oahu, HI	PR	Leeward	1945, 1965–66	na	Natural
			Moloka'i			
16400000	Halawa Stream near Halawa, Molokai, HI	CT-A	Windward	1917–32, 1937–P	88	Natural
16402000	Pulena Stream near Wailau, Molokai, HI	CT-I	Windward	1919–28, 1937–57	27	Natural
16403000	Waiakeakua Stream nr Wailau, Molokai, HI	CT-I	Windward	1919–29, 1937–57	27	Natural
16403400	Kapuhi Str at alt 1000 ft nr Pelekunu, Molokai, HI	PR	Windward	1968–95	na	Natural
16403500	Kawailena Stream nr Pelekunu, Molokai, HI	PR	Windward	1968–95	na	Natural
16403600	Kapuhi Stream nr Pelekunu, Molokai, HI	CT-I	Windward	1968–70	2	Natural
16403700	Kawainui Str at alt 1000 ft nr Pelekunu, Molokai, HI	PR	Windward	1968–95	na	Natural
16403800	Kawaipaka Stream nr Pelekunu, Molokai, HI	PR	Windward	1968–95	na	Natural
[4]16403900	Kawainui Stream nr Pelekunu, Molokai, HI	CT-I	Windward	1968–79, 1994–96	13	Natural
[4]16403900	Kawainui Stream nr Pelekunu, Molokai, HI	PR	Windward	1970–71, 1980–96	na	Natural
[3]16404000	Pelekunu Stream nr Pelekunu, Molokai, HI	CT-I	Windward	1919–28, 1937–57, 1971–82	36	Natural
[3]16404000	Pelekunu Stream nr Pelekunu, Molokai, HI	PR	Windward	1956–57, 1968–71	na	Natural
16404200	Pilipililau Stream nr Pelekunu, Molokai, HI	CT-I	Windward	1968–97	28	Natural
16405000	Lanipuni Stream near Pelekunu, Molokai, HI	CT-I	Windward	1919–29, 1937–57	27	Natural

[5]16405500	Waikolu Str at alt 900 ft nr Kalaupapa, Molokai, HI	CT-I	Windward	1956–2003	46	Regulated since 11/1960
[5]16408000	Waikolu Str bl pipe cross nr Kalaupapa, Molokai	CT-I	Windward	1919–32, 1937–96	68	Regulated since 11/1960
16411400	Kakaako Gulch near Mauna Loa, Molokai, HI	CT-I	Leeward	1963–72	9	Natural
16413000	Kapuna Stream nr Kalae, Molokai, HI	CT-I	Leeward	1940–49	9	Natural
16414000	Kaunakakai Gulch at Kaunakakai, Molokai, HI	CT-I	Leeward	1950–98	48	Natural
[4]16416000	Punaula Gulch nr Pukoo, Molokai, HI	CT-I	Leeward	1947–72	25	Natural
[4]16416000	Punaula Gulch nr Pukoo, Molokai, HI	PR	Leeward	1970–72	na	Natural
210759156525801	LB Pilipililau Str .6 mi US Pelekunu, Molokai, HI	PR	Windward	1968–73	na	Natural
210822156550401	Waikolu Str .1 mi US Molokai Tun, Molokai, HI	PR	Windward	1956–57, 1960–63	na	Regulated since 11/1960
210914156523701	Pelekunu Str .25 mi US Kawaiiki Str, Molokai, HI	PR	Windward	1956–57	na	Natural
211008156554901	Waikolu Stream near mouth, Molokai, HI	PR	Windward	1956–58, 1960, 1963	na	Regulated since 11/1960
			Maui			
16500100	Kepuni Gulch near Kahikinui House, Maui, HI	CT-I	Leeward	1963–72	9	Natural
16500800	Kukuiula Gulch near Kipahulu, Maui, HI	CT-I	Leeward	1963–68	2	Natural
16501000	Palikea Stream bl div dam nr Kipahulu, Maui, HI	CT-I	Leeward	1927–29, 1932–83	48	Natural
16501200	Oheo Gulch at dam near Kipahulu, Maui, HI	CT-A	Leeward	1988–97, 2002–11, P	18	Natural
[3]16502000	Hahalawe Gulch near Kipahulu, Maui, HI	CT-I	Leeward	1927–69	39	Natural
[3]16502000	Hahalawe Gulch near Kipahulu, Maui, HI	PR	Leeward	1969–77	na	Natural
16508000	Hanawi Stream near Nahiku, Maui, HI	CT-A	Windward	1914–15, 1921–P	91	Natural
16510000	Kapaula Gulch near Nahiku, Maui, HI	CT-I	Windward	1921–62	40	Natural
16513000	Waiaka Stream near Nahiku, Maui, HI	CT-I	Windward	1932–47	14	Natural
16515000	Waiohue Gulch near Nahiku, Maui, HI	CT-I	Windward	1921–63	40	Natural
16516000	Kopiliula Stream near Keanae, Maui, HI	CT-I	Windward	1914–17, 1921–57	36	Natural
16517000	East Wailuaiki Stream near Keanae, Maui, HI	CT-I	Windward	1914–17, 1922–57	37	Natural
16518000	West Wailuaiki Stream near Keanae, Maui, HI	CT-A	Windward	1914–17, 1921–P	93	Natural
16519000	West Wailuanui Stream near Keanae, Maui, HI	CT-I	Windward	1914–17, 1922–57	37	Natural
16520000	East Wailuanui Stream near Keanae, Maui, HI	CT-I	Windward	1914–17, 1921–57	38	Natural
16524000	Honomanu Str at Haiku-uka Bdry nr Kailiili, Maui, HI	CT-I	Windward	1919–27, 1932–34, 1962–68	14	Regulated since 9/1968
16527000	Honomanu Stream near Keanae, Maui, HI	CT-I	Windward	1913–63	49	Natural
16531000	Kula div from Haipuaena Str nr Olinda, Maui, HI	Ditch	Windward	1945–85	40	Regulated
[6]16531100	Haipuaena Str at Kula PL intake nr Olinda, Maui, HI	CT-I	Windward	1946–68	22	Regulated
16542000	E B Puohokamoa Str at Haiku-uka Brdy nr Kailiili, Maui, HI	PR	Windward	1963–68	na	Natural
16552600	Waikamoi Stream at Puu Luau nr Olinda, Maui, HI	CT-I	Windward	1949–66	15	Natural
16552800	Waikamoi Str abv Kula PL intake nr Olinda, Maui,HI	CT-A	Windward	1953–68, 2009–P	19	Natural
16557000	Alo Stream near Huelo, Maui, HI	CT-I	Windward	1911–57	46	Natural
16565000	Kaaiea Gulch near Huelo, Maui, HI	CT-I	Windward	1922–62	39	Natural
16566000	Oopuola Stream near Huelo, Maui, HI	CT-I	Windward	1930–57	27	Natural
16569100	Nailiilihaele Stream nr Kailiili, Maui, HI	PR	Windward	1963–68	na	Natural
16569700	W Br Nailiilihaele Stream near Kailiili, Maui, HI	PR	Windward	1965–69	na	Natural

16570000	Nailiihaele Stream nr Huelo, Maui, HI	CT-I	Windward	1911, 1913–75	55	Regulated prior to 1922
16576200	E Br Kailua Stream nr Kailiili, Maui, HI	PR	Windward	1963–69	na	Natural
16577000	Kailua Stream near Huelo, Maui, HI	CT-I	Windward	1913–58	40	Natural
16585000	Hoolawanui Stream nr Huelo, Maui, HI	CT-I	Windward	1911–71	60	Natural
16586000	Hoolawaliilii Stream near Huelo, Maui, HI	CT-I	Windward	1912–57	45	Natural
16587000	Honopou Stream near Huelo, Maui, HI	CT-A	Windward	1911–P	102	Natural
16596200	Halehaku Gulch near Kailiili, Maui, HI	CT-I	Windward	1965–71	6	Natural
16604500	Wailuku River at Kepaniwai Park nr Wailuku, Maui, HI	CT-A	Windward	1983–P	30	Natural
16614000	Waihee River at Dam near Waihee, Maui, HI	CT-A	Windward	1983–P	29	Natural
16618000	Kahakuloa Stream near Honokohau, Maui, HI	CT-A	Windward	1939–43, 1947–70, 1974–P	64	Natural
16620000	Honokohau Stream near Honokohau, Maui, HI	CT-A	Windward	1913–20, 1922–88, 1990–P	95	Natural
[4]16647000	Ukumehame Gulch nr Olowalu, Maui, HI	CT-I	Windward	1911–19	3	Natural
[4]16647000	Ukumehame Gulch nr Olowalu, Maui, HI	PR	Leeward	1920, 2006, 2012–P	na	Natural
16660000	Kulanihakoi Gulch near Kihei, Maui, HI	CT-I	Leeward	1962–70	7	Natural
205000156355801	Olowalu Stream 800 ft abv intake, Maui, HI	PR	Leeward	2012–P	na	Natural
205117156365201	Launiupoko Stream 100 ft abv intake, Maui, HI	PR	Leeward	2008, 2012–P	na	Natural
205121156321501	Waikapu Stream near alt 1,160 ft, Maui, HI	PR	Windward	2006–08	na	Natural
205122156320101	Unnamed Trib to Waikapu Str at 1060 ft, Maui, HI	PR	Windward	2004, 2007–08	na	natural
205239156372101	Kauaula Stream US of upper intake, Maui, HI	PR	Leeward	2012–P	na	Natural
205257156321002	Trib to Wailuku River at Kepaniwai Park, Maui, HI	PR	Windward	2004, 2006–08	na	Natural
205302156305601	Wailuku River near alt 395 ft, Maui, HI	PR	Windward	2006, 2008	na	Regulated
205303156314701	Wailuku River near alt 595 ft, Maui, HI	PR	Windward	2006–08	na	Regulated
205334156382201	Kanaha Stream .2 mi abv intake, Maui, HI	PR	Leeward	2012–P	na	Natural
205404156372401	Kahoma Stream US of upper intake, Maui, HI	PR	Leeward	2012–P	na	Natural
205426156313601	South Waiehu Stream near alt 670 ft, Maui, HI	PR	Windward	2007–08	na	Natural
205434156315701	North Waiehu Stream near alt 920 ft, Maui, HI	PR	Windward	2006–08	na	Natural
205455156394301	Hahakea Gulch 500 ft abv Honokohau Ditch, Maui, HI	PR	Leeward	2011–12	na	Natural
205511156393401	Wahikuli Gulch .2 mi abv Honokohau Ditch, Maui, HI	PR	Leeward	2011–12	na	Natural
205545156371601	Kapaloa Str 50 ft abv intake, Maui, HI	PR	Leeward	2012–P	na	Natural
205554156370701	Amalu Str 100 ft abv intake, Maui, HI	PR	Leeward	1911, 1967, 2012–P	na	Natural
205627156323401	Huluhulupueo Stream at Waihee River, Maui, HI	PR	Windward	2004, 2006–08	na	Natural
205740156385601	Kahana Str at Honokohau siphon, Maui, HI	PR	Leeward	2011–12	na	Natural
205844156380501	Honokahua Str 500 ft abv Honokohau Ditch, Maui, HI	PR	Leeward	2011–12	na	Natural
205856156370801	Honolua Stream 40 ft abv intake, Maui, HI	PR	Leeward	1920–21, 1967, 2008, 2012–P	na	Natural
205921156370101	Papua Gulch .5 mi bl Honokohau Ditch, Maui, HI	PR	Leeward	2011–12	na	Natural
205938156382201	Mokupea Gulch at alt. 280 ft, Maui, HI	PR	Leeward	2012	na	Natural
			Hawai‘i			
16700000	Waiakea Stream nr Mountain View, HI	CT-I	Windward	1930–95	65	Natural
16700600	Waiakea Stream at Hoaka Road, HI	CT-I	Windward	2003–05	2	Natural

16701700	Wailuku River near Pua Akala, HI	CT-I	Windward	1964–65	1	Natural
16701750	Wailuku River nr Humuula, HI	CT-I	Windward	1965–72	7	Natural
16701800	Wailuku River nr Kaumana, HI	CT-I	Windward	1966–82	16	Natural
16704000	Wailuku River nr Piihonua, HI	CT-A	Windward	1928–P	82	Regulated prior to 1968 and after 5/1993
16717000	Honolii Stream nr Papaikou, HI	CT-A	Windward	1911–13, 1967–P	47	Natural
16717600	Alia Stream near Hilo, HI	CT-I	Windward	1962–72	9	Natural
16717800	Pohakupuka Stream near Papaaloa, HI	CT-I	Windward	1962–79	17	Natural
16720000	Kawainui Stream nr Kamuela, HI	CT-A	Windward	1964–P	49	Natural
16720300	Kawaiki Stream near Kamuela, HI	CT-I	Windward	1968–99	31	Natural
16725000	Alakahi Stream near Kamuela, HI	CT-A	Windward	1964–P	49	Regulated prior to 1997
16737000	Waiilikahi Stream near Waimanu, HI	CT-I	Windward	1939–59	20	Natural
16737500	Waimanu Stream near Kamuela, HI	PR	Windward	1992–94	na	Natural
16738000	Kaimu Stream near Waimanu, HI	CT-I	Windward	1939–47, 1950–52	8	Natural
16739000	Punaluu Stream near Waimanu, HI	CT-I	Windward	1939–52	12	Natural
16740000	Waiaalala Stream near Waimanu, HI	CT-I	Windward	1939–52	12	Natural
16741000	Paopao Stream near Waimanu, HI	CT-I	Windward	1939–52	13	Natural
16742000	Kukui Stream near Waimanu, HI	CT-I	Windward	1939–52, 1959–66	19	Natural
16757000	Waikoloa Stream nr Kamuela, HI	CT-I	Windward	1947–71	24	Natural
16759200	R Br Waiaha Stream near Holualoa, HI	CT-I	Leeward	1960–82	22	Natural
16759600	Waiaha Stream at Holualoa, HI	CT-I	Leeward	2002–03	0	Natural
16759800	Kiilae Stream near Honaunau, HI	CT-I	Leeward	1958–82	24	Natural
16764000	Hilea Gulch tributary near Honuapo, HI	CT-I	Leeward	1966–91	25	Natural
16765000	Hilea Gulch Trib No 2 near Honuapo	CT-I	Leeward	1966–82	16	Natural
16767000	Ninole Gulch near Punaluu, HI	CT-I	Leeward	1966–82	16	Natural
16770500	Paauau Gulch at Pahala, HI	CT-A	Leeward	1962–79, 2001–P	28	Natural
194258155163301	Wailuku River trib Site B1 nr conf, HI	PR	Windward	1965–66	na	Natural
200351155372801	Waima Stream above L. Hamakua Ditch near Waipio,HI	PR	Windward	2000–01, 2003–05	na	Natural
200505155383801	Kawainui Str above L. Hamakua Ditch nr Waipio, HI	PR	Windward	2000–01, 2003–05	na	Natural
200657155395301	Waihilau Str 2 mi US Kakaauki conf, HI	PR	Windward	1939–52	na	Natural

[1]Natural-flow record based on combined concurrent records at stations 16061000, 16062000, and 16063000, and subtracting concurrent flow record at station 16100000.

[2]Natural-flow record based on combined concurrent records at stations 16095900 and 16097000, and the combined record consisted of less than 10 complete water years.

[3]Station operated as a continuous-record and partial-record station; continuous-record data were used in the low-flow analysis of this study.

[4]Station operated as a continuous-record and partial-record station; partial-record data were used in the low-flow analysis of this study.

[5]Only data collected prior to November 1960 were used on Waikolu Stream because of the unknown effects associated with diversions by the Molokai Tunnel.

[6]Natural-flow record based on combined concurrent records at stations 16531000 and 16531100.

Appendix 2. Summary of Record-Augmentation Technique, Regression Equations, and Associated Select Regression Statistics for Natural Low-Flow Duration Estimates at Continuous-Record Streamflow-Gaging Stations and Partial-Record Stations on the Islands of Kaua‘i, O‘ahu, Moloka‘i, Maui, and Hawai‘i for Base Period 1984–2013.

[--, not applicable; ft^3/s, cubic feet per second; Graphical, graphical-correlation record-extension technique; ID, identifier; MOVE.1, Maintenance of Variance Extension Type 1; NSE, Nash-Sutcliff coefficient of efficiency; r, correlation coefficient; r^2, coefficient of determination; RMSE, root mean square error; Qxx, selected percentages of time (from 50–95 percent) a discharge was equaled or exceeded; SREF, Streamflow Record Extension Facilitator; X_i, base-10 logarithm of the computed low-flow duration discharge at the index station; Y_i, base-10 logarithm of the estimated low-flow duration discharge at the partial-record station]

Station ID	Q_{xx}	Index station ID	Record-augmentation technique	Number of concurrent data values	Range of flows at index station, in ft^3/s	MOVE.1 regression equation[1]	Regression statistics generated from SREF			
							r	r^2	RMSE	NSE
Kaua‘i										
16013000	50	16010000	MOVE.1	26	5.6–22	$Y_i = 0.48 + 1.18 (X_i - 1.10)$	0.92	0.84	0.070	0.57
	55	16010000	MOVE.1	26	4.8–20	$Y_i = 0.42 + 1.16 (X_i - 1.04)$	0.88	0.78	0.083	0.49
	60	16010000	MOVE.1	26	4.3–18	$Y_i = 0.37 + 1.11 (X_i - 1.00)$	0.87	0.76	0.080	0.44
	65	16010000	MOVE.1	26	3.9–16	$Y_i = 0.32 + 1.16 (X_i - 0.95)$	0.84	0.70	0.093	0.39
	70	16010000	MOVE.1	26	3.6–14	$Y_i = 0.26 + 1.13 (X_i - 0.90)$	0.82	0.68	0.094	0.36
	75	--	--	--	--	--	--	--	--	--
	80	--	--	--	--	--	--	--	--	--
	85	16019000	MOVE.1	17	2.6–11	$Y_i = 0.10 + 2.28 (X_i - 0.51)$	0.77	0.60	0.14	0.38
	90	--	--	--	--	--	--	--	--	--
	95	--	--	--	--	--	--	--	--	--
16017000	50	16108000	MOVE.1	10	70–99	$Y_i = 0.93 + 1.76 (X_i - 1.92)$	0.93	0.86	0.034	0.59
	55	16108000	MOVE.1	10	65–88	$Y_i = 0.86 + 1.79 (X_i - 1.88)$	0.90	0.81	0.038	0.54
	60	16108000	MOVE.1	10	60–82	$Y_i = 0.81 + 1.90 (X_i - 1.85)$	0.93	0.87	0.033	0.66
	65	16108000	MOVE.1	10	56–79	$Y_i = 0.75 + 2.09 (X_i - 1.82)$	0.96	0.92	0.028	0.66
	70	16108000	MOVE.1	13	53–75	$Y_i = 0.69 + 1.01 (X_i - 0.63)$	0.94	0.88	0.032	0.58
	75	16108000	MOVE.1	13	51–69	$Y_i = 0.64 + 0.97 (X_i - 0.58)$	0.93	0.87	0.032	0.50
	80	16108000	MOVE.1	13	51–66	$Y_i = 0.58 + 1.08 (X_i - 0.54)$	0.84	0.71	0.052	0.38
	85	16108000	MOVE.1	13	48–62	$Y_i = 0.52 + 1.17 (X_i - 0.50)$	0.85	0.72	0.055	0.40
	90	16108000	MOVE.1	13	45–59	$Y_i = 0.45 + 1.11 (X_i - 0.44)$	0.78	0.61	0.069	0.39
	95	16108000	MOVE.1	13	41–55	$Y_i = 0.37 + 1.31 (X_i - 0.36)$	0.86	0.74	0.063	0.56
16063000	50	16068000	MOVE.1	41	16–51	$Y_i = 1.66 + 0.91 (X_i - 1.46)$	0.92	0.85	0.037	0.59
	55	16068000	MOVE.1	41	15–47	$Y_i = 1.63 + 0.90 (X_i - 1.43)$	0.91	0.82	0.040	0.55
	60	16068000	MOVE.1	41	14–44	$Y_i = 1.60 + 0.87 (X_i - 1.40)$	0.88	0.77	0.046	0.50
	65	16068000	MOVE.1	41	14–41	$Y_i = 1.57 + 0.90 (X_i - 1.37)$	0.88	0.77	0.045	0.54
	70	16068000	MOVE.1	41	13–40	$Y_i = 1.54 + 0.84 (X_i - 1.34)$	0.87	0.76	0.045	0.53
	75	16068000	MOVE.1	41	12–38	$Y_i = 1.52 + 0.84 (X_i - 1.32)$	0.88	0.77	0.043	0.52
	80	16068000	MOVE.1	41	12–36	$Y_i = 1.49 + 0.79 (X_i - 1.29)$	0.87	0.76	0.042	0.53

	85	16068000	MOVE.1	41	11–33	$Y_i = 1.46 + 0.72 (X_i - 1.26)$	0.89	0.79	0.037	0.56
	90	16068000	MOVE.1	41	10–29	$Y_i = 1.43 + 0.68 (X_i - 1.22)$	0.86	0.74	0.040	0.50
	95	16068000	Graphical	41	9.4–25	--	0.82	--	--	--
16081500	50–95	16071500	MOVE.1	9	0.54–3.3	$Y_i = -0.12 + 0.75 (X_i - 0.14)$	0.95	0.91	0.077	0.69
16085500	50–95	16097500	MOVE.1	9	4.0–8.8	$Y_i = 0.44 + 1.85 (X_i - 0.76)$	0.89	0.79	0.090	0.51
16088300	50–95	16097500	MOVE.1	9	4.0–8.8	$Y_i = 0.66 + 1.59 (X_i - 0.76)$	0.91	0.83	0.078	0.52
16088500	50–95	16071500	MOVE.1	9	0.54–3.0	$Y_i = 0.37 + 0.66 (X_i - 0.16)$	0.96	0.92	0.054	0.70
16097000	50–95	16068000	Graphical	107	9.7–32	--	0.79	--	--	--
16101003	50	16068000	MOVE.1	10	20–39	$Y_i = 1.80 + 0.70 (X_i - 1.43)$	0.95	0.91	0.021	0.67
	55	16068000	MOVE.1	10	18–39	$Y_i = 1.77 + 0.62 (X_i - 1.40)$	0.95	0.90	0.022	0.63
	60	16068000	MOVE.1	10	17–36	$Y_i = 1.75 + 0.62 (X_i - 1.38)$	0.95	0.90	0.020	0.65
	65	16068000	MOVE.1	10	16–34	$Y_i = 1.73 + 0.67 (X_i - 1.35)$	0.96	0.93	0.017	0.72
	70	16068000	MOVE.1	10	16–32	$Y_i = 1.71 + 0.66 (X_i - 1.32)$	0.95	0.91	0.018	0.66
	75	16068000	MOVE.1	10	15–30	$Y_i = 1.69 + 0.69 (X_i - 1.31)$	0.95	0.91	0.019	0.70
	80	16068000	MOVE.1	10	14–28	$Y_i = 1.67 + 0.66 (X_i - 1.28)$	0.95	0.89	0.020	0.68
	85	16068000	MOVE.1	10	14–27	$Y_i = 1.65 + 0.66 (X_i - 1.25)$	0.96	0.91	0.017	0.74
	90	16068000	MOVE.1	10	13–24	$Y_i = 1.63 + 0.60 (X_i - 1.22)$	0.94	0.89	0.020	0.67
	95	16068000	MOVE.1	10	11–22	$Y_i = 1.60 + 0.54 (X_i - 1.17)$	0.97	0.93	0.014	0.74
16103000	50	16097500	MOVE.1	17	5.0–8.1	$Y_i = 2.08 + 1.23 (X_i - 0.79)$	0.90	0.81	0.037	0.59
	55	16097500	MOVE.1	17	4.8–7.7	$Y_i = 2.06 + 1.22 (X_i - 0.77)$	0.90	0.81	0.036	0.60
	60	16097500	MOVE.1	17	4.6–7.2	$Y_i = 2.04 + 1.21 (X_i - 0.75)$	0.92	0.85	0.031	0.64
	65	16097500	MOVE.1	17	4.4–6.7	$Y_i = 2.01 + 1.20 (X_i - 0.73)$	0.91	0.83	0.032	0.61
	70	16097500	MOVE.1	17	4.1–6.4	$Y_i = 1.99 + 1.15 (X_i - 0.72)$	0.92	0.85	0.029	0.62
	75	16097500	MOVE.1	17	3.9–6.1	$Y_i = 1.97 + 1.21 (X_i - 0.70)$	0.91	0.83	0.031	0.59
	80	16097500	MOVE.1	17	3.6–6.0	$Y_i = 1.95 + 1.16 (X_i - 0.68)$	0.89	0.79	0.034	0.54
	85	16097500	MOVE.1	17	3.4–5.7	$Y_i = 1.93 + 1.19 (X_i - 0.65)$	0.89	0.80	0.033	0.52
	90	16097500	MOVE.1	17	3.1–5.4	$Y_i = 1.91 + 1.19 (X_i - 0.63)$	0.88	0.78	0.036	0.52
	95	16097500	MOVE.1	17	2.9–5.1	$Y_i = 1.88 + 1.08 (X_i - 0.60)$	0.85	0.72	0.037	0.41
16115000	50	16010000	MOVE.1	9	5.6–16	$Y_i = 0.87 + 0.91 (X_i - 1.04)$	0.91	0.83	0.065	0.53
	55	16010000	MOVE.1	9	4.8–15	$Y_i = 0.84 + 0.84 (X_i - 0.98)$	0.93	0.87	0.053	0.60
	60	16010000	MOVE.1	9	4.3–13	$Y_i = 0.81 + 0.83 (X_i - 0.95)$	0.94	0.89	0.049	0.65
	65	16010000	MOVE.1	9	3.9–11	$Y_i = 0.79 + 0.88 (X_i - 0.89)$	0.94	0.88	0.051	0.65
	70	16010000	MOVE.1	9	3.6–9.8	$Y_i = 0.77 + 0.90 (X_i - 0.84)$	0.91	0.84	0.060	0.58
	75	16010000	MOVE.1	9	3.4–8.7	$Y_i = 0.74 + 0.91 (X_i - 0.79)$	0.91	0.82	0.059	0.57
	80	16010000	MOVE.1	9	3.1–7.6	$Y_i = 0.72 + 0.85 (X_i - 0.73)$	0.83	0.69	0.072	0.47
	85	16010000	MOVE.1	9	2.8–6.7	$Y_i = 0.70 + 0.86 (X_i - 0.67)$	0.79	0.63	0.077	0.50
	90	16010000	MOVE.1	9	2.5–5.9	$Y_i = 0.67 + 0.92 (X_i - 0.61)$	0.74	0.55	0.086	0.42
	95	16010000	MOVE.1	9	2.2–5.3	$Y_i = 0.63 + 0.92 (X_i - 0.51)$	0.83	0.69	0.073	0.50
16116000	50	16010000	MOVE.1	9	5.6–16	$Y_i = 0.19 + 0.87 (X_i - 1.04)$	0.95	0.90	0.047	0.72

	55	16010000	MOVE.1	9	4.8–15	$Y_i = 0.14 + 0.85 (X_i - 0.98)$	0.97	0.95	0.034	0.75
	60	16010000	MOVE.1	9	4.3–13	$Y_i = 0.09 + 0.84 (X_i - 0.95)$	0.98	0.95	0.033	0.78
	65	16010000	MOVE.1	9	3.9–11	$Y_i = 0.05 + 0.85 (X_i - 0.89)$	0.95	0.90	0.044	0.67
	70	16010000	MOVE.1	9	3.6–9.8	$Y_i = 0.00 + 0.73 (X_i - 0.84)$	0.97	0.95	0.027	0.76
	75	16010000	MOVE.1	9	3.4–8.7	$Y_i = -0.04 + 0.69 (X_i - 0.79)$	0.96	0.92	0.030	0.72
	80	16010000	MOVE.1	9	3.1–7.6	$Y_i = -0.09 + 0.66 (X_i - 0.73)$	0.93	0.87	0.035	0.71
	85	16010000	MOVE.1	9	2.8–6.7	$Y_i = -0.13 + 0.60 (X_i - 0.67)$	0.90	0.80	0.039	0.58
	90	16010000	MOVE.1	9	2.5–5.9	$Y_i = -0.17 + 0.65 (X_i - 0.61)$	0.86	0.74	0.045	0.46
	95	16010000	MOVE.1	9	2.2–5.3	$Y_i = -0.23 + 0.55 (X_i - 0.51)$	0.85	0.72	0.041	0.39
16130000	50–95	All[2]	Graphical	--	--	--	--	--	--	--
O‘ahu										
16201000	50–95	16200000	MOVE.1	344	0.29–8.2	$Y_i = 0.19 + 0.85 (X_i - 0.32)$	0.95	0.91	0.087	0.71
16206000	50–95	16200000	MOVE.1	251	0.34–8.2	$Y_i = -0.09 + 1.24 (X_i - 0.31)$	0.94	0.89	0.135	0.68
16211003	50	16330000	Graphical	15	2.0–7.1	--	0.88	--	--	--
	55	16330000	MOVE.1	15	1.6–6.0	$Y_i = 0.41 + 0.83 (X_i - 0.47)$	0.91	0.84	0.060	0.58
	60	16330000	MOVE.1	15	1.3–5.3	$Y_i = 0.34 + 0.79 (X_i - 0.39)$	0.93	0.86	0.055	0.63
	65	16330000	MOVE.1	15	0.89–4.3	$Y_i = 0.27 + 0.78 (X_i - 0.30)$	0.95	0.91	0.050	0.70
	70	16345000	MOVE.1	14	1.2–3.0	$Y_i = 0.21 + 1.50 (X_i - 0.36)$	0.91	0.83	0.073	0.59
	75	16345000	MOVE.1	14	1.0–2.5	$Y_i = 0.14 + 1.54 (X_i - 0.28)$	0.88	0.78	0.096	0.54
	80	16345000	MOVE.1	14	0.80–2.2	$Y_i = 0.06 + 1.66 (X_i - 0.21)$	0.91	0.83	0.093	0.64
	85	16345000	MOVE.1	14	0.57–1.8	$Y_i = -0.03 + 1.69 (X_i - 0.11)$	0.88	0.78	0.117	0.52
	90	16345000	MOVE.1	14	0.30–1.5	$Y_i = -0.15 + 1.72 (X_i + 0.01)$	0.85	0.73	0.151	0.42
	95	--	--	--	--	--	--	--	--	--
16211300	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16212800	50	16226200	MOVE.1	25	0.010–2.0	$Y_i = 0.43 + 0.32 (X_i + 0.63)$	0.89	0.80	0.103	0.57
	55	16226200	MOVE.1	24	0–1.7	$Y_i = 0.36 + 0.34 (X_i + 0.75)$	0.91	0.83	0.097	0.61
	60	16345000	MOVE.1	49	1.4–7.3	$Y_i = 0.27 + 1.48 (X_i - 0.50)$	0.91	0.83	0.090	0.59
	65	16226200	MOVE.1	25	0–0.90	$Y_i = 0.23 + 0.34 (X_i + 1.03)$	0.90	0.81	0.10	0.62
	70	16226200	MOVE.1	22	0–0.65	$Y_i = 0.18 + 0.34 (X_i + 1.14)$	0.91	0.82	0.092	0.60
	75	16226200	MOVE.1	20	0–0.46	$Y_i = 0.10 + 0.39 (X_i + 1.25)$	0.90	0.82	0.102	0.64
	80	16226200	MOVE.1	20	0–0.33	$Y_i = 0.03 + 0.41 (X_i + 1.40)$	0.94	0.89	0.078	0.70
	85	16345000	Graphical	49	0.50–3.6	--	0.86	--	--	--
	90	16345000	Graphical	49	0.24–3.0	--	0.80	--	--	--
	95	16345000	Graphical	49	0.034–2.2	--	0.81	--	--	--
16216000	50	16226200	Graphical	[3]20	0.020–2.0	--	0.91	--	--	--
	55	16226200	Graphical	[3]20	0.010–1.7	--	0.87	--	--	--
	60	16226200	Graphical	[3]20	0–1.2	--	0.84	--	--	--
	65	16226200	Graphical	[3]20	0–0.90	--	0.83	--	--	--
	70	16226200	Graphical	[3]20	0–0.65	--	0.91	--	--	--

	75	16226200	Graphical	[3] 20	0–0.46	--	0.80	--	--	--
	80	16226200	Graphical	21	0–0.33	--	0.86	--	--	--
	85	16226200	Graphical	21	0–0.18	--	0.81	--	--	--
	90	--	--	--	--	--	--	--	--	--
	95	--	--	--	--	--	--	--	--	--
16226000	50	16226200	MOVE.1	23	0.020–2.0	Y_i = -0.52 + 0.99 (X_i + 0.51)	0.97	0.95	0.147	0.77
	55	16226200	MOVE.1	23	0.010–1.7	Y_i = -0.73 + 1.07 (X_i + 0.71)	0.96	0.93	0.192	0.74
	60	16226200	MOVE.1	22	0–1.2	Y_i = -0.84 + 1.01 (X_i + 0.85)	0.95	0.90	0.210	0.74
	65	16226200	MOVE.1	20	0–0.90	Y_i = -0.96 + 1.01 (X_i + 0.94)	0.95	0.90	0.210	0.71
	70	16226200	MOVE.1	18	0–0.65	Y_i = -1.05 + 1.00 (X_i + 1.00)	0.95	0.91	0.179	0.77
	75	16226200	MOVE.1	16	0–0.46	Y_i = -1.16 + 1.01 (X_i + 1.10)	0.88	0.77	0.267	0.68
	80	16226200	MOVE.1	14	0–0.33	Y_i = -1.30 + 1.07 (X_i + 1.21)	0.93	0.86	0.189	0.65
	85	16226200	MOVE.1	10	0–0.18	Y_i = -1.43 + 1.24 (X_i + 1.23)	0.79	0.62	0.273	0.37
	90	--	--	--	--	--	--	--	--	--
	95	--	--	--	--	--	--	--	--	--
16226400	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16227500	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16228000	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16228200	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16228900	50–95	16345000	MOVE.1	87	0.10–4.7	Y_i = -0.51 + 0.73 (X_i - 0.12)	0.88	0.77	0.156	0.54
16229300	50	16229000	MOVE.1	42	0.78–5.0	Y_i = 0.56 + 0.91 (X_i - 0.37)	0.97	0.94	0.044	0.76
	55	16229000	MOVE.1	42	0.73–4.3	Y_i = 0.51 + 0.88 (X_i - 0.33)	0.95	0.90	0.054	0.68
	60	16229000	MOVE.1	42	0.68–4.0	Y_i = 0.46 + 0.90 (X_i - 0.28)	0.95	0.91	0.055	0.68
	65	16229000	MOVE.1	42	0.62–3.6	Y_i = 0.41 + 0.90 (X_i - 0.23)	0.95	0.90	0.058	0.66
	70	16229000	MOVE.1	42	0.50–3.4	Y_i = 0.37 + 0.88 (X_i - 0.18)	0.94	0.88	0.063	0.64
	75	16229000	MOVE.1	42	0.50–30	Y_i = 0.33 + 0.88 (X_i - 0.13)	0.93	0.86	0.069	0.65
	80	16229000	MOVE.1	42	0.40–2.6	Y_i = 0.27 + 0.88 (X_i - 0.07)	0.88	0.78	0.091	0.57
	85	16229000	MOVE.1	[3] 41	0.35–2.3	Y_i = 0.21 + 0.84 (X_i - 0.02)	0.92	0.85	0.073	0.61
	90	16229000	MOVE.1	[3] 41	0.31–1.9	Y_i = 0.14 + 0.81 (X_i + 0.06)	0.89	0.79	0.088	0.52
	95	16229000	MOVE.1	[3] 41	0.22–1.8	Y_i = 0.06 + 0.81 (X_i + 0.16)	0.90	0.80	0.087	0.56
16237600	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16238500	50–95	16200000	MOVE.1	78	0.47–6.1	Y_i = -0.23 + 1.12 (X_i + 0.34)	0.91	0.83	0.140	0.59
16241600	50–95	16200000	MOVE.1	97	0.47–6.1	Y_i = 0.55 + 0.41 (X_i - 0.35)	0.86	0.73	0.065	0.46
16242500	50	16345000	MOVE.1	11	2.0–5.7	Y_i = 0.71 + 1.04 (X_i - 0.57)	0.92	0.84	0.054	0.57
	55	16208000	MOVE.1	8	3.6–12	Y_i = 0.68 + 0.80 (X_i - 0.82)	0.95	0.90	0.043	0.60
	60	16208000	MOVE.1	8	2.9–11	Y_i = 0.65 + 0.74 (X_i - 0.77)	0.96	0.93	0.037	0.69
	65	16208000	MOVE.1	8	2.4–9.5	Y_i = 0.62 + 0.74 (X_i - 0.71)	0.98	0.95	0.031	0.74
	70	16208000	MOVE.1	8	1.8–8.6	Y_i = 0.60 + 0.63 (X_i - 0.65)	0.98	0.96	0.029	0.79
	75	16208000	MOVE.1	8	1.4–7.6	Y_i = 0.57 + 0.58 (X_i - 0.58)	0.97	0.95	0.031	0.75

	80	16208000	MOVE.1	8	1.1–6.8	$Y_i = 0.54 + 0.50 (X_i - 0.51)$	0.94	0.89	0.044	0.63
	85	16229000	MOVE.1	11	0.44–1.8	$Y_i = 0.51 + 0.71 (X_i - 0.07)$	0.89	0.79	0.060	0.49
	90	16229000	MOVE.1	11	0.37–1.4	$Y_i = 0.46 + 0.81 (X_i + 0.05)$	0.90	0.81	0.063	0.51
	95	16240500	MOVE.1	11	0.91–2.7	$Y_i = 0.39 + 1.19 (X_i - 0.20)$	0.91	0.83	0.061	0.55
16244000	50	16229000	MOVE.1	45	0.78–5.0	$Y_i = -0.16 + 0.98 (X_i - 0.37)$	0.91	0.82	0.077	0.56
	55	16229000	MOVE.1	45	0.73–4.3	$Y_i = -0.20 + 0.90 (X_i - 0.33)$	0.89	0.79	0.079	0.53
	60	16330000	MOVE.1	30	0.59–11	$Y_i = -0.24 + 0.66 (X_i - 0.40)$	0.90	0.81	0.076	0.52
	65	16330000	MOVE.1	30	0.34–10	$Y_i = -0.28 + 0.54 (X_i - 0.29)$	0.92	0.85	0.064	0.61
	70	16330000	MOVE.1	30	0.14–9.0	$Y_i = -0.32 + 0.45 (X_i - 0.18)$	0.92	0.84	0.066	0.60
	75	16330000	MOVE.1	30	0.070–7.0	$Y_i = -0.35 + 0.38 (X_i - 0.06)$	0.89	0.80	0.076	0.54
	80	16345000	MOVE.1	29	0.79–4.1	$Y_i = -0.39 + 0.85 (X_i - 0.20)$	0.86	0.74	0.082	0.48
	85	--	--	--	--	--	--	--	--	--
	90	16240500	MOVE.1	45	0.98–4.0	$Y_i = -0.49 + 1.11 (X_i - 0.31)$	0.79	0.62	0.107	0.38
	95	--	--	--	--	--	--	--	--	--
16256000	50–95	16240500	MOVE.1	8	2.1–3.4	$Y_i = -0.16 + 3.49 (X_i - 0.45)$	0.98	0.96	0.062	0.81
16265600	50	16275000	Graphical	14	1.3–2.3	--	0.86	--	--	--
	55	16275000	Graphical	14	1.3–2.2	--	0.87	--	--	--
	60	16275000	Graphical	14	1.2–2.1	--	0.84	--	--	--
	65	16275000	Graphical	14	1.2–2.1	--	0.84	--	--	--
	70	16275000	Graphical	14	1.1–2.0	--	0.85	--	--	--
	75	16275000	Graphical	14	1.1–2.0	--	0.90	--	--	--
	80	16275000	Graphical	14	1.1–2.0	--	0.89	--	--	--
	85	16275000	Graphical	14	1.1–1.9	--	0.83	--	--	--
	90	16275000	Graphical	14	1.1–1.8	--	0.84	--	--	--
	95	16275000	Graphical	14	1.0–1.7	--	0.80	--	--	--
16278000	50	16301050	Graphical	11	16–28	--	0.86	--	--	--
	55	16240500	Graphical	22	1.4–5.3	--	0.85	--	--	--
	60	16240500	Graphical	22	1.4–5.0	--	0.86	--	--	--
	65	16240500	Graphical	22	1.4–4.9	--	0.87	--	--	--
	70	16240500	Graphical	22	1.3–4.7	--	0.85	--	--	--
	75	16240500	Graphical	22	1.2–4.6	--	0.86	--	--	--
	80	16240500	Graphical	22	1.1–4.4	--	0.81	--	--	--
	85	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--
	95	--	--	--	--	--	--	--	--	--
16284000	50	16240500	Graphical	11	1.6–3.9	--	0.81	--	--	--
	55	16240500	Graphical	11	1.4–3.9	--	0.84	--	--	--
	60	16240500	MOVE.1	11	1.4–3.7	$Y_i = 0.87 + 0.60 (X_i - 0.41)$	0.89	0.79	0.039	0.58
	65	16240500	MOVE.1	11	1.4–3.6	$Y_i = 0.86 + 0.58 (X_i - 0.39)$	0.95	0.90	0.025	0.71

	70	16240500	MOVE.1	11	1.3–3.5	$Y_i = 0.85 + 0.56\ (X_i - 0.37)$	0.96	0.91	0.023	0.73
	75	16240500	MOVE.1	11	1.2–3.3	$Y_i = 0.85 + 0.52\ (X_i - 0.34)$	0.97	0.94	0.019	0.75
	80	16240500	MOVE.1	11	1.1–3.3	$Y_i = 0.84 + 0.47\ (X_i - 0.33)$	0.98	0.96	0.014	0.83
	85	16240500	MOVE.1	11	1.1–3.1	$Y_i = 0.83 + 0.49\ (X_i - 0.30)$	0.97	0.94	0.018	0.82
	90	16240500	MOVE.1	11	1.0–2.9	$Y_i = 0.82 + 0.49\ (X_i - 0.27)$	0.92	0.85	0.028	0.66
	95	16240500	MOVE.1	11	1.0–2.8	$Y_i = 0.81 + 0.53\ (X_i - 0.24)$	0.90	0.82	0.033	0.58
16308990	50–95	16330000	Graphical	195	0–4.9	--	0.81	--	--	--
16325000	50	16330000	MOVE.1	38	1.3–14	$Y_i = 0.51 + 0.75\ (X_i - 0.59)$	0.98	0.97	0.033	0.80
	55	16330000	MOVE.1	38	1.0–12	$Y_i = 0.46 + 0.74\ (X_i - 0.51)$	0.98	0.96	0.038	0.79
	60	16330000	MOVE.1	38	0.84–11	$Y_i = 0.39 + 0.73\ (X_i - 0.42)$	0.98	0.96	0.039	0.80
	65	16330000	MOVE.1	38	0.68–10	$Y_i = 0.32 + 0.70\ (X_i - 0.33)$	0.97	0.94	0.050	0.74
	70	16330000	MOVE.1	38	0.30–9.0	$Y_i = 0.25 + 0.67\ (X_i - 0.23)$	0.96	0.92	0.063	0.72
	75	16330000	MOVE.1	38	0.12–7.0	$Y_i = 0.17 + 0.61\ (X_i - 0.10)$	0.95	0.89	0.082	0.68
	80	16330000	MOVE.1	38	0.040–5.3	$Y_i = 0.09 + 0.53\ (X_i + 0.06)$	0.93	0.87	0.103	0.65
	85	16330000	MOVE.1	38	0.010–4.4	$Y_i = -0.02 + 0.51\ (X_i + 0.29)$	0.90	0.80	0.159	0.60
	90	16330000	Graphical	38	0–3.1	--	0.85	--	--	--
	95	16330000	Graphical	38	0–1.7	--	0.83	--	--	--
16329000	50–95	All[2]	Graphical	--	--	--	--	--	--	--
212639157515901	50–95	16200000	Graphical	13	0.48–6.7	--	0.79	--	--	--
212644157514801	50–85	16200000	Graphical	10	2.2–6.3	--	0.85	--	--	--
213439157545001	50–95	16304200	MOVE.1	10	0.18–1.6	$Y_i = -0.18 + 0.83\ (X_i + 0.17)$	0.99	0.97	0.040	0.79
213503157543201	50–95	16304200	MOVE.1	11	0.18–1.6	$Y_i = -0.15 + 0.95\ (X_i + 0.15)$	0.99	0.98	0.038	0.86
213726158004901	50–90	16330000	Graphical	9	0.12–4.0	--	0.88	--	--	--
213801158011201	50–95	All[2]	Graphical	--	--	--	--	--	--	--
Moloka‘i										
16402000	50	16518000	MOVE.1	13	5.8–13	$Y_i = 1.27 + 0.78\ (X_i - 0.99)$	0.90	0.81	0.038	0.52
	55	16518000	MOVE.1	13	5.0–102	$Y_i = 1.23 + 0.79\ (X_i - 0.93)$	0.90	0.81	0.040	0.48
	60	16518000	MOVE.1	13	4.6–10	$Y_i = 1.19 + 0.82\ (X_i - 0.87)$	0.91	0.82	0.038	0.54
	65	16518000	MOVE.1	13	4.1–9.6	$Y_i = 1.15 + 0.82\ (X_i - 0.83)$	0.90	0.80	0.042	0.47
	70	16518000	MOVE.1	13	3.8–8.7	$Y_i = 1.12 + 0.78\ (X_i - 0.79)$	0.87	0.75	0.044	0.54
	75	16518000	MOVE.1	13	3.4–8.0	$Y_i = 1.07 + 0.81\ (X_i - 0.74)$	0.85	0.72	0.050	0.49
	80	16518000	MOVE.1	13	3.0–7.1	$Y_i = 1.03 + 0.78\ (X_i - 0.68)$	0.80	0.64	0.058	0.50
	85	16518000	MOVE.1	13	2.6–6.5	$Y_i = 0.99 + 0.82\ (X_i - 0.62)$	0.85	0.73	0.054	0.51
	90	16518000	MOVE.1	13	2.2–6.0	$Y_i = 0.95 + 0.79\ (X_i - 0.56)$	0.90	0.81	0.047	0.61
	95	16518000	MOVE.1	13	1.6–5.1	$Y_i = 0.88 + 0.68\ (X_i - 0.47)$	0.83	0.69	0.058	0.36
16403000	50	16400000	MOVE.1	[4] 12	9.3–16	$Y_i = 0.84 + 0.56\ (X_i - 1.12)$	0.93	0.86	0.018	0.62
	55	16400000	MOVE.1	[4] 12	8.4–14	$Y_i = 0.81 + 0.57\ (X_i - 1.07)$	0.92	0.85	0.018	0.57
	60	16400000	MOVE.1	[4] 12	7.6–13	$Y_i = 0.79 + 0.46\ (X_i - 1.03)$	0.93	0.86	0.015	0.61
	65	16400000	MOVE.1	[4] 12	6.8–12	$Y_i = 0.76 + 0.40\ (X_i - 0.99)$	0.88	0.77	0.018	0.52

	70	16400000	MOVE.1	[4] 12	6.0–11	$Y_i = 0.73 + 0.33\ (X_i - 0.94)$	0.92	0.84	0.012	0.52
	75	16620000	Graphical	[4] 12	12–23	--	0.84	--	--	--
	80	--	--	--	--	--	--	--	--	--
	85	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--
	95	--	--	--	--	--	--	--	--	--
16404000	50	16587000	Graphical	22	0.96–3.4	--	0.78	--	--	--
	55	16620000	Graphical	22	13–34	--	0.79	--	--	--
	60	16400000	Graphical	22	5.5–14	--	0.76	--	--	--
	65	16400000	Graphical	22	5.0–13	--	0.77	--	--	--
	70	16508000	Graphical	22	2.2–6.3	--	0.75	--	--	--
	75	16400000	Graphical	22	4.0–10	--	0.77	--	--	--
	80	16400000	Graphical	22	3.3–9.1	--	0.76	--	--	--
	85	16400000	Graphical	22	2.9–8.2	--	0.77	--	--	--
	90	16400000	Graphical	22	2.6–8.0	--	0.77	--	--	--
	95	--	--	--		--	--	--	--	--
16404200	50	16620000	Graphical	26	14–37	--	0.83	--	--	--
	55	16620000	Graphical	25	13–34	--	0.83	--	--	--
	60	16620000	Graphical	25	13–31	--	0.82	--	--	--
	65	16620000	Graphical	25	12–28	--	0.78	--	--	--
	70	--	--	--	--	--	--	--	--	--
	75	--	--	--	--	--	--	--	--	--
	80	--	--	--	--	--	--	--	--	--
	85	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--
	95	--	--	--	--	--	--	--	--	--
16405000	50	16620000	Graphical	13	14–29	--	0.85	--	--	--
	55	16620000	Graphical	13	13–27	--	0.86	--	--	--
	60	16508000	Graphical	13	3.8–7.9	--	0.84	--	--	--
	65	16587000	Graphical	13	1.0–2.3	--	0.81	--	--	--
	70	16508000	Graphical	13	3.2–6.3	--	0.78	--	--	--
	75	16508000	Graphical	13	2.6–5.6	--	0.75	--	--	--
	80	--	--	--	--	--	--	--	--	--
	85	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--
	95	--	--	--	--	--	--	--	--	--
16408000	50	16618000	MOVE.1	12		$Y_i = 1.07 + 1.82\ (X_i - 0.96)$	0.76	0.57	0.087	0.39
	55	--	--	--	--	--	--	--	--	--
	60	--	--	--	--	--	--	--	--	--

	65	16620000	MOVE.1	16		$Y_i = 0.99 + 1.05\ (X_i - 1.26)$	0.82	0.68	0.070	0.43
	70	16620000	MOVE.1	16		$Y_i = 0.97 + 1.05\ (X_i - 1.24)$	0.83	0.69	0.067	0.45
	75	16620000	MOVE.1	16		$Y_i = 0.96 + 1.11\ (X_i - 1.22)$	0.88	0.78	0.056	0.51
	80	16620000	MOVE.1	16		$Y_i = 0.94 + 1.09\ (X_i - 1.21)$	0.88	0.77	0.053	0.55
	85	16620000	MOVE.1	16		$Y_i = 0.92 + 1.01\ (X_i - 1.18)$	0.85	0.73	0.057	0.49
	90	16620000	MOVE.1	16		$Y_i = 0.89 + 0.96\ (X_i - 1.16)$	0.81	0.66	0.056	0.36
	95	--	--	--	--	--	--	--	--	--
16411400	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16413000	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16414000	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16416000	60–95	16400000	Graphical	8	0.98–8.5	--	0.92	--	--	--
Maui										
16500100	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16501200	50	16518000	Graphical	18	5.3–15	--	0.78	--	--	--
	55	16604500	Graphical	18	25–58	--	0.83	--	--	--
	60	16604500	Graphical	18	22–52	--	0.84	--	--	--
	65	16587000	Graphical	18	0.79–2.8	--	0.86	--	--	--
	70	16587000	Graphical	18	0.66–2.5	--	0.84	--	--	--
	75	16508000	Graphical	18	2.5–6.9	--	0.82	--	--	--
	80	16508000	Graphical	18	2.2–6.5	--	0.81	--	--	--
	85	16508000	Graphical	18	1.9–6.1	--	0.81	--	--	--
	90	--	--	--	--	--	--	--	--	--
	95	--	--	--	--	--	--	--	--	--
16510000	50	16508000	MOVE.1	19	4.1–9.9	$Y_i = 0.66 + 1.11\ (X_i - 0.82)$	0.96	0.92	0.036	0.74
	55	16508000	MOVE.1	19	3.8–8.7	$Y_i = 0.59 + 1.19\ (X_i - 0.77)$	0.95	0.91	0.040	0.70
	60	16508000	MOVE.1	19	3.5–7.9	$Y_i = 0.54 + 1.21\ (X_i - 0.72)$	0.95	0.90	0.042	0.67
	65	16508000	MOVE.1	19	3.3–7.0	$Y_i = 0.49 + 1.26\ (X_i - 0.68)$	0.94	0.88	0.047	0.63
	70	16508000	MOVE.1	19	3.0–6.3	$Y_i = 0.44 + 1.30\ (X_i - 0.65)$	0.92	0.85	0.053	0.66
	75	16508000	MOVE.1	19	2.6–5.6	$Y_i = 0.38 + 1.31\ (X_i - 0.61)$	0.90	0.81	0.061	0.61
	80	16508000	MOVE.1	19	2.5–5.1	$Y_i = 0.32 + 1.39\ (X_i - 0.57)$	0.87	0.76	0.068	0.54
	85	16508000	MOVE.1	19	2.3–4.6	$Y_i = 0.26 + 1.37\ (X_i - 0.53)$	0.89	0.78	0.062	0.59
	90	16587000	MOVE.1	19	0.46–1.4	$Y_i = 0.20 + 0.87\ (X_i + 0.12)$	0.86	0.73	0.076	0.45
	95	16587000	MOVE.1	19	0.31–1.2	$Y_i = 0.11 + 0.91\ (X_i + 0.19)$	0.93	0.86	0.054	0.62
16513000	50–95	16587000	Graphical	350	0.46–2.7	--	0.75	--	--	--
16515000	50	16508000	MOVE.1	19	4.1–9.9	$Y_i = 0.73 + 0.60\ (X_i - 0.82)$	0.96	0.91	0.021	0.75
	55	16508000	MOVE.1	19	3.8–8.7	$Y_i = 0.70 + 0.60\ (X_i - 0.77)$	0.97	0.94	0.017	0.79
	60	16508000	MOVE.1	19	3.5–7.9	$Y_i = 0.67 + 0.56\ (X_i - 0.72)$	0.97	0.95	0.014	0.80
	65	16508000	MOVE.1	19	3.3–7.0	$Y_i = 0.65 + 0.54\ (X_i - 0.68)$	0.96	0.93	0.015	0.76
	70	16508000	MOVE.1	19	3.0–6.3	$Y_i = 0.62 + 0.55\ (X_i - 0.65)$	0.96	0.93	0.016	0.73

	75	16508000	MOVE.1	19	2.6–5.6	$Y_i = 0.60 + 0.58 (X_i - 0.61)$	0.96	0.91	0.017	0.71
	80	16508000	MOVE.1	19	2.5–5.1	$Y_i = 0.58 + 0.63 (X_i - 0.57)$	0.93	0.87	0.022	0.65
	85	16508000	MOVE.1	19	2.3–4.6	$Y_i = 0.55 + 0.69 (X_i - 0.53)$	0.94	0.88	0.023	0.66
	90	16508000	MOVE.1	19	2.2–4.2	$Y_i = 0.52 + 0.72 (X_i - 0.49)$	0.93	0.87	0.025	0.65
	95	16508000	MOVE.1	19	2.0–3.7	$Y_i = 0.49 + 0.86 (X_i - 0.45)$	0.92	0.84	0.030	0.58
16516000	50	16518000	MOVE.1	14	5.8–13	$Y_i = 0.85 + 0.95 (X_i - 0.99)$	0.92	0.85	0.039	0.61
	55	16508000	MOVE.1	14	4.2–8.7	$Y_i = 0.79 + 1.01 (X_i - 0.78)$	0.92	0.84	0.042	0.56
	60	16508000	MOVE.1	14	3.8–7.9	$Y_i = 0.74 + 0.89 (X_i - 0.73)$	0.88	0.78	0.043	0.52
	65	16518000	Graphical	14	4.1–9.6	--	0.86	--	--	--
	70	16518000	Graphical	14	3.8–8.7	--	0.84	--	--	--
	75	16518000	Graphical	14	3.4–8.0	--	0.85	--	--	--
	80	16518000	Graphical	14	3.0–7.1	--	0.85	--	--	--
	85	16508000	Graphical	14	2.3–4.6	--	0.82	--	--	--
	90	16518000	Graphical	14	2.2–6.0	--	0.79	--	--	--
	95	16587000	Graphical	14	0.31–1.2	--	0.83	--	--	--
16517000	50	16518000	MOVE.1	14	5.8–13	$Y_i = 0.92 + 1.04 (X_i - 0.99)$	0.95	0.91	0.034	0.69
	55	16518000	MOVE.1	14	5.0–12	$Y_i = 0.87 + 0.98 (X_i - 0.93)$	0.96	0.92	0.030	0.73
	60	16508000	MOVE.1	14	3.8–7.9	$Y_i = 0.82 + 1.01 (X_i - 0.73)$	0.96	0.92	0.029	0.73
	65	16508000	MOVE.1	14	3.4–7.0	$Y_i = 0.78 + 1.03 (X_i - 0.69)$	0.97	0.95	0.024	0.78
	70	16508000	MOVE.1	14	3.2–6.3	$Y_i = 0.73 + 1.07 (X_i - 0.65)$	0.98	0.96	0.022	0.79
	75	16508000	MOVE.1	14	2.6–5.6	$Y_i = 0.69 + 1.06 (X_i - 0.61)$	0.97	0.95	0.026	0.77
	80	16508000	MOVE.1	14	2.5–5.1	$Y_i = 0.64 + 1.15 (X_i - 0.58)$	0.95	0.90	0.035	0.69
	85	16508000	MOVE.1	14	2.3–4.6	$Y_i = 0.60 + 1.16 (X_i - 0.54)$	0.98	0.95	0.025	0.78
	90	16508000	MOVE.1	14	2.2–4.2	$Y_i = 0.54 + 1.24 (X_i - 0.50)$	0.95	0.89	0.038	0.67
	95	16508000	MOVE.1	14	2.0–3.7	$Y_i = 0.47 + 1.36 (X_i - 0.45)$	0.91	0.83	0.048	0.53
16519000	50	16518000	MOVE.1	14	5.8–13	$Y_i = 0.62 + 1.02 (X_i - 0.99)$	0.96	0.92	0.030	0.74
	55	16518000	MOVE.1	14	5.0–12	$Y_i = 0.56 + 0.95 (X_i - 0.93)$	0.92	0.84	0.042	0.62
	60	16518000	MOVE.1	14	4.6–10	$Y_i = 0.50 + 1.05 (X_i - 0.87)$	0.93	0.87	0.040	0.63
	65	16518000	MOVE.1	14	4.1–9.6	$Y_i = 0.45 + 1.00 (X_i - 0.83)$	0.93	0.86	0.042	0.59
	70	16518000	MOVE.1	14	3.8–8.7	$Y_i = 0.41 + 1.03 (X_i - 0.78)$	0.96	0.92	0.031	0.69
	75	16518000	MOVE.1	14	3.4–8.0	$Y_i = 0.36 + 0.97 (X_i - 0.74)$	0.96	0.92	0.031	0.68
	80	16518000	MOVE.1	14	3.0–7.1	$Y_i = 0.30 + 1.01 (X_i - 0.68)$	0.96	0.93	0.030	0.68
	85	16518000	MOVE.1	14	2.6–6.5	$Y_i = 0.25 + 1.12 (X_i - 0.63)$	0.96	0.91	0.039	0.70
	90	16508000	MOVE.1	14	2.2–4.2	$Y_i = 0.18 + 1.60 (X_i - 0.50)$	0.92	0.84	0.061	0.59
	95	16508000	MOVE.1	14	2.0–3.7	$Y_i = 0.08 + 2.03 (X_i - 0.45)$	0.92	0.85	0.066	0.64
16520000	50	16587000	MOVE.1	14	1.3–3.4	$Y_i = 0.51 + 0.64 (X_i - 0.33)$	0.94	0.89	0.032	0.71
	55	16587000	MOVE.1	14	1.2–3.0	$Y_i = 0.45 + 0.61 (X_i - 0.29)$	0.94	0.88	0.031	0.65
	60	16587000	MOVE.1	14	1.2–2.7	$Y_i = 0.41 + 0.67 (X_i - 0.24)$	0.94	0.88	0.033	0.68
	65	16508000	MOVE.1	14	3.4–7.0	$Y_i = 0.35 + 0.89 (X_i - 0.69)$	0.93	0.87	0.032	0.62

	70	16508000	MOVE.1	14	3.2–6.3	$Y_i = 0.30 + 0.97 (X_i - 0.65)$	0.94	0.89	0.032	0.66
	75	16518000	MOVE.1	14	3.4–8.0	$Y_i = 0.26 + 0.91 (X_i - 0.74)$	0.93	0.87	0.036	0.66
	80	16518000	MOVE.1	14	3.0–7.1	$Y_i = 0.26 + 0.91 (X_i - 0.74)$	0.93	0.87	0.036	0.66
	85	16518000	MOVE.1	14	2.6–6.5	$Y_i = 0.14 + 1.08 (X_i - 0.63)$	0.95	0.91	0.039	0.73
	90	16518000	MOVE.1	14	2.2–6.0	$Y_i = 0.08 + 1.01 (X_i - 0.56)$	0.92	0.85	0.052	0.64
	95	16508000	MOVE.1	14	2.0–3.7	$Y_i = -0.02 + 1.65 (X_i - 0.45)$	0.90	0.82	0.059	0.56
16524000	50–95	16518000	MOVE.1	152	1.6–12	$Y_i = -0.20 + 1.40 (X_i - 0.65)$	0.86	0.74	0.151	0.49
16527000	50	16518000	MOVE.1	20	5.8–13	$Y_i = 0.72 + 1.08 (X_i - 0.97)$	0.92	0.85	0.047	0.64
	55	16518000	MOVE.1	20	5.0–12	$Y_i = 0.66 + 1.09 (X_i - 0.92)$	0.93	0.86	0.045	0.67
	60	16518000	MOVE.1	20	4.6–10	$Y_i = 0.61 + 1.18 (X_i - 0.86)$	0.91	0.84	0.051	0.59
	65	16518000	MOVE.1	20	4.1–9.6	$Y_i = 0.55 + 1.14 (X_i - 0.82)$	0.93	0.87	0.045	0.66
	70	16518000	MOVE.1	20	3.8–8.7	$Y_i = 0.50 + 1.23 (X_i - 0.78)$	0.94	0.89	0.043	0.66
	75	16518000	MOVE.1	20	3.4–8.0	$Y_i = 0.43 + 1.14 (X_i - 0.74)$	0.94	0.88	0.043	0.66
	80	16518000	MOVE.1	20	3.0–7.1	$Y_i = 0.37 + 1.28 (X_i - 0.68)$	0.95	0.90	0.045	0.70
	85	16518000	MOVE.1	20	2.6–6.5	$Y_i = 0.30 + 1.47 (X_i - 0.63)$	0.93	0.86	0.065	0.60
	90	16518000	MOVE.1	20	2.2–6.0	$Y_i = 0.20 + 1.49 (X_i - 0.56)$	0.92	0.85	0.072	0.65
	95	16518000	MOVE.1	20	1.6–5.1	$Y_i = 0.08 + 1.58 (X_i - 0.48)$	0.89	0.79	0.104	0.53
16531100	50	16518000	MOVE.1	21	6.5–13	$Y_i = -0.31 + 1.09 (X_i - 0.99)$	0.83	0.69	0.060	0.40
	55	--	--	--	--	--	--	--	--	--
	60	--	--	--	--	--	--	--	--	--
	65	--	--	--	--	--	--	--	--	--
	70	--	--	--	--	--	--	--	--	--
	75	16518000	MOVE.1	21	4.0–8.0	$Y_i = -0.72 + 1.85 (X_i - 0.77)$	0.81	0.65	0.101	0.36
	80	--	--	--	--	--	--	--	--	--
	85	16518000	MOVE.1	21	3.1–6.5	$Y_i = -0.96 + 2.11 (X_i - 0.66)$	0.86	0.74	0.107	0.47
	90	--	--	--	--	--	--	--	--	--
	95	--	--	--	--	--	--	--	--	--
16542000	50–95	16508000	Graphical	21	1.9–7.7	--	0.78	--	--	--
16552600	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16552800	50	16518000	MOVE.1	19	5.0–13	$Y_i = -0.94 + 1.67 (X_i - 0.95)$	0.90	0.81	0.092	0.52
	55	16518000	MOVE.1	19	4.6–11	$Y_i = -1.03 + 1.59 (X_i - 0.89)$	0.91	0.83	0.077	0.60
	60	16518000	MOVE.1	19	4.2–9.8	$Y_i = -1.12 + 1.64 (X_i - 0.84)$	0.90	0.80	0.087	0.51
	65	16518000	MOVE.1	19	3.7–8.8	$Y_i = -1.18 + 1.42 (X_i - 0.81)$	0.87	0.76	0.084	0.49
	70	16518000	Graphical	19	3.4–8.0	--	0.85	--	--	--
	75	16518000	MOVE.1	19	3.0–7.6	$Y_i = -1.31 + 1.50 (X_i - 0.72)$	0.90	0.80	0.077	0.50
	80	16518000	MOVE.1	19	2.6–6.8	$Y_i = -1.39 + 1.53 (X_i - 0.67)$	0.87	0.76	0.089	0.53
	85	16518000	Graphical	19	2.2–6.0	--	0.81	--	--	--
	90	16518000	MOVE.1	19	1.9–5.3	$Y_i = -1.55 + 1.93 (X_i - 0.54)$	0.83	0.69	0.134	0.44
	95	--	--	--	--	--	--	--	--	--

16557000	50	16587000	MOVE.1	14	1.3–3.4	$Y_i = 0.42 + 0.77 (X_i - 0.33)$	0.93	0.86	0.043	0.67
	55	16587000	MOVE.1	14	1.2–3.0	$Y_i = 0.35 + 0.82 (X_i - 0.29)$	0.94	0.88	0.041	0.67
	60	16508000	MOVE.1	14	3.8–7.9	$Y_i = 0.29 + 1.30 (X_i - 0.73)$	0.92	0.84	0.053	0.63
	65	16508000	MOVE.1	14	3.4–7.0	$Y_i = 0.24 + 1.22 (X_i - 0.69)$	0.93	0.86	0.046	0.64
	70	16508000	MOVE.1	14	3.2–6.3	$Y_i = 0.19 + 1.25 (X_i - 0.65)$	0.91	0.83	0.051	0.62
	75	16508000	MOVE.1	14	2.6–5.6	$Y_i = 0.14 + 1.16 (X_i - 0.61)$	0.92	0.85	0.048	0.65
	80	16518000	MOVE.1	14	3.0–7.1	$Y_i = 0.08 + 1.11 (X_i - 0.68)$	0.90	0.81	0.056	0.54
	85	16518000	MOVE.1	14	2.6–6.5	$Y_i = 0.02 + 1.10 (X_i - 0.63)$	0.88	0.78	0.063	0.58
	90	16518000	MOVE.1	14	2.2–6.0	$Y_i = -0.04 + 1.03 (X_i - 0.56)$	0.84	0.71	0.073	0.53
	95	16508000	MOVE.1	14	2.0–3.7	$Y_i = -0.11 + 1.54 (X_i - 0.45)$	0.88	0.77	0.063	0.55
16565000	50	16587000	MOVE.1	18	1.3–3.4	$Y_i = 0.41 + 0.75 (X_i - 0.34)$	0.95	0.91	0.034	0.72
	55	16587000	MOVE.1	18	1.2–3.0	$Y_i = 0.35 + 0.73 (X_i - 0.30)$	0.95	0.90	0.034	0.72
	60	16587000	MOVE.1	18	1.1–2.7	$Y_i = 0.30 + 0.75 (X_i - 0.25)$	0.93	0.87	0.040	0.69
	65	16587000	MOVE.1	18	0.93–2.4	$Y_i = 0.25 + 0.71 (X_i - 0.19)$	0.94	0.88	0.039	0.65
	70	16518000	MOVE.1	18	3.8–8.7	$Y_i = 0.20 + 1.16 (X_i - 0.79)$	0.93	0.87	0.044	0.64
	75	16518000	MOVE.1	18	3.4–8.0	$Y_i = 0.16 + 1.08 (X_i - 0.75)$	0.93	0.86	0.043	0.61
	80	16518000	MOVE.1	18	3.0–7.1	$Y_i = 0.09 + 1.11 (X_i - 0.70)$	0.94	0.89	0.040	0.67
	85	16518000	MOVE.1	18	2.6–6.5	$Y_i = 0.04 + 1.11 (X_i - 0.64)$	0.90	0.81	0.056	0.54
	90	16518000	MOVE.1	18	2.2–6.0	$Y_i = -0.03 + 1.02 (X_i - 0.58)$	0.88	0.78	0.060	0.53
	95	16508000	MOVE.1	18	2.0–3.7	$Y_i = -0.10 + 1.56 (X_i - 0.45)$	0.84	0.71	0.072	0.46
16566000	50	16587000	MOVE.1	14	1.3–3.4	$Y_i = 0.00 + 0.82 (X_i - 0.33)$	0.92	0.84	0.049	0.63
	55	16587000	MOVE.1	14	1.2–3.0	$Y_i = -0.07 + 0.92 (X_i - 0.29)$	0.94	0.89	0.044	0.70
	60	16587000	MOVE.1	14	1.2–2.7	$Y_i = -0.12 + 0.98 (X_i - 0.24)$	0.93	0.86	0.053	0.62
	65	16508000	MOVE.1	14	3.4–7.0	$Y_i = -0.18 + 1.45 (X_i - 0.69)$	0.91	0.83	0.060	0.64
	70	16587000	MOVE.1	14	0.87–2.0	$Y_i = -0.24 + 1.01 (X_i - 0.13)$	0.93	0.87	0.055	0.67
	75	16508000	MOVE.1	14	2.6–5.6	$Y_i = -0.30 + 1.26 (X_i - 0.61)$	0.93	0.87	0.049	0.66
	80	16587000	MOVE.1	14	0.70–1.7	$Y_i = -0.36 + 0.81 (X_i - 0.03)$	0.93	0.87	0.044	0.60
	85	16587000	Graphical	14	0.62–1.5	--	0.84	--	--	--
	90	16508000	Graphical	14	2.2–4.2	--	0.85	--	--	--
	95	16508000	MOVE.1	14	2.0–3.7	$Y_i = -0.56 + 1.76 (X_i - 0.45)$	0.89	0.79	0.069	0.60
16569700	50–95	16508000	MOVE.1	11	2.0–6.5	$Y_i = -0.69 + 2.50 (X_i - 0.57)$	0.88	0.77	0.250	0.54
16570000	50	16587000	MOVE.1	31	1.2–4.6	$Y_i = 1.17 + 0.68 (X_i - 0.32)$	0.94	0.89	0.035	0.68
	55	16587000	MOVE.1	31	1.1–4.2	$Y_i = 1.12 + 0.66 (X_i - 0.27)$	0.95	0.91	0.031	0.70
	60	16587000	MOVE.1	31	0.91–3.6	$Y_i = 1.08 + 0.67 (X_i - 0.22)$	0.94	0.89	0.036	0.68
	65	16587000	MOVE.1	31	0.72–3.2	$Y_i = 1.03 + 0.65 (X_i - 0.17)$	0.93	0.87	0.039	0.67
	70	16518000	MOVE.1	31	3.3–8.7	$Y_i = 0.98 + 0.95 (X_i - 0.77)$	0.92	0.85	0.041	0.65
	75	16587000	MOVE.1	31	0.55–2.2	$Y_i = 0.94 + 0.65 (X_i - 0.06)$	0.93	0.86	0.042	0.63
	80	16587000	MOVE.1	31	0.47–1.8	$Y_i = 0.89 + 0.65 (X_i + 0.01)$	0.92	0.85	0.042	0.63
	85	16518000	MOVE.1	31	2.1–6.5	$Y_i = 0.83 + 0.94 (X_i - 0.61)$	0.90	0.81	0.050	0.59

	90	16518000	MOVE.1	31	1.7–6.0	$Y_i = 0.75 + 0.96 (X_i - 0.54)$	0.90	0.81	0.054	0.60
	95	16508000	MOVE.1	31	1.8–3.8	$Y_i = 0.67 + 1.39 (X_i - 0.42)$	0.87	0.76	0.066	0.50
16576200	50–95	16508000	MOVE.1	18	2.0–7.6	$Y_i = -0.40 + 1.36 (X_i - 0.62)$	0.93	0.87	0.095	0.69
16577000	50	16587000	MOVE.1	14	1.3–3.4	$Y_i = 0.92 + 0.87 (X_i - 0.33)$	0.96	0.92	0.036	0.72
	55	16587000	MOVE.1	14	1.2–3.0	$Y_i = 0.86 + 0.93 (X_i - 0.29)$	0.97	0.93	0.035	0.77
	60	16587000	MOVE.1	14	1.2–2.7	$Y_i = 0.81 + 0.92 (X_i - 0.24)$	0.95	0.90	0.041	0.74
	65	16518000	MOVE.1	14	4.1–9.6	$Y_i = 0.75 + 1.16 (X_i - 0.83)$	0.96	0.92	0.037	0.73
	70	16518000	MOVE.1	14	3.8–8.7	$Y_i = 0.71 + 1.20 (X_i - 0.78)$	0.95	0.91	0.038	0.69
	75	16587000	MOVE.1	14	0.77–1.8	$Y_i = 0.65 + 0.83 (X_i - 0.08)$	0.96	0.93	0.034	0.74
	80	16587000	MOVE.1	14	0.70–1.7	$Y_i = 0.59 + 0.91 (X_i - 0.03)$	0.95	0.90	0.044	0.73
	85	16518000	MOVE.1	14	2.6–6.5	$Y_i = 0.52 + 1.19 (X_i - 0.63)$	0.94	0.89	0.046	0.68
	90	16518000	MOVE.1	14	2.2–6.0	$Y_i = 0.44 + 1.27 (X_i - 0.56)$	0.93	0.86	0.061	0.66
	95	16508000	MOVE.1	14	2.0–3.7	$Y_i = 0.35 + 1.95 (X_i - 0.45)$	0.93	0.86	0.061	0.64
16585000	50	16587000	MOVE.1	28	1.2–4.6	$Y_i = 0.68 + 0.95 (X_i - 0.34)$	0.97	0.94	0.036	0.73
	55	16587000	MOVE.1	28	1.1–4.2	$Y_i = 0.63 + 0.99 (X_i - 0.29)$	0.97	0.93	0.038	0.75
	60	16587000	MOVE.1	28	0.93–3.6	$Y_i = 0.58 + 0.97 (X_i - 0.24)$	0.98	0.96	0.031	0.81
	65	16587000	MOVE.1	28	0.84–3.2	$Y_i = 0.53 + 0.97 (X_i - 0.19)$	0.97	0.94	0.035	0.77
	70	16587000	MOVE.1	28	0.74–2.7	$Y_i = 0.48 + 0.94 (X_i - 0.14)$	0.97	0.94	0.037	0.77
	75	16587000	MOVE.1	28	0.65–2.2	$Y_i = 0.42 + 0.96 (X_i - 0.08)$	0.97	0.94	0.038	0.76
	80	16587000	MOVE.1	28	0.56–1.8	$Y_i = 0.37 + 0.96 (X_i - 0.02)$	0.97	0.94	0.038	0.75
	85	16587000	MOVE.1	28	0.46–1.6	$Y_i = 0.29 + 0.97 (X_i + 0.06)$	0.97	0.93	0.038	0.77
	90	16587000	MOVE.1	28	0.23–1.4	$Y_i = 0.21 + 0.92 (X_i + 0.15)$	0.96	0.92	0.049	0.75
	95	16587000	MOVE.1	28	0.23–1.2	$Y_i = 0.11 + 1.00 (X_i + 0.23)$	0.93	0.86	0.068	0.68
16586000	50	16587000	MOVE.1	14	1.3–3.4	$Y_i = 0.58 + 0.58 (X_i - 0.33)$	0.96	0.92	0.024	0.76
	55	16587000	MOVE.1	14	1.2–3.0	$Y_i = 0.55 + 0.59 (X_i - 0.29)$	0.97	0.95	0.020	0.80
	60	16587000	MOVE.1	14	1.2–2.7	$Y_i = 0.51 + 0.56 (X_i - 0.24)$	0.96	0.93	0.021	0.74
	65	16587000	MOVE.1	14	1.0–2.3	$Y_i = 0.48 + 0.54 (X_i - 0.18)$	0.96	0.93	0.021	0.73
	70	16587000	MOVE.1	14	0.87–2.0	$Y_i = 0.45 + 0.57 (X_i - 0.13)$	0.95	0.89	0.027	0.69
	75	16587000	MOVE.1	14	0.77–1.8	$Y_i = 0.43 + 0.55 (X_i - 0.08)$	0.95	0.91	0.026	0.70
	80	16587000	MOVE.1	14	0.70–1.7	$Y_i = 0.39 + 0.55 (X_i - 0.03)$	0.95	0.90	0.027	0.71
	85	16518000	MOVE.1	14	2.6–6.5	$Y_i = 0.36 + 0.73 (X_i - 0.63)$	0.94	0.88	0.030	0.66
	90	16518000	MOVE.1	14	2.2–6.0	$Y_i = 0.31 + 0.68 (X_i - 0.56)$	0.93	0.87	0.032	0.63
	95	16508000	MOVE.1	14	2.0–3.7	$Y_i = 0.25 + 1.13 (X_i - 0.45)$	0.95	0.90	0.030	0.67
16596200	50–95	16518000	MOVE.1	311	1.7–12	$Y_i = -0.57 + 1.72 (X_i - 0.65)$	0.89	0.79	0.160	0.58
16647000	50–95	16604500	MOVE.1	15	13–95	$Y_i = 0.65 + 0.64 (X_i - 1.48)$	0.94	0.88	0.066	0.67
16660000	50–95	All[2]	Graphical	--	--	--	--	--	--	--
205000156355801	50–95	16604500	MOVE.1	9	12–53	$Y_i = 0.66 + 0.85 (X_i - 1.41)$	0.96	0.91	0.049	0.69
205117156365201	50–95	16647000	MOVE.1	10	3.8–10	$Y_i = -0.29 + 0.65 (X_i - 0.74)$	0.90	0.81	0.060	0.55
205239156372101	50–95	16620000	MOVE.1	11	11–24	$Y_i = 0.84 + 1.07 (X_i - 1.19)$	0.85	0.72	0.069	0.38

205334156382201	50–95	16400000	MOVE.1	8	3.4–15	$Y_i = 0.65 + 0.17 (X_i - 0.81)$	0.90	0.81	0.020	0.52
205404156372401	50–95	16620000	Graphical	10	11–27	--	0.80	--	--	--
205426156313601	50–95	16620000	Graphical	9	9.3–24	--	0.75	--	--	--
205455156394301	50–95	All[2]	Graphical	--	--	--	--	--	--	--
205511156393401	50–95	All[2]	Graphical	--	--	--	--	--	--	--
205545156371601 + 205554156370701	50–95	16620000	MOVE.1	10	12–23	$Y_i = 0.64 + 0.73 (X_i - 1.20)$	0.88	0.77	0.035	0.42
205740156385601	50–95	All[2]	Graphical	--	--	--	--	--	--	--
205844156380501	50–95	All[2]	Graphical	--	--	--	--	--	--	--
205856156370801	50–95	16620000	Graphical	11	13–25	--	0.84	--	--	--
205921156370101	50–95	All[2]	Graphical	--	--	--	--	--	--	--
205938156382201	50–95	All[2]	Graphical	--	--	--	--	--	--	--
Hawai‘i										
16700000	50	16717000	Graphical	28	15–86	--	0.85	--	--	--
	55	16717000	Graphical	28	13–75	--	0.86	--	--	--
	60	16717000	Graphical	28	11–68	--	0.84	--	--	--
	65	16717000	Graphical	28	9.3–60	--	0.84	--	--	--
	70	16717000	Graphical	28	7.8–50	--	0.85	--	--	--
	75	16717000	Graphical	28	6.5–46	--	0.84	--	--	--
	80	16717000	Graphical	28	6.0–39	--	0.82	--	--	--
	85	16717000	Graphical	28	5.6–34	--	0.79	--	--	--
	90	--	--	--	--	--	--	--	--	--
	95	--	--	--	--	--	--	--	--	--
16701700	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16704000	50	16717000	MOVE.1	24	15–86	$Y_i = 1.89 + 1.49 (X_i - 1.61)$	0.91	0.82	0.110	0.54
	55	16717000	MOVE.1	24	13–75	$Y_i = 1.80 + 1.47 (X_i - 1.55)$	0.92	0.85	0.103	0.59
	60	16717000	MOVE.1	24	11–68	$Y_i = 1.71 + 1.48 (X_i - 1.49)$	0.93	0.87	0.098	0.63
	65	16717000	MOVE.1	24	9.3–60	$Y_i = 1.61 + 1.52 (X_i - 1.43)$	0.93	0.86	0.107	0.60
	70	16717000	MOVE.1	24	7.8–50	$Y_i = 1.51 + 1.62 (X_i - 1.37)$	0.93	0.86	0.115	0.62
	75	16717000	MOVE.1	24	6.5–46	$Y_i = 1.40 + 1.66 (X_i - 1.30)$	0.93	0.86	0.120	0.62
	80	16717000	MOVE.1	24	6.0–39	$Y_i = 1.27 + 1.88 (X_i - 1.23)$	0.90	0.81	0.157	0.57
	85	16717000	Graphical	24	5.6–34	--	0.82	--	--	--
	90	16717000	Graphical	24	4.7–25	--	0.81	--	--	--
	95	--	--	--	--	--	--	--	--	--
16717800	50	16717000	MOVE.1	[5] 11	30–47	$Y_i = 0.87 + 1.63 (X_i - 1.57)$	0.91	0.83	0.044	0.53
	55	16717000	MOVE.1	[5] 11	27–41	$Y_i = 0.81 + 1.78 (X_i - 1.51)$	0.91	0.83	0.048	0.55
	60	16717000	MOVE.1	[5] 11	25–36	$Y_i = 0.75 + 2.14 (X_i - 1.47)$	0.92	0.85	0.050	0.56
	65	16717000	MOVE.1	[5] 11	22–32	$Y_i = 0.69 + 2.16 (X_i - 1.41)$	0.90	0.82	0.056	0.54
	70	16717000	MOVE.1	[5] 11	19–30	$Y_i = 0.64 + 2.21 (X_i - 1.36)$	0.88	0.77	0.068	0.47

	75	--	--	--	--	--	--	--	--	--
	80	--	--	--	--	--	--	--	--	--
	85	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--
	95	--	--	--	--	--	--	--	--	--
16720300	50	16720000	Graphical	[6]29	1.3–11	--	0.86	--	--	--
	55	16720000	Graphical	[6]29	1.1–8.9	--	0.85	--	--	--
	60	16720000	Graphical	[6]29	0.91–6.9	--	0.89	--	--	--
	65	16720000	Graphical	[6]29	0.67–5.2	--	0.83	--	--	--
	70	16720000	Graphical	[6]29	0.50–4.5	--	0.79	--	--	--
	75	16720000	Graphical	[6]29	0.34–3.7	--	0.76	--	--	--
	80	--	--	--	--	--	--	--	--	--
	85	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--
	95	--	--	--	--	--	--	--	--	--
16725000	50	16720000	Graphical	16	1.8–9.1	--	0.88	--	--	--
	55	16720000	Graphical	16	1.5–6.8	--	0.84	--	--	--
	60	16720000	Graphical	16	1.2–4.9	--	0.82	--	--	--
	65	16720000	Graphical	16	1.0–3.8	--	0.79	--	--	--
	70	--	--	--	--	--	--	--	--	--
	75	--	--	--	--	--	--	--	--	--
	80	--	--	--	--	--	--	--	--	--
	85	--	--	--	--	--	--	--	--	--
	90	--	--	--	--	--	--	--	--	--
	95	--	--	--	--	--	--	--	--	--
16737500	50–95	16720000	Graphical	11	0.13–4.5	--	0.89	--	--	--
16759600	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16765000	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16767000	50–95	All[2]	Graphical	--	--	--	--	--	--	--
16770500	50–95	All[2]	Graphical	--	--	--	--	--	--	--
200505155383801	50–95	16717000	MOVE.1	9	7.6–49	$Y_i = 1.36 + 0.61 (X_i - 1.32)$	0.95	0.90	0.059	0.65

[1]Coefficients of the MOVE.1 equations presented in the appendix are rounded for simplicity. Flow-duration discharges estimated with MOVE.1 equations, presented in tables 3-7 of the report, are computed using coefficients that have not been rounded. Therefore, discrepancy between the discharge computed directly with the equation presented in this appendix and the discharge presented in tables 3-7 of the report is due to rounding of the coefficients of the MOVE.1 equation and rounding of the estimated discharge.

[2]Measurement site on ephemeral stream reach that uses all index stations on the same island for low-flow analysis. Index stations by island are listed below:
Kaua‘i: stations 16010000, 16019000, 16068000, 16071500, 16097500, 16108000;
O‘ahu: stations 16200000, 16208000, 16211600, 16226200, 16229000, 16240500, 16275000, 16301050, 16304200, 16330000, 16345000;
Moloka‘i and Maui: 16400000, 16508000, 16518000, 16587000, 16604500, 16614000, 16618000, 16620000; and
Hawai‘i: 16717000, 16720000.

[3]Number of concurrent measurements used to estimate flow-duration discharges excludes 1 outlier: annual flow-duration statistic for water year 1994.

[4]Number of concurrent measurements used to estimate flow-duration discharges excludes 1 outlier: annual flow-duration statistic for water year 1948.

[5]Number of concurrent measurements used to estimate flow-duration discharges excludes 1 outlier: annual flow-duration statistic for water year 1972.

[6]Number of concurrent measurements used to estimate flow-duration discharges excludes 2 outliers: annual flow-duration statistic for water years 1990 and 1991.